STORMING THE BEACHES
SURFACE WATER ASPECTS OF THE BRITANNIA MINE REMEDIATION

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ABSTRACT

The Britannia Beach area has been affected by historical mining activity with deposits of mine waste (mostly waste rock and concentrated ore) at various locations. The area is characterized by steep slopes draining onto a flat alluvial fan, bisected by Britannia Creek. The mine is located in the temperate rainforest region of B.C., and significant volumes of stormwater run-off are generated in the wet months (October through April). Where surface water runs off mine wastes, the water quality is adversely affected (low pH and increased metal concentrations), and this water ultimately discharges to Howe Sound.

A study of the existing surface water drainage system was initiated in 2006 with the objective of characterizing the metal flux discharging to Howe Sound via Britannia Beach storm drains. The purpose of the study was to identify ways to reduce this flux. This paper describes the field program and instrumentation used to collect flow and water quality data, and outlines different mitigation measures that could improve the stormwater discharge quality to Howe Sound. Such measures include separation of uncontaminated stormwater from contaminated run-off, rehabilitation of existing infrastructure, integration with the existing mine water treatment facility and lime addition.

BACKGROUND

The Britannia Mine (the Site) is located at Britannia Beach on the east shore of Howe Sound, approximately 45 km north of Vancouver. The mine site covers an extensive area, with mineral tenure associated with the mine extending over some 37 km^2 (approximately 9,000 acres). Metal mining at the Site (predominantly copper and zinc) took place underground and in open pits and glory holes (the "Jane Basin" area about 5 km inland), with mineral processing areas at the coast, located at Britannia Beach, and inland, located at the former "Townsite" at Mt. Sheer.

The mine was closed in 1974 in compliance with the legislation of the time, but it subsequently developed into a legacy of environmental problems. Since 2001, an extensive program of environmental remediation work has been implemented in stages at the mine. By 2006, acid rock drainage (ARD), discharging from the underground workings and groundwater in and around the processing plant, centered on the iconic Concentrator building, (now the BC Museum of Mining (Museum)), were being captured and treated prior to discharge through a new deep water outfall. However, surface waters in the alluvial fan area of the lowest reach of Britannia Creek also become contaminated by contacting metalliferous soils. This was first recorded by URS during investigations at the site in 2001/2002, where it was noted that these waters were discharging onto the foreshore through a series of pipes and culverts. This work in 2003 resulted in the design and installation of a new stormwater drainage system through the Museum property, feeding a new storm drain which then carried the stormwater to the old (northern) mine outfall, discharging at 26 m depth rather than into the environmentally sensitive surface water of Howe Sound.

Completion of the water treatment plant (WTP) feeding the new outfall to Minaty Bay, south of Britannia Beach, resulted in much-reduced service flow to the old outfall. Over time, this has resulted in the end of the outfall being covered in silt and the development of a restricted flow capability. The consequence was periodic discharges of stormwater onto the foreshore/intertidal zone from an emergency overflow weir built into the storm sewer system.

Identifying this as a significant environmental problem for the sensitive intertidal zone, a detailed plan (Plan) was developed in 2006 to monitor the volumes of water being conveyed through the storm sewer system, examine the associated surface water source areas, determine water quality trends within both the storm sewer system and contributing surface water sources, and to estimate contaminant loading to Howe Sound. The primary objective of the Plan was to collect data necessary for developing a long-term water drainage study for the Site.

The Plan also required water quality samples to be collected manually at selected monitoring locations and supplementary samples from an ephemeral drainage on the West Mill Slope, which flows directly to the intertidal zone via a concrete pipe (Figure 2).

A preliminary study conducted in 2005/2006 identified options for managing surface water flows, including diversion of Stream #4 flow away from the East Mill slope, to reduce the hydraulic load on the Fan Area sewer system and preserve the relatively good quality of that surface water, and re-direction of the West Mill slope seepage into the Fan Area storm sewer system to stop direct discharge to the foreshore. Importantly, it was recommended at that time that the monitoring and sampling program be extended through the winter season (*i.e.*, December 2006 to March 2007) to obtain data during sustained wet conditions, as required to further evaluate sources of hydraulic and/or contaminant loading on the northern outfall and also characterize conditions contributing to the overflow at the ST-1 baffle. This paper summarizes the findings of the 2006/2007 field program and the use of the data collected in remedial decision making for the Fan Area surface water drainage.

During the period of May 24 to August 9, 2006, data was collected from automated monitoring devices and sampling/measuring equipment installed at five locations (Figures 1 and 2) at the Site, in agreement with the approved Plan:

- **Stream #1** – North end of the Water Treatment Plant (WTP) site, discharges onto waste rock and drains directly to Britannia Creek;
- **Copper Launders –** Old mine infrastructure, receives water from Stream #2 and Stream #3 via the WTP site storm sewer system and a dilapidated timber “drop box” structure (energy dissipater) and discharges directly into northern outfall pipeline;

- **Stream #4** – South of the WTP site, flows along a concrete wall (former mine water diversion) and over the East Mill slope, which contains mine wastes. Stream #4 drainage is collected by the Fan Area storm sewer system; and
- **Fan Area Storm Sewer System** – Manholes ST-1 and ST-4, along the primary collector pipe (525 mm diameter PVC). Manhole ST-1 includes an overflow baffle that directs flow toward ST-4 during low-flow conditions, but, when the baffle height is exceeded, stormwater flows into a 1000 mm diameter concrete pipe (old infrastructure) that discharges to the marine foreshore.

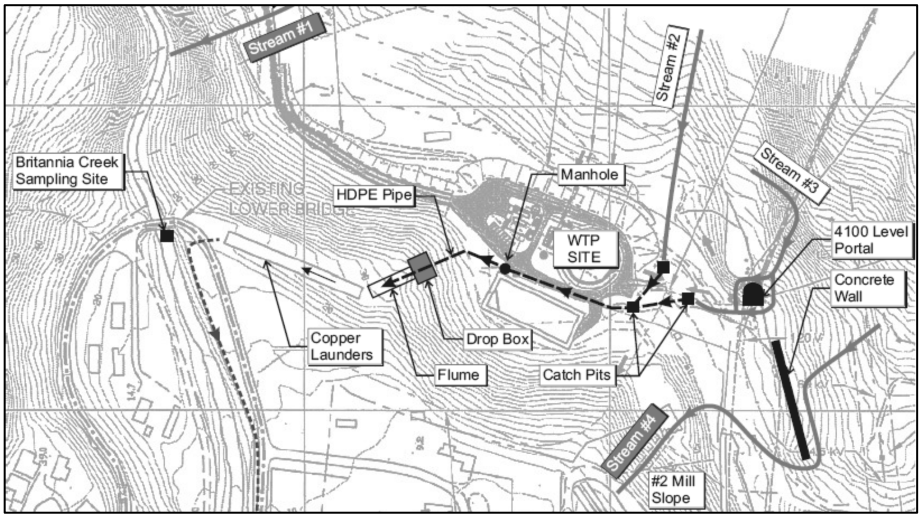

Figure 1: Britannia Mine, Water Treatment Plant and east alluvial fan areas storm drainage 2006/2007, showing surface water monitoring sites.

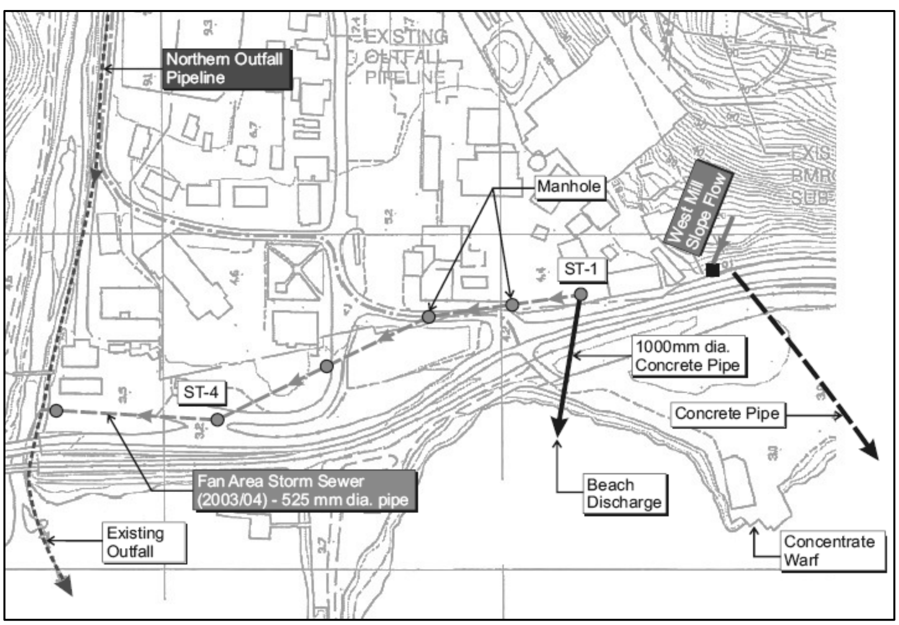

Figure 2: Britannia Mine, west alluvial fan area storm drainage 2006/2007, showing surface water monitoring sites.

WINTER 2006/2007 FIELD PROGRAM

Field tasks associated with the 2006/2007 winter field program closely resembled work undertaken during the 2005/2006 monitoring period as noted above, except water quality sampling was expanded to include Britannia Creek.

<u>Monitoring Locations and Instrumentation</u>

- Manhole ST-1 – An automatic water sampler (*i.e.*, auto-sampler) was installed with a sampling tube extending to the downstream side of the manhole overflow "baffle" to obtain discrete samples during overflow (*i.e.*, stormwater bypass) events and provide a direct measure of the water quality discharging onto the foreshore. A pressure transducer was placed on the upstream side of the baffle to continuously record manhole water levels and trigger the auto-sampler during overflow events. The 1,000 mm diameter outlet pipe at ST-1 was outfitted with an area-velocity meter to continuously record water velocities flowing to the foreshore.

- Manhole ST-4 – An area-velocity meter coupled with a conventional pressure transducer was installed in manhole ST-4 to continuously record the total flows through the Fan Area storm sewer system. Water quality samples were obtained manually from manhole ST-4, during storm events.

- Copper Launders – A weir assembly with a pressure transducer was installed at the launders outlet to record the rate of discharge to the northern outfall pipeline. Water quality samples were obtained manually from the weir discharge, during storm events.

- Britannia Creek – Water quality samples were obtained directly from the Creek channel at a location adjacent to the copper launders. All samples were obtained concurrently with sampling at the copper launders weir.

- WTP Storm Sewer System – Stormwater originating from the WTP site was sampled for quality analysis from a HDPE pipe discharging into a "drop box" located upstream from the copper launders. Manual estimates of total WTP storm sewer flow were obtained at the HDPE pipe discharge.

- Stream #4 – A continuous record of stream flow was obtained from a baske-type flume outfitted with a pressure transducer, which was installed in the stream channel immediately upstream of a concrete wall that directs all flow toward the East Mill slope.

- Stream #1 – A pressure transducer was installed at the discharge end of a large corrugated steel pipe (CSP) to continuously record water levels in the CSP, to facilitate development of stage-flow curve for estimating Stream #1 flows.

Water Quality Sampling and Data Collection

All quality samples were submitted to ALS Environmental's Vancouver laboratory on the same day as sampling for analysis of contaminants of concern (CoC). A summary of the resulting analytical data is provided in Table 1.

Table 1: Water Quality Results Summary

Location	Parameters			
	pH	Cu*	Cd*	Zn*
ST-1	3.7 – 4.7	1.48 – 12.70	0.0052 – 0.0440	1.02 – 8.40
ST- 4	5.1 – 7.3	0.02 – 1.29	0.0002 – 0.0046	0.05 – 1.37
Launders	6.8 – 7.3	0.01 – 0.02	0.0002	0.04 – 0.05
Britannia Cr.	6.9 – 7.6	0.02	0.0001 – 0.0002	0.03
Stream #1	6.0	0.13	0.0005	0.11

***** Dissolved concentrations in mg/L

Analytical data are compared to WTP outfall discharge criteria (MWLAP Permit PE-17469) and, as an initial screening approach, are compared with CSR Standards and CCME guidelines for freshwater aquatic life (AW).

DATA REVIEW

Previous studies have demonstrated that copper concentrations are a reliable indictor of general water chemistry. Where appropriate, flow data and water quality data have been combined to estimate daily copper loading, which is an approach previously employed at the mine as a decision tool for setting remediation priorities in accordance with the Overall Remediation Plan for the Mine.

Precipitation data for December 2006 to March 2007 indicate conditions at the Site were characterized by a succession of relatively wet weather periods, ranging in duration from 7 to 19 days, separated by relatively dry weather periods, ranging from 6 to 21 days in duration. Water level (i.e., elevations) recorded in manhole ST-4 demonstrate an overall strong correlation with diurnal tidal variations in Howe Sound. Fan Area storm sewer water levels correspond very strongly to precipitation events of relatively longer duration and/or intensity. Storm sewer water levels exceeded the manhole ST-1 baffle elevation on 50 occasions over the 16-week observation period, resulting in direct discharge of stormwater to the foreshore for a combined duration of over 17 days.

Flow data recorded at the downstream side of the ST-1 baffle includes several extended periods of zero flow, corresponding to relatively dry weather conditions (Figure 3). However, also included in the ST-1 flow data are four intervals of measured flows during early January, late January, mid-February and mid-March, which are concurrent with periods of relatively wet weather and also correspond to numerous overflow from the storm sewer events confirmed by water elevation measurements. Flow data obtained at manhole ST-4 also includes extended periods of zero flow, during periods of prevailing dry weather.

However, during the wetter late January, mid-February and mid-March overflow intervals, both “positive” and “negative” flows were recorded at ST-4. The negative flow rates range from approximately -2 L/s on January 19 to -33 L/s on March 11, while the positive flow rates range from 6 L/s on January 19 to 26 L/s on March 11 (Figure 3). Approximately 62,000 m^3 of stormwater was discharged to the foreshore area through manhole ST-1 during the 80-day period from January 3, 2007 to March 21, 2007. A significant portion of this total discharge occurred during a 32.5-hour period, including the wettest day on record, when some 32,000 m^3 of stormwater was conveyed to the foreshore.

The B.C. MoE’s discharge Permit PE-17469 (the Permit) issued for the WTP outfall sets maximum allowable concentrations (MACs) for six dissolved metals (copper, iron, zinc, d-aluminium, manganese and cadmium), total suspended solids (TSS) and pH. These MACs do not apply to the discharge from the Fan Area storm sewer; however, they are used here as preliminary water quality assessment criteria.

Analysis of four storm sewer water samples obtained at ST-1 (Table 1) indicates that dissolved metals concentrations in water flowing over the ST-1 baffle would not meet the WTP Permit requirements. Manhole ST-4 water quality varies significantly from the ST-1 stormwater data. All ST-4 TSS values are below the Permit value, while two of three ST-4 pH values are within the stipulated Permit range.

Copper Launders, Drop Box and Britannia Creek

Flow rates measured at the copper launders discharge correspond strongly to daily precipitation data. In general, instantaneous peak flows were recorded on days with highest recorded daily precipitation, ranging from approximately 11 L/s on February 15 to 72 L/s on March 11, while low-flow or no flow was recorded during periods of low precipitation. The quality of water discharged from the copper launders was found to be very similar to the quality of water conveyed to the launders from the drop box. Samples obtained concurrently at both discharge sites, on four separate days, indicate very similar concentrations for all tested parameters, including similar exceedances of CSR standards and CCME guidelines for both total and dissolved copper (t-copper and d-copper) and total cadmium (t-cadmium). Analysis of Britannia Creek water samples, collected concurrently with the launders and drop box samples, also indicated exceedances of CSR Standards and CCME guidelines (AW) for t-copper, d-copper, t-cadmium and d-cadmium.

Stream #1

Flow rates at the Stream #1 CSP discharge point include peak flow rates ranging from about 10 L/s on several days, to a maximum 54 L/s on March 11. Overall, the Stream #1 flow record exhibited a positive correlation to rain events throughout the observation period. Concentrations of total copper, total cadmium and total zinc exceeded the CSR Standard for freshwater aquatic life, and the total aluminium concentration exceeded the CCME guideline.

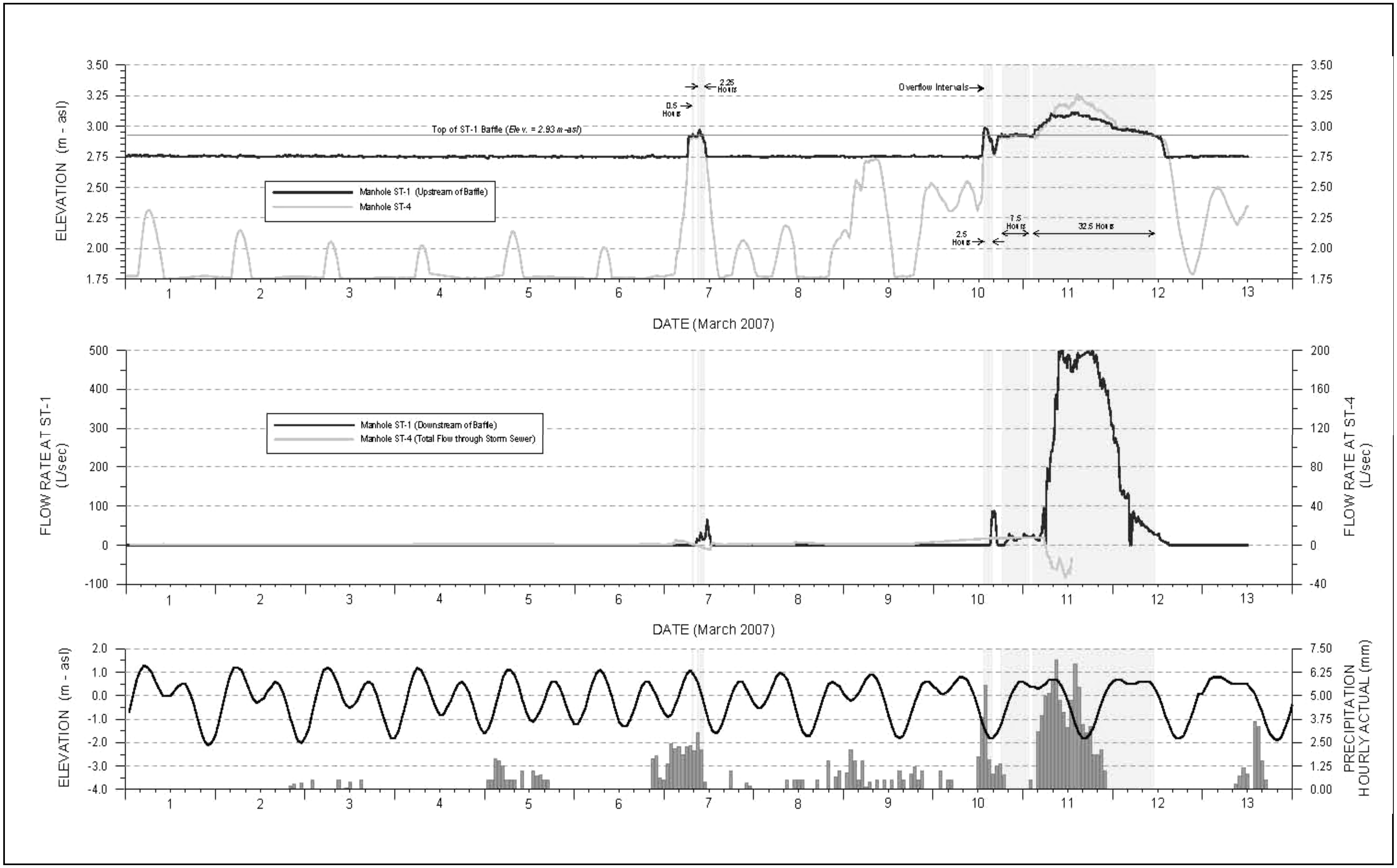

Figure 3: Water elevation, and flow rate from storm sewer manholes ST-1 and ST-4. Shown relative to tidal elevation and precipitation.

Stream #4

Flow rates measured at the Stream #4 flume correspond strongly to daily precipitation data with peak flows ranging from approximately 5.7 L/s on February 19 to 19.3 L/s on January 9, during days with relative high daily precipitation.

DISCUSSION

The primary objectives of the winter 2006/2007 monitoring program were to obtain information to:

1) characterize conditions contributing to ST-1 baffle overflow and related discharge to the marine foreshore;
2) determine the quality of stormwater flowing over the ST-1 baffle and onto the foreshore;
3) estimate the copper loading to Howe Sound resulting from ST-1 baffle overflow; and,
4) review options for managing sources flows contributing to the Fan Area storm sewer system and/or northern outfall.

Figure 3 summarizes all storm sewer water level and flow data during the 13-day period commencing March 1, 2007, these data being selected as: it includes a relatively dry weather period from March 1 to 4; followed by the wettest day on record (March 11); the highest recorded ST-4 and ST-1 flow rates and is a portion of the monitoring period supported by hourly on-site precipitation data (actual) from the WTP site station.

Fan Area Storm Sewer System

As flow through the northern outfall is known to be restricted, additional head must be applied in the storm system to maintain effective passage of stormwater through the outfall. Currently, additional head can only be achieved by the passive accumulation of water in the storm system, above the ambient tidal elevation, during rainfall events. Water levels prior to rainfall events are frequently near the ST-4 invert, and the available freeboard (for developing additional pressure) is limited to approximately 1.2 m, before water overflows the ST-1 baffle. Observations show that application of 1.2 m additional head is not sufficient to move water efficiently through the northern outfall. During all winter 2006/2007 rainfall events, the area-velocity meter in manhole ST-4 did not detect a measurable rate of flow corresponding to the “first flush” of stormwater toward the outfall. This observation confirms the Fan Area storm sewer system is not functioning as intended and is not effectively conveying water to the northern outfall.

On March 11, 2007, the WTP weather station reported 76 mm of precipitation (Figures 2 and 3). The relatively high rate of negative flow during this event cannot be attributed to Fan Area surface water sources that directly load the storm sewer system and, therefore, must originate from the only downstream source, which is the northern outfall pipeline (Figures 1 and 2). Accordingly, the high rate of negative flow measured at ST-4 during the intense winter rainfall represents water that has entered the northern outfall pipeline and re-directed to the Fan Area storm sewer system under pressure sufficient to lift the water to manhole ST-1. The 1,000 mm diameter outlet pipe at ST-1 is capable of conveying water at the maximum rates measured on March 11 (*i.e.*, 500 L/s). The discharge end of the pipe is also completely unobstructed and is located above the low tide position; therefore, the ST-1 outlet pipe represents a preferred decant point in the storm sewer system, as compared to the partially blocked northern outfall discharge.

A review of the ST-1 and ST-4 data (Figure 3) shows that baffle overflow events of varying duration occur in response to a range of contributory site conditions. However, a fundamental relationship exists between the incidence of baffle overflow and rainfall intensity, as exhibited in the strong correlation between these two data sets in Figure 3. It is observed that days with 28 mm or more rainfall account for the vast majority of long duration overflow events and are a primary indicator of significant baffle overflow. Comparison of the 28 mm lower bound precipitation estimate to the complete precipitation record confirms that minor baffle overflow occurred on days with less than 28 mm total precipitation. The frequency of foreshore discharge from ST-1 can be estimated by comparing the threshold daily precipitation value to historic precipitation records: on a yearly average basis, 40 rainfall events with precipitation exceeding 28 mm/day occurred, primarily during the period from October to March each year.

As anticipated, the combined results of winter 2006/2007 water quality and flow measurements at ST-1 indicate a substantial copper loading was conveyed to Howe Sound during 50 discrete baffle overflow events. Two water quality samples obtained from manhole ST-4 on January 23, 2007 and March 19, 2007 satisfied all WTP discharge Permit requirements and for dissolved metals, pH and total suspended solids. The variation in water quality between ST-1 and ST-4 can be attributed to the timing of sample acquisition: all ST-1 water quality samples were obtained automatically during the early stage of baffle overflow, when the Fan Area storm sewer system capacity had been exceeded and stormwater arriving at ST-1 was preferentially flowing over the ST-1 baffle. The ST-1 samples are primarily representative of stormwater quality from the catchment immediately upslope of ST-1, although some water flowing negatively through ST-4 might have contributed to the overflow water sampled at ST-1. In contrast, all ST-4 samples were collected in peak flow intervals of rainfall events, either several hours (e.g., February 15, 2007) or several days (e.g., February 19) after the ST-1 samples were collected. The results show the East Mill slope runoff is thus a primary source of metal loading in the storm sewer.

Copper Launders, Drop Box and Britannia Creek

The quality of water discharging from both the copper launders and upstream drop box is very similar suggesting that stormwater, originating from the WTP site, is not becoming significantly contaminated from contact with the drop box structure or the wooden flume, or while flowing through the copper launders. Total copper concentrations in most copper launders and drop box samples were marginally higher than samples collected concurrently from Britannia Creek, but were within the reported range of concentrations typical for the creek.

Streams #1 and #4

Analysis of water entering the Stream #1 culvert on January 2, 2007 confirms the stream quality is significantly impacted by metals contaminant source(s) located in the catchment upslope of the CSP. Isolation of Stream #1 from the waste rock downstream may provide a potential improvement to the water quality. Additional water quality sampling in Stream #1, at both the CSP outlet and at a downstream location near Britannia Creek, is needed to confirm this. Monitoring of flow rates at Stream #4 continued during winter 2006/2007 to gather additional hydraulic information pertaining to that watercourse. The resulting data will be used in the design of a collection system and diversion structure to re-direct Stream #4 away from the East Mill slopes and reduce both the hydraulic loading and contaminant loading on the storm sewer.

CONCLUSIONS AND NEXT STEPS

Based on the above review of surface water and stormwater quality/flow data for the periods of April to August 2006 and December 2006 to April 2007, the following conclusions were reached:

- Stormwater is not routinely discharging to the sub-tidal zone, via the north outfall;

- Stream #4 could be re-directed to the copper launders to reduce flow over the (metal-contaminated) east mill slope;

- The copper launder discharge, i.e., Streams #2 and #3 (and Stream #4 if it is diverted to the copper launders), could be re-directed to Britannia Creek, thus removing a significant hydraulic loading from the storm sewer during storm events;

- The majority of the winter 2006/2007 stormwater collected in the Fan Area storm sewers flowed over the baffle in manhole ST-1 and was discharged to the shallow intertidal zone;

- Water quality within the Fan Area storm sewer system exceeds the current WTP Permit discharge criteria and has an equivalent load of approximately 6kg/day of total copper; and,

- It is recommended that a feasibility study be undertaken to consider options for stormwater treatment and/or rehabilitation of the northern outfall. Options for stormwater treatment may (pending an engineering feasibility study and resolution of permitting issues) include:

    - Installation of a pumping chamber within the Fan Area storm sewer, fitted with a level-controlled transfer pump to pump stormwater to the groundwater management system pump house located on the shoreline. The pump house contains a holding tank and two transfer pumps currently used for pumping groundwater to the WTP. Surplus capacity within this system could be utilized until the WTP was at treating a combination of mine water, groundwater and stormwater at its capacity; then, under extreme storm events during periods of high mine flows; and,

    - Any additional volume within the storm sewer over and above that which could be pumped to the WTP, be treated with lime to neutralize the water and precipitate dissolved metals and then combined with the treated WTP effluent prior to discharge through the new deep outfall.

This paper represents a work-in-progress to resolve a remaining issue of significant environmental concern at the Britannia Mine. A long-term program of environmental effects monitoring (EEM) has been in place since 2004, and one of this program's main points of focus is the intertidal zone.

Remediation effort to mitigate the uncontrolled discharge of metal-contaminated groundwater will be linked to the EEM program, leading to a Tier 2 ecological risk assessment. Progress of this aspect of the remediation work will be reported at future MEND symposiums.

REFERENCES

URS. 2002. Britannia Contaminated Site Investigation: Fan Area Detailed Site Investigation. <http://www.agf.gov.bc.ca/clad/britannia/reports.html>.