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The role of aquatic ecological risk assessment to guide effluent management from mine waste

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Abstract

Mine waste can pose a risk to the natural environment, especially if on-site closure conditions change. At remote locations in particular, such sites can be viewed as an unknown risk by regulators, and mining companies are often asked to monitor or treat an unknown risk or to develop management options to reduce them. This paper presents a case study for a historic mine site in northwest British Columbia. Discharges from the mine portals and waste dumps are entering the river, which flows into southeast Alaska. Aquatic risk assessment was used to evaluate the potential for contamination of aquatic biota due to changes in water quality. To complete the risk assessment, scientists studied water quality upstream and downstream from mine site discharges and completed a detailed review of historic data. The team identified cadmium, copper, lead and zinc as the contaminants of potential concern and assessed the discharges' impact on a variety of fish species including coho salmon, sockeye salmon, Chinook salmon and bull trout. Although significant levels of copper and zinc were found downstream from the mine, the drainage was assessed to pose a low risk to fish in the river. The potential risks to fish were measured using a hazard quotient (HQ): if this is greater than one, it can indicate unacceptable risks to fish and other aquatic life. The study concluded that, regardless of whether a water treatment plant were to be operating or not, the HQs were less than one for the majority of the year, including during critical time periods for fish migration and spawning. The study identifies data gaps on the ecology of the river, for example, the use of the river by fish during the winter and spring thaw; if needed, additional data collection could be targeted to supplement the aquatic risk assessment. This case study showcases an approach to evaluating ecological risk at remote locations and guiding focused data collection and management options. This demonstrates the need to implement treatment and management strategies that are appropriate to reduce off-site impacts.

1 Introduction

Mine sites can pose a risk to the natural environment, particularly if on-site conditions change and discharge from mine waste materials enters adjacent natural waterbodies. It can be difficult to accurately assess the degree of risk of effects to the natural environment, particularly in remote and northern sites where extensive monitoring can be time consuming and data can be difficult to collect. It can also be difficult to determine a focused and effective mitigation plan if the risks are unknown or too general in nature.

At a remote historical mine site in northwest British Columbia (BC), effluent from the old mine portals and waste rock piles converges and drains into a river, which ultimately flows through southeast Alaska. In an attempt to reduce this effluent loading, a temporary water treatment plant (WTP) was operated on-site for six months. The plant was originally envisaged through an environmental assessment (EA) commitment to provide an interim treatment facility for the incremental loading that might occur as a result of relocating potential acid generating (PAG) historical waste rock to facilitate construction as part of a new mine project. Operating costs were significantly higher than anticipated for this WTP, and design parameters were not met. As part of the WTP commissioning, a monitoring and surveillance program was developed to monitor the effects of the WTP on the receiving environment. This monitoring program continued even after the plant was shut down. An aquatic ecological risk assessment (AERA) was subsequently conducted to specifically address the potential for impacts of this historical mine discharge to fish in the receiving waterbody. This AERA also compared the risks between the period when the WTP was in operation and when it was not.

The AERA combined historic literature with current water-quality data of the mine effluent and the receiving environment. Surface water-quality data was available on a mainly monthly basis from 2008 to 2013. This period included both the operational and nonoperational periods of the WTP. Data on sediment and benthic invertebrates in the receiving waterbody were limited. The hydrologic regime of the receiving waterbody (seasonal major glacial outbursts) precluded collecting stable baseline datasets on the benthic invertebrate community. Therefore, the AERA focused on fish, in particular salmonids, which are prevalent in the receiving water body, considered to be the most sensitive fish receptor in the known fish community and are of significant cultural and economic importance in the local area.

2 Methods

The AERA followed a tiered approach using the steps below:

- Document relevant receptor information (for example, fish community and life history data).
- Compile available water-quality data.
- Identify water-quality screening levels and determine constituents of potential concern (COPCs).
- Estimate environmental concentration (EEC) for each COPC.
- Determine appropriate toxicity reference values (TRVs) specific to the receptors of concern and exposure media.
- Characterise potential adverse effects associated with each COPC.
- Characterise risk through estimating hazard quotients (HQs) and considering uncertainties.

The specific approach for the risk assessment was as follows.

Water quality screening levels were derived for the identification of COPCs through consideration of provincial and federal criteria, and with consideration of background water quality (i.e., water representing regional levels). Where background levels were greater than regulatory criteria, the 90th percentile background value for each relevant parameter was selected as the COPC screening level. This is consistent with the BC Ministry of Environment guidance for completing risk assessments and was considered a conservative approach, given that there were generally 47 or more monitoring events available for the background parameters.

Water quality for the monitoring location nearest to the point of discharge to the river (site exfiltration pond SE-2) was selected for the identification of COPCs that would be considered in the aquatic receiving environment with respect to their potential to cause adverse effects in fish.

Summary statistics and trend graphs were generated for the measured COPCs at each of the monitoring stations located within the river to gain an improved understanding of COPCs within the aquatic receiving environment and to form the basis for fish exposure levels. The EEC for each COPC at each receiving environment location was the 90th percentile value for the available data sets.

Project-specific TRVs were derived by considering published toxicity literature specific to freshwater fish. Salmonid data was prioritised, in keeping with the project scope. The exposure pathway was from direct surface water contact.

Risk estimates were generated in the form of hazard quotients (HQs) for each COPC at each of the three monitoring locations in the receiving environment, for both dissolved and total metals. HQ results greater than one indicate that the potential for unacceptable adverse effects exists, and this suggests that more refined consideration may be warranted to reduce uncertainty and/or mitigate the risk. The HQ is calculated by dividing the estimated environment concentration (EEC) by a single point toxicity reference value (TRV).

The collective HQ results, particularly those with results greater than one, were further considered prior to forming a conclusion with respect to mine discharge and its potential to adversely affect fish as a whole in the receiving waterbody.

In order to come up with a level of potential risk based on the HQ, the *Recommended Guidance and Checklist for Tier 1 Ecological Risk Assessment of Contaminated Sites in British Columbia* (Government of British Columbia, 1999) was used. According to this document, if a receptor is known (or assumed) to be present, it is categorised as follows:

- Low risk is when HQ < 1.
- Moderate (intermediate) risk is when1 < HQ < 100.
- High risk is when HQ > 100.

Further details on these three levels of risk are provided by the Science Advisory Board for Contaminated Sites in British Columbia (2008):

- *Low risks: Implies that adverse effects are likely not present based on the totality of data available. Low risk differs from the term negligible risk in that the former designation is more appropriate for situations where the conclusion is based on the balance of probabilities;*
- *Moderate (or intermediate) risks: Implies that some degree of adverse effects are likely, based on the totality of data available. Risk estimates suggest that risk management or remediation is necessary, unless further refinement of the risk estimate is conducted*
- *High (or severe) risks: Implies that adverse effects are likely based on the totality of data. Risk estimates suggest that risk management or remediation is necessary and that this conclusion is unlikely to change even if further refinement of the risk estimate is conducted.*

3 Results

3.1 Aquatic environment site description

Aquatic monitoring data in the area was available from 1988, and more intensively from 1994 as part of an environmental assessment (EA) certificate. Various environmental effects monitoring (EEM) studies were also conducted as a follow-up to the EA and for preconstruction activities. Data was available not only on water quality but also on fish health and contaminant loadings.

The receiving waterbody from the mine site is one of the major tributaries to the Taku River. The Taku River is a transboundary river originating in northwest BC and flowing 266 km before emptying into the Taku Inlet just south of Juneau, Alaska. The Taku River commercial salmon fishery is vital to the traditional and subsistence-based lifestyles of the Tlingit people. Throughout much of the year, the local hydrograph is snow and glacial melt-driven. However, on at least one occasion per year, the river is subject to extreme flood surges from a glacier-impounded lake that drains quickly (jökulhlaups). During such events, the water levels can rise over a period of 24 to 48 hours with flows > 2,000 m^3/s, compared to typical maximum daily flows of 300 – 400 m^3/s. Near the confluence with the Taku River, the receiving waterbody has a catchment area of 781 km^2, and approximately 42% of this is covered in glacier. The mean annual discharge was estimated to be 39 m^3/s, with the lowest monthly flow in March or April. Within the study area, the receiving waterbody is considered as one reach, with no obvious break based on gradient or other important hydraulic or habitat features.

Comprehensive fish and fish habitat data was available for the site from work completed between 1989 and 2007. The site and receiving waterbody was therefore considered to be well-characterised. The receiving environment supports several nonsalmonid species (e.g., stickleback and sculpin) and up to nine salmonid species, including all five Pacific salmon species (*Oncorhynchus* sp.), anadromous and resident Dolly Varden (*Salvelinus malma*) and bull trout (*S. confluentus*), steelhead/rainbow trout (*O. mykiss*) and cutthroat trout (*O. clarki*). Within the receiving environment watershed, juvenile Coho salmon (*O. kisutch*) and Dolly Varden were the most common and ubiquitous species captured during monitoring programs.

Fish habitat quality throughout a large portion of the floodplain is limited by elevated turbidity during the open water season and extreme turbidity and flow during the seasonal glacial outburst floods. The receiving waterbody is primarily used as a migration corridor and only provides temporary refuge habitat for salmonids and other fish species. However, there are well-defined, clear-water (groundwater upwelling) side channels downstream of the mine site, which provide important overwintering, spawning and rearing habitat for both resident and anadromous fish.

3.1.1 Receptor description

The risk assessment focused on the four most common and abundant species in the receiving waterbody: Chinook salmon (*Oncorhynchus tshawytscha*); coho salmon (*O. kisutch*); sockeye salmon (*O. nerka*); and Dolly Varden/bull trout (*Salvelinus malma/S.confluentus*). Chinook salmon are not ubiquitous in the immediate receiving environment, but likely use the Taku River confluence and therefore may occur within the zone of influence. All key receptor species are of economic, cultural and/or recreational importance to marine and freshwater fisheries. Juveniles from all these species spend at least 18 months in freshwater before migrating to the ocean. Dolly Varden/bull trout comprise both anadromous and resident forms. Salmonid species are known to be sensitive to environmental or chemical perturbations and therefore are suitable receptor species that conservatively measure potential risks from water quality. Figure 1 provides the residence timings of the selected receptor species.

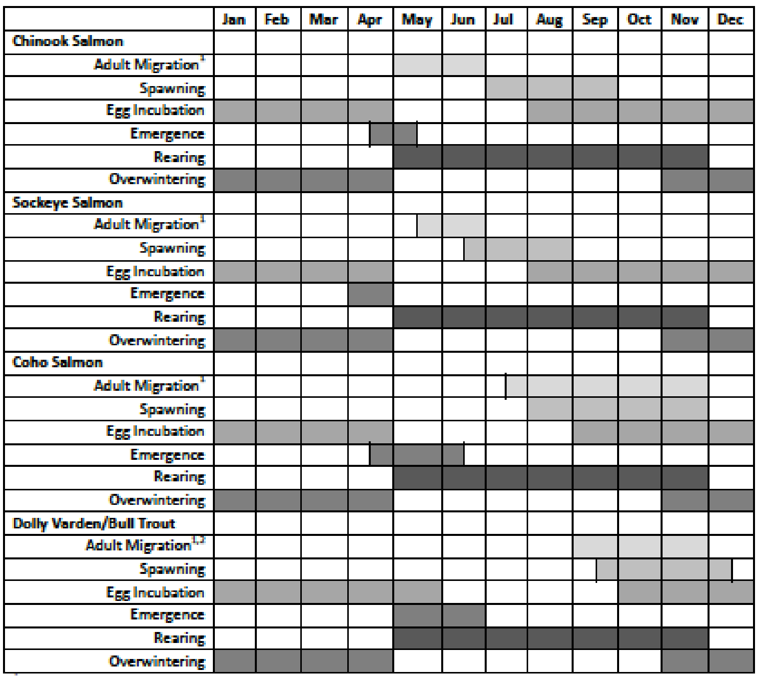

Figure 1 Approximate timing of receptor species presence by life-stage in the receiving environment (Government of Canada, 2001)

3.2 Water quality

3.2.1 Source description

Acid rock drainage (ARD) has been leaching from the mine site since operations ceased in 1957. The major metals in the PAG waste rock are aluminium, calcium, iron, magnesium and sodium. Field bin testing showed leachate from the PAG waste rock is acidic with < pH 3.5 and with elevated zinc and copper concentrations.

Since the shutdown of the WTP in 2012, the discharge from the historic portals has been directed to the site exfiltration pond, along with site runoff, waste rock runoff and neutral mine water discharges.

3.2.2 Receiving environment

Available receiving environment water-quality data for samples collected between June 2008 and July 2013 was used in the risk assessment. Specifically, four stations were established: station W10 is 4.5 km upstream of mine site discharges (background); station W46 is downstream of WTP effluent discharges; station W51 is 325 m downstream of site exfiltration pond drainage; and station W32 is 2.7 km downstream of site exfiltration pond. Station W10 is representative of water-quality conditions upstream of the mine discharges. Stations W51 and W32 represent the water quality downstream of the mine discharges. W46 is located directly downstream of the WTP discharge but upstream of the site exfiltration pond (SE)-2.

As part of a previous EEM study, monthly samples were collected at these stations between June 2008 and February 2009, and then additional monitoring was conducted as part of the WTP discharge permit. From August 2012 to July 2013, stations W10 and W32 were sampled biweekly from August to December, and then weekly from January to June 2013, for a total of 37 samples from each site. Samples were taken from stations W46 and W51 weekly from September 2012 to July 2013.

Monitoring of the receiving waterbody includes analysing water samples for total and dissolved metals and specified physical parameters: pH, conductivity, turbidity, total suspended solids, hardness and alkalinity. Station W10 is representative of water quality conditions upstream of the mine discharges, and stations W51 and W32 represent the water quality downstream of the mine discharges. Concentrations of copper and zinc remain relatively stable at station W10; however, the concentrations at stations W32 and W51 increase as flow diminishes over the winter, then peak in late April (due to snowmelt and the first flushing of the waste rock combined with the portal discharges into SE-2), and then decrease again with increased river flows. During the ice-free periods, the concentrations of total and dissolved metals are similar between station W10 upstream of the mine and station W32 downstream of the mine. Even station W51, immediately downstream of the mine, is comparable to stations W10 and W32. There appears to be enough dilution during high flows that mine effluent concentration in the receiving waterbody is vastly reduced, even without the WTP operation.

There is good correlation between W32 and W51, which reflects the dilution occurring on average of about 20 to 50-fold. Table 1 summarises the dilution rations from W51 to W32 for copper, cadmium, zinc and lead during prefreshet (April 20 – May 4, 2013), high flows (September 12, 2012 – January 5, 2013; May 11 – July 20, 2013) and low flows (January 19, 2013 – April 13, 2013). Dilution ratios were based on median concentrations for each parameter for each station. The dilution ratios are lower during high flows, as compared to low (including prefreshet) flows because abundant, rapid dilution is available, even between the mine and W51.

Table 1 Dilution ratios from W51 to W32

Parameter	Prefreshet	High flows	Low flows
Dissolved copper (Cu)	26	15	30
Total copper (Cu)	67	10	46
Dissolved cadmium (Cd)	21	18	29
Total cadmium (Cd)	20	9	29
Dissolved zinc (Zn)	22	21	34
Total zinc (Zn)	24	11	34
Dissolved lead (Pb)	16	1	5
Total lead (Pb)	198	4	47

3.2.3 Screening level selection

Risk potential screening levels used to identify COPCs considered provincial and federal regulatory criteria and local background water quality concentrations in the receiving environment. The criteria included British Columbia Water Quality Objectives (BCWQO); Canadian Council of Ministers of the Environment (CCME) water quality guidelines; and local background concentrations as defined by the 90th percentiles for measured parameters at upstream monitoring station W10 (Table 2). The screening level selection approach was as follows: the background water quality took precedence over the BCWQO and CCME values; otherwise, the lowest of the provincial and federal values was selected as the screening level, except where the background level exceeded regulatory criteria. In such cases, the 90th percentile for the background data was carried forward as the screening level; this was the case for total aluminium, chromium, copper, iron, vanadium and zinc.

The COPCs identified were based on comparison of the project screening levels with the available data representative of the worst-case water quality being discharged from the mine. The station used for the identification of COPCs was station SE-2, which is a sampling point located prior to discharge into the aquatic receiving environment. This approach identified a rather broad range of COPCs that were then carried forward into the evaluation of risk at the monitoring stations representative of the receiving environment (stations W32, W46 and W51).

Table 2 Water quality screening levels

Parameter	Units	CCME	BCWQO	Background 90th percentile	Screening level
Fluoride (F)	mg/L	0.12	2	0.06	0.12
Nitrite (N)	mg/L	0.06	0.02	0.03	0.02
Nitrate (N)	mg/L	13	3	0.06	3
Dissolved sulphate (SO_4)	mg/L		218	13.9	218
Dissolved chloride (Cl)	mg/L	120	150	1.81	120
pH	pH units	6.5 – 9.0	6.5 – 9.0	7.7	6.5 – 9.0
Total aluminium (Al)	µg/L	100		4,538	4,538
Total arsenic (As)	µg/L	5	5	2.5	5
Total barium (Ba)	µg/L		1,000	89	1,000
Total beryllium (Be)	µg/L		5.3	0.1	5.3
Total boron (B)	µg/L	1,500		25	1,500
Total cadmium (Cd)	µg/L	0.09	0.01 – 0.06	0.11	0.16
Total chromium (Cr)	µg/L	1	1	7.1	7.1
Total cobalt (Co)	µg/L		4	25	4
Total copper (Cu)	µg/L	4	2	10.7	13
Total iron (Fe)	µg/L	300	1,000	5,428	6,265
Total lead (Pb)	µg/L	7	12	3.4	7
Total lithium (Li)	µg/L		14	25	14
Total manganese (Mn)	µg/L		700	116	700
Total mercury (Hg)	µg/L	0.026	0.00125	0.025	0.00125
Total molybdenum (Mo)	µg/L	73	1,000	2.7	73
Total nickel (Ni)	µg/L	150	25	9.2	25
Total selenium (Se)	µg/L	1	2	0.26	1
Total silver (Ag)	µg/L	0.1	0.05	0.04	0.05
Total thallium (Tl)	µg/L	0.8	0.8	0.00546	0.3
Total titanium (Ti)	µg/L		2,000	264.4	2,000
Total uranium (U)	µg/L	15	300	15	
Total vanadium (V)	µg/L		6	11.8	11.8
Total zinc (Zn)	µg/L	30	7.5	20.8	31.9

Subsequent to the screening, a more detailed consideration was given to each of the preliminary COPCs. This process identified that mercury was not detected in the discharge at SE-2 or the receiving environment stations. Given that mercury has not been detected at the mine, or within the local receiving environment, it was not carried forward for quantitative evaluation in the risk assessment. Similarly, when the screening was applied to the remaining list of preliminary COPCs, only seven were found to be present at concentrations exceeding the project screening levels in the receiving environment: aluminium, cadmium, copper, iron, lead, nickel and zinc. Further review of these metals resulted in four metals being carried forward for quantitative evaluation in the risk characterisation because they exceeded the criteria in at least 10% of the samples (and more than once) at one or more of the monitoring stations. These were cadmium, copper, lead and zinc. The screening identified total metals as the COPCs; this is a function of the regulatory surface water criteria being set for total concentrations rather than dissolved. However, to provide a more comprehensive evaluation of the potential for risk in the aquatic receiving environment, HQs were calculated for both the total and dissolved concentrations for each COPC.

3.3 Exposure assessment

Exposure to COPCs was characterised using two methods: COPC concentrations in surface water and COPC concentrations in fish tissues, where data was available. Data was available for juvenile Dolly Varden collected from upstream and downstream from the mine discharge site. The results found no significant differences in tissue metal concentrations between sample site locations (Hitselberger, 2012).

Each surface water sample result represents an estimated environmental concentration (EEC) from which an HQ was calculated. The fish receptors are also known to prefer certain habitat conditions, and Table 3 compares the water-quality parameters from the background river main stem and clear-water side channel to the guideline criteria.

Table 3 Comparison of receiving environment main stem and clear-water side channels

Parameter	CCME guidelines	Range in main stem background concentration	Range in clear-water side channels
Hardness	–	23 – 33 mg/L	29 – 57 mg/L
Conductivity	–	54.0 – 78.2 µS/cm	68.4 – 132 µS/cm
pH	6.5 – 9.0	7.65 – 7.81	7.64 – 7.90
TSS		49 – 111 mg/L	< 3 – 40 mg/L
Turbidity	–	44 – 145 NTU	0.48 – 44 NTU
Total aluminium	0.005 – 0.1	0.89 – 2.9 mg/L	0.01 – 0.51 mg/L
Total cadmium	0.000017	< 0.000070 – 0.000070 mg/L	0.000021 – 0.000026 mg/L
Total copper	0.002 – 0.004	0.0047 – 0.0076 mg/L	< 0.0010 – 0.0033 mg/L
Total iron	0.30	0.94 – 2.95 mg/L	< 0.03 – 0.69 mg/L
Total lead	0.0010 – 0.0070	0.0015 – 0.0028 mg/L	< 0.0005 – 0.0007 mg/L
Total zinc	0.03	0.009 – 0.0160 mg/L	< 0.0050 mg/L

3.4 Toxicity reference values

The effects of a chemical contaminant on an ecological receptor are characterised by an exposure-response curve. The toxicity reference values (TRVs) selected for salmonids were considered to be threshold concentrations or doses/intakes of the COPCs that could cause harm if exceeded. The TRVs considered for use in this risk assessment were based on chronic toxicity tests carried out under standardised laboratory conditions (Table 4). All TRVs were based on average hardness measured over the sampling events at the four sampling stations.

Table 4 Acute and chronic TRVs and acute to chronic ratio

Chemical	TRV chronic (µg/L)	TRV acute (µg/L)	Acute to chronic ratio
Cadmium	1.3	1.3	1
Zinc	187	460	2.5
Lead	15	1,170	78.0
Copper	13	19	1.5

3.5 Hazard quotient estimates

HQ box-plot graphs were generated for each of the four COPCs at stations W46, W51 and W32 for WTP operational and nonoperational scenarios. For cadmium, plots indicate a potential unacceptable hazard to fish at station W51, even when the WTP was operational. Total cadmium HQ also exceeded one in one sample at W10, suggesting that total cadmium may be naturally elevated. Plots indicate a potential unacceptable risk to fish at W51 when the WTP was not operational. The maximum HQ when the WTP was not operational was approximately eight times higher than the maximum HQ when the WTP was operational.

Copper HQs indicate a potential unacceptable hazard to fish at station W51 when the WTP was operational. Dissolved copper also marginally exceeded the HQ of one at sample stations W46 and W32; however, total copper HQs were less than one. Total copper exceeded the HQ of one in one sample at station W10, suggesting naturally elevated copper. Dissolved and total copper HQs when the WTP was not operational indicate a potential unacceptable hazard to fish at stations W5 and W32. Almost all fish HQs based on dissolved and total copper at site W51 were greater than one. Two fish HQs for total copper at stations W10 and W46 marginally exceeded the HQ of one, indicating natural elevations. The selected TRV was equivalent to the P95 value for copper at W10.

Dissolved and total lead HQs for surface water exposures to fish indicate a negligible risk at stations W46, W51 and W46 when the WTP was operational. Dissolved and total lead HQs indicate an occasional potential unacceptable hazard at station W51 when the WTP was not operational. One fish HQ based on dissolved lead in surface water and two fish HQs based on total lead in surface water exceeded the HQ of one at station W51. All other fish HQs for lead were less than one.

Dissolved and total zinc HQs indicate a potential unacceptable hazard at station W51 when the WTP was operational. All other fish HQs for zinc in water were less than one. Dissolved and total HQs for zinc indicate a potential unacceptable risk at station W51 when the WTP was not operational. Almost all fish HQs based on dissolved and total zinc at W51 were greater than one. All other fish HQs for zinc in water were less than one.

Trends in COPC concentrations at stations W51 and W32 appear to follow seasonal discharges and climatic conditions. The highest flows at these stations occurred between mid-May to December, and the period between January and early April had HQs that were on average three to four times higher than during the high flow period. These winter months represent low flows and the least amount of dilution. The highest HQs at these stations occurred during late April and early May for all COPCs. This is the result of snow melt and precipitation and the subsequent annual flush of historic waste dumps into the river.

4 Discussion

The hazard quotients were highest at station W51, followed by station W32. The HQ results at stations W10 and W46 (upstream of the mine) rarely exceeded one for any sampling event. Station W51 appears to be the station most affected by discharge from the mine site. At this location, the HQs for all COPCs were greater than one under both WTP operational and nonoperational conditions, with the exception of lead, which had an HQ consistently less than one under the WTP operational period. At each station, HQs were considerably lower during WTP operational conditions compared to when the WTP was not operating, indicating that the WTP has a positive influence on water quality.

Until such time that the historical waste rock is capped to reduce infiltration, it does not appear possible to prevent occurrences of HQs exceeding one during the spring freshet. This is true whether or not the WTP is operating or not. The HQ was less than one for the majority of the year, with or without WTP operation, including the critical time periods when Chinook, sockeye and coho salmon are migrating to spawn and eggs are incubating and hatching.

The most sensitive life stage of Chinook and steelhead trout for acute toxicity for cadmium, copper and zinc is the juvenile form (Chapman, 1978). Juvenile salmonids in the receiving environment are very unlikely to rear in the fast-flowing, turbid water of the main channel. As such, the juvenile forms of the receptors of concern are less likely to be exposed to the episodic loadings of COPCs from mine discharge. Potential impacts to salmon spawning are one of the key issues to evaluate in this risk assessment. The highest concentrations of COPCs coincides with the period of the annual snowmelt and rainfall in late April to early May. Both spawning periods of the coho and sockeye salmon coincide with a time of low HQs for COPCs and therefore result in relatively lower exposure levels. Coho enter the river between mid-July and November and spawn in the watershed between August and December. Sockeye spawn between mid-June and August. Moreover, all of these salmonid species are more likely to be found in the clear-water side channels than the main stem of the river.

Given the frequency (annual) and size of jökulhlaup events combined with high turbidity, unsuitable substrate (cobble) and very cold temperatures (< 1°C), it can be reasonably predicted that the receiving environment only provides marginal or transitional habitat and that fish utilisation of the main stem is transient and primarily for migratory purposes. As is the case during the rest of the year (late spring through early fall), most fish (including fall spawners) would likely be found in the clear-water side channels along the river margins.

This risk assessment focused on direct surface water contact. Knowledge of the tissue residue levels in food consumed by the salmonid species could provide information about whether dietary uptake is the major route of exposure. Generally, the higher the metal concentration in the water, the more metal is taken up and accumulated by fish. The relative importance of waterborne versus dietary uptake differs greatly among metal species and may differ between fish species (Miller et al., 1993; Sappal et al., 2009; Franklin et al., 2005; Mount et al., 1994). Tissue residue concentration in fish depends on more than just dietary and waterborne metal concentrations. Time of exposure, environmental conditions (water temperature, pH, hardness, salinity) and intrinsic factors (fish age, feeding habits) must also be considered (Jezierska and Witeska, 2006). Additional detailed studies would need to be undertaken in this receiving environment to determine whether dietary metals uptake or waterborne uptake is the key uptake mechanism. However, it is highly likely that resident fish are largely drift feeders and that direct surface water contact is the key exposure source.

Based on the seasonal trends of metal concentrations and the life cycles and habitat preferences of the receptors of concern, the risk is considered low for anadromous species. The risk to resident receptors of concern (if any are present in the main stem during the prefreshet period) is greater (i.e., moderate) due to increased potential for exposure to COPCs.

5 Conclusions

The objective of the study was to determine the potential for risk to fish species in the receiving environment from discharge from a historical mine site. A second objective was to attempt to assess the effectiveness of the WTP that operated briefly in 2012. A systematic screening of all measured surface water quality parameters resulted in the identification of four contaminants of potential concern: cadmium, copper, lead and zinc. Using the hazard quotient methodology, evaluation of mine effluent showed that the highest HQs in the receiving environment coincided with the period of site snowmelt. This is believed to be the result of the annual flushing of the historic mine waste rock during the spring thaw. During the annual flushing period, most juvenile salmonids will be overwintering in the preferred habitats of the clear-water side channels.

With respect to the effectiveness of the WTP, surface water quality monitoring during its operation did show that the HQs were lower at sites downstream from the points of discharge. However, during the annual flush period, HQs for copper and zinc were still greater than one. Until such time that the historic waste rock is capped to reduce infiltration, it does not appear that the WTP is capable of reducing mine discharge to levels where resulting HQs do not exceed the threshold of one. Regardless of whether the WTP was operating or not, the HQs at all sites except W51 were less than one for the majority of the year.

Overall the potential risk to aquatic receptors as a result of mine discharge is considered low (HQ < 1 most of the year). As HQs at some sites were greater than one, the risk to main stem aquatic receptors would be considered moderate (HQ < 100) during those times. However, as most migratory species are known to utilise clear-water side channels removed from direct influences of the mine discharges, and there were no effects on tissue metal concentrations in the resident species (Dolly Varden/bull trout), the moderate risk designation for the selected aquatic receptors is considered conservative.

It is important to note that the goal of the AERA was to determine the relationship between the mine discharge and the risk to aquatic life. The goal was not to provide a specific description of the potential impacts of aquatic receptors. One important application of the AERA is help identify data gaps and focus data collection as part of future monitoring plans. This targeted data collection can then be used to refine risk assessments and help appropriately monitor treatment and management strategies to reduce off-site impacts under changing conditions. For example, monitoring is now focused on the snowmelt period in April, recognising that there is no or only low potential for adverse effects during the open-water summer season.

This case study outlines an approach at a mine where available background information was put to good use in helping to define potential risk to the aquatic environment and focus resources for future monitoring and management strategies. Such an approach is recommended at other sites, particularly remote sites or closed sites where resources may be limited. Risk should be determined and only appropriate environmental protection measures put into place.

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