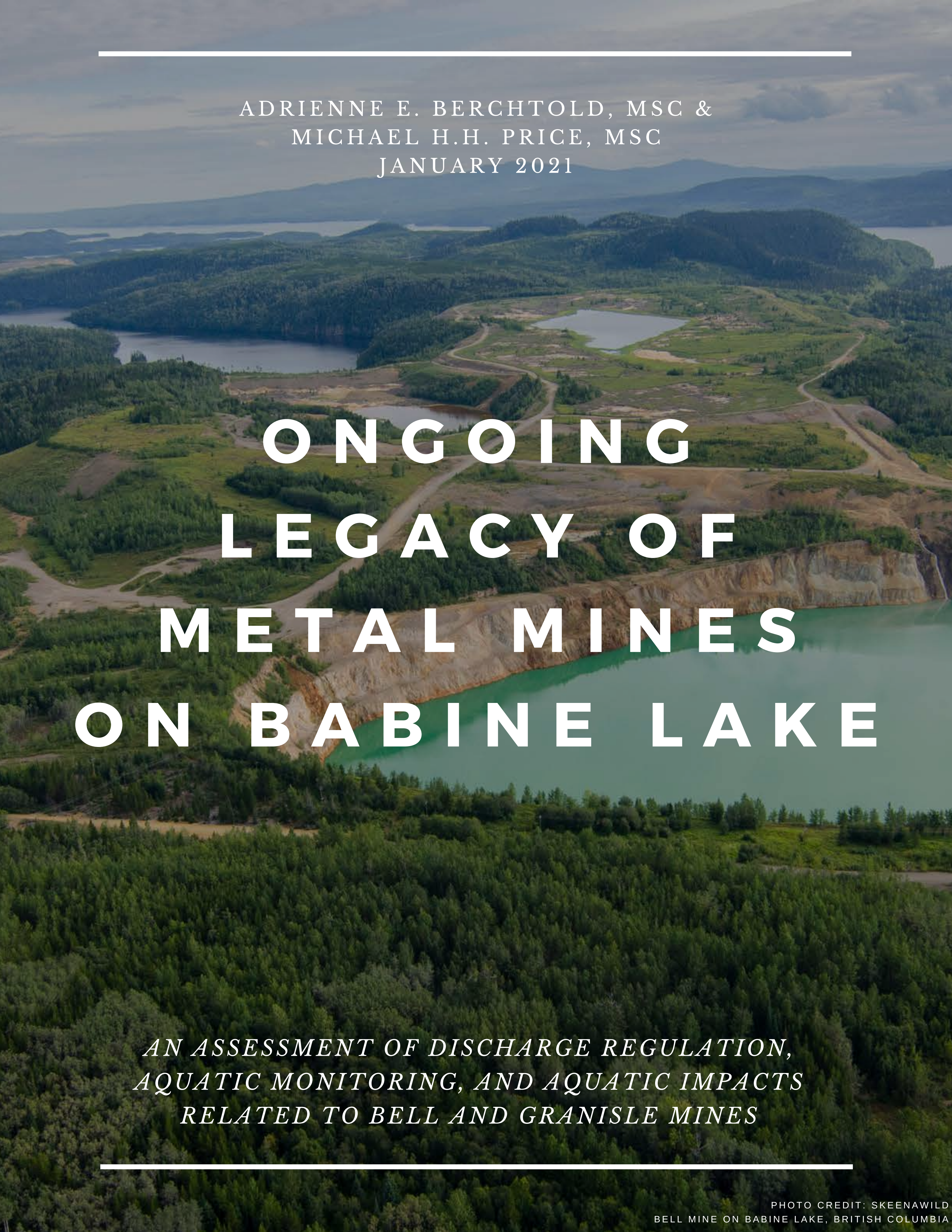

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JANUARY 2021

ONGOING LEGACY OF METAL MINES ON BABINE LAKE

AN ASSESSMENT OF DISCHARGE REGULATION, AQUATIC MONITORING, AND AQUATIC IMPACTS RELATED TO BELL AND GRANISLE MINES

PHOTO CREDIT: SKEENAWILD
BELL MINE ON BABINE LAKE, BRITISH COLUMBIA

PREPARED FOR
SKEENAWILD CONSERVATION TRUST

PREPARED IN PARTNERSHIP WITH
LAKE BABINE NATION

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SUMMARY

Babine Lake, situated in the Skeena watershed of British Columbia, provides rearing habitat for ~90% of the watershed's sockeye salmon, and carries great significance to Lake Babine Nation. Two decommissioned open-pit copper mines, Bell and Granisle, continue to discharge both treated and untreated mine-impacted water to Babine Lake, thereby exerting potential aquatic impacts. This report reviews: i) current mine-impacted water discharges from Bell and Granisle mines, including discharge volume and quality limits, as regulated by the BC Ministry of Environment (BC MOE), ii) aquatic monitoring programs for surface water, sediment, and fish in Babine Lake, as regulated by the BC MOE and performed by the mines' owner, Glencore Canada Corporation (Glencore), and iii) results of recent monitoring in Babine Lake, which highlight evidence of mine-related aquatic impacts.

Our assessment demonstrates that current permits regulating discharges from Bell and Granisle mines are limited in extent and stringency. The Granisle mine site does not have any volume or quality limits applied to its multiple discharge sources. Permits for Bell mine allow high discharge concentrations of some harmful contaminants (i.e., copper, iron, and zinc) and leave many other contaminants – such as aluminum, cadmium, and selenium, all of which are known to harm salmon at elevated concentrations – completely unregulated. These mine water discharges entering Babine Lake consistently exhibit negative effects to aquatic invertebrates during toxicity tests, and contain metal concentrations that are well above the lake's natural background levels and/or levels known to cause chronic (i.e., sublethal), and sometimes even lethal, effects to salmonids. Additionally, the combination of contaminants in mine discharges has the potential to exert amplified negative effects on salmon.

PHOTO CREDIT: SKEENAWILD
BELL MINE'S OPEN PIT, WHICH STORES MINE-IMPACTED WATER THAT IS TREATED BEFORE DISCHARGE TO BABINE LAKE

The aquatic monitoring program of Babine Lake also contains gaps that limit the monitoring information obtained, thereby inhibiting identification and tracking of mine-related aquatic impacts. Overall, sampling is inadequate across time and space to provide scientifically robust information required to accurately characterize impacts. Notably, there are limited baseline and/or historical data for water, sediment and salmonid fish in the area receiving discharges from Bell mine's new water treatment plant, fish and water quality are never sampled in the vicinity of some Granisle mine discharges, and monitoring of water quality and other aquatic indicators in Hagan Arm (which receives a significant volume of untreated discharge from Bell mine) occurs only every ten years. Additionally, sockeye salmon are not a focal monitoring species, resulting in very little information regarding potential impacts to these important fish. Other gaps exist in the thresholds used by Glencore to identify whether mine-related aquatic effects are occurring; in particular, only provincial guidelines are used even though more protective thresholds, and thresholds for indicators that provincial guidelines do not cover (e.g., fish tissue metal concentrations), are reported in the scientific literature. Lastly, even when aquatic impacts are identified, additional follow-up monitoring is not performed. Full awareness of mine-related impacts to Babine Lake will not be possible without more exhaustive, consistent, and scientifically accurate monitoring.

Despite the current monitoring gaps, our assessment found evidence of aquatic impacts in Babine Lake linked to both historical and recent mining activities. Persisting historical impacts include a number of elevated metals in both sediments and benthic fish tissues surrounding both mines – some of which, especially copper, exceed thresholds that indicate the potential for mine-related chronic effects. Recently occurring impacts include: i) increases to already elevated copper in mine-exposed sediments, and selenium in mine-exposed benthic fish tissues, ii) new metal elevations (i.e., iron and lead) in mine-exposed benthic fish tissues, iii) elevated aluminum and sulphate in water near Bell mine, and iv) elevated copper in water near Granisle mine that potentially exceeds the provincial chronic effect threshold. Additionally, we found evidence of potential impacts to lake trout in Babine Lake that previously had been overlooked. In recent years, lake trout tissue metal concentrations have increased; specifically, copper in recently collected lake trout far exceeds that known to cause chronic effects.

These impacts to salmonids could be mine-related given that the highest metal concentrations are observed in lake trout collected from mine-affected areas. Regrettably, impacts to sockeye salmon remain unknown due to insufficient monitoring. As both Bell and Granisle mines will continue to discharge impacted water into the foreseeable future, mine-related deteriorations to the aquatic environment in Babine Lake are likely to persist.

Regulatory stringency, scientific rigour in environmental monitoring, and effective mitigation of environmental impacts are essential to curb further mine-related damage to Babine Lake and its aquatic community. Regulation by the BC MOE of Bell and Granisle mines can be improved via expanded permits that: i) cover all mine water discharges to Babine Lake, ii) implement more exhaustive and stringent limits regarding discharge quality, iii) require more thorough and species-relevant salmonid toxicity testing of discharge water, and iv) require greater follow-up measures when discharge quality demonstrates the potential for chronic or lethal effects to aquatic life. Aquatic monitoring efforts in Babine Lake, as regulated by the BC MOE and performed by Glencore, can be improved by: i) monitoring all aquatic indicators during every monitoring cycle in all areas receiving mine discharges, ii) increasing the repetition of aquatic sampling in both space and time, iii) using thresholds for chronic effects obtained from the best available science, iv) incorporating fish movement habits and diet when investigating potential mine-related impacts, v) enhancing sockeye salmon monitoring, vi) implementing additional follow-up monitoring when aquatic impacts are identified, vii) enhancing baseline monitoring to adequately quantify any impacts caused by future mine-related discharges, and viii) releasing all information (including raw data) related to monitoring efforts in Babine Lake to the public. We include a list of recommended actions to support these improvements at the end of our report.

PHOTO CREDIT: SKEENAWILD
BELL MINE'S OPEN PIT, WATER TREATMENT PLANT, AND POLISHING POND

BACKGROUND

Babine Lake is the longest natural lake in British Columbia (BC), located in the Skeena watershed. The lake provides essential habitat for a number of salmonid fishes; importantly, it is the largest nursery lake in Canada for sockeye salmon (*Oncorhynchus nerka*), and now produces on average 90% of the Skeena River's annual sockeye abundance (Price et al. 2019). Babine Lake is within the traditional territory of Lake Babine Nation, many members of which rely on salmon and trout harvested from the lake for economic livelihood, as well as dietary and cultural purposes (Lake Babine Nation 2008).

Two decommissioned open-pit copper mines are situated towards the north end of Babine Lake. Both mines have maintained successions of active ownership (i.e., have never been bankrupted or abandoned), and now currently are owned by Glencore Canada Corporation (Glencore). Bell mine, located on Newman Peninsula, operated from 1972-1992, milling 17,000 tonnes of ore per day (tpd) at peak production (Glencore 2017a). Approximately 143 million (M) tonnes of rock were excavated from Bell's open pit, which measures 97 m x 790 m, and the project infrastructure overall disturbed a total of 505 hectares (ha) of land (Glencore 2017a; Figure 1). Granisle mine, which spans two islands southeast of Newman Peninsula, operated from 1966-1982, milling 12,000 tpd at peak; 132 M tonnes of rock were removed from the open pit, which measures 777 m x 1020 m, and the project disturbed a total of 395 ha (Remington 1996, Glencore 2017b; Figure 1).

PHOTO CREDIT: SKEENAWILD
COLLECTION POND FOR MINE-IMPACTED WATER AT BELL MINE

Acid rock drainage (ARD) and associated leaching of metal contaminants – particularly copper (Cu), iron (Fe), and zinc (Zn) – are generated by all mine components at both sites, including rock dumps, tailings dams, and mill sites (Remington 1996). Historically, both mines discharged untreated ARD and other contaminated water (elevated in metals and sulphate (SO_4)) directly into Babine Lake; in 1996, permitted discharge volumes were 9,000 m^3 and 4,100 m^3 per day for Bell and Granisle mines, respectively (Remington 1996). Negative effects to Babine Lake were attributed to these mine discharges during mining operations, including elevated metals (e.g., Cu, Fe, Zn, and aluminum (Al)) and other contaminants (e.g., SO_4) in surface water and/or sediment surrounding the mines, as well as elevated Cu, Zn, and cadmium (Cd) in fish tissues compared to fish from unpolluted lakes in BC (Remington 1996).

FIGURE 1. BELL AND GRANISLE MINES, TWO DECOMMISSIONED OPEN-PIT COPPER MINES LOCATED ON BABINE LAKE.

Concerns for new and persisting impacts to Babine Lake remain as both Bell and Granisle mines continue to discharge mine-impacted water (most of which is potentially ARD-affected). In 2015, and in accordance with its closure plan, Bell mine began discharging mine-impacted water into the lake from a waste-water treatment plant (Glencore 2015). The discharge water originates from Bell's open pit, which has been collecting the site's impacted water, and now has reached its storage capacity (Glencore 2015).

This contaminated pit water is treated using a High Density Sludge system that adds lime to neutralize and partially remove metals before release to Babine Lake. Bell mine also continues to discharge untreated water from a separate location, some of which drains from a potentially acid-generating rock dump (Glencore 2018a). At Granisle mine, there currently are three areas characterized as potentially releasing untreated surface flow and/or shallow seepage into Babine Lake, all of which come into contact with potentially acid-generating mine components (Glencore 2018b).

Additionally, Granisle's tailings dam is built directly into the lake (Remington 1996), potentially releasing subsurface flows of contaminated water. When the Granisle open pit – which collects mine-impacted water – reaches capacity, additional water treatment and discharge to the lake will be required.

To identify historical and recent aquatic impacts due to ongoing mine-impacted water discharges into Babine Lake, effective environmental monitoring is essential. Sampling of aquatic indicators like water quality, sediment quality, and fish tissue metals content must be performed at appropriate sites in the lake prior to, during, and after the occurrence of mine water discharge. Sampling replication (i.e., repeated sampling) also is important because it increases the probability that changes to the aquatic environment can be detected. For an indicator like water quality, which can change relatively quickly over space and time, sufficient sampling involves collecting multiple samples from each potentially affected area, and performing sample collections frequently (i.e., multiple times per year). For indicators such as sediment quality and fish tissue metals content, which do not change as quickly, sampling can be performed less frequently; however, acquiring enough samples to account for variation in space or among individuals is key to determine whether changes have occurred. Lastly, thresholds must be used to identify changes to the aquatic environment that could have adverse biological effects; often, provincial guidelines for water quality are not stringent enough to protect important species, such as salmonids, nor do they account for potential effects of combined contaminants in water, and more protective thresholds are reported in the scientific literature (Price 2013). Furthermore, the most precautionary threshold is that of "no change" (i.e., there is no change in water quality, sediment quality, or fish toxicity from natural background levels).

In this report, we review: i) current mine-impacted water discharges from Bell and Granisle mines, including permitted discharge volume and quality limits, ii) aquatic monitoring programs for surface water, sediment, and fish in Babine Lake, and iii) results of recent monitoring of mine discharges and Babine Lake, highlighting evidence of persisting historical and recently occurring mine-related impacts. We discuss limitations of mine-impacted water discharge regulation and aquatic monitoring efforts, and make recommendations for their improvement.

BELL AND GRANISLE MINE DISCHARGE LIMITS & MONITORING

Treated and untreated water discharges from Bell and Granisle mines are regulated by permits from the BC Ministry of Environment (BC MOE). These permits specify limits on discharge volume and quality, and require discharge monitoring to be performed by Glencore.

Bell Mine Discharges

The Bell mine waste-water treatment plant releases treated water to a polishing pond. Polishing Pond Outflow is excess water from the polishing pond that is actively discharged to the Bell Diffuser Area in Babine Lake on the west side of Newman Peninsula (Figure 2). Untreated runoff, potentially containing ARD, passively discharges from a site called 8D on the Bell mine site into the north end of Hagan Arm in Babine Lake (Figure 2).

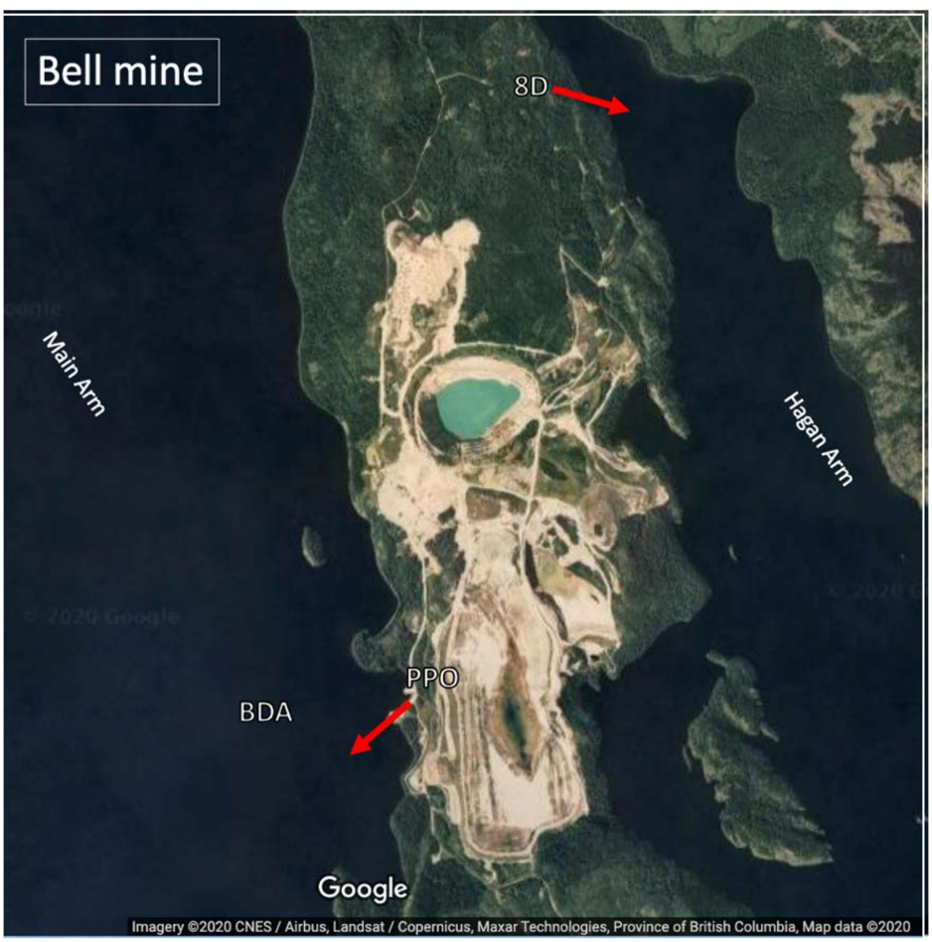

FIGURE 2. MINE-IMPACTED WATER DISCHARGES (RED ARROWS) FROM BELL MINE INTO BABINE LAKE. POLISHING POND OUTFLOW (PPO) IS TREATED WATER THAT ACTIVELY DISCHARGES TO THE BELL DIFFUSER AREA (BDA); 8D DISCHARGE IS UNTREATED WATER THAT PASSIVELY DISCHARGES TO THE NORTH END OF HAGAN ARM.

Permits allow a large quantity of Polishing Pond Outflow to enter Babine Lake, and do not specify a volume limit on 8D discharge (Table 1). Permit limits on the quality of both discharges cover only a small number of potential contaminants, and are well above provincial guidelines for the protection of aquatic life (i.e., BC Water Quality Guidelines (BCWQGs); BC MOE 2019a; Table 1). Based on volume and quality limits, Bell mine is authorized to discharge over three quarters of a tonne of Cu into Babine Lake via Polishing Pond Outflow alone every year.

Discharge of Polishing Pond Outflow typically is active for two months within an authorized discharge period of May 1-Oct 31 (Glencore 2018a), and monitoring of discharge volume and quality occurs during this period (Table 2). Monitoring of 8D discharge volume and quality occurs throughout the year (Table 2). Lethality of Polishing Pond Outflow discharge to rainbow trout (*O. mykiss*) is tested prior to and partway through the discharge period every year, and lethality of 8D discharge to rainbow trout is tested annually in April (Glencore 2018a; Table 2). However, the relevance of toxicity tests performed on rainbow trout to sockeye salmon or other fish inhabiting Babine Lake is unclear.

TABLE 1. AUTHORIZED VOLUME AND QUALITY OF POLISHING POND OUTFLOW (PPO) AND 8D DISCHARGES FROM BELL MINE TO BABINE LAKE, COMPARED WITH BC WATER QUALITY GUIDELINES TO PROTECT AQUATIC LIFE FROM CHRONIC EFFECTS. (ADAPTED FROM GLENCORE 2018A.)

Parameter	PPO Discharge	8D Discharge	BC Guideline
pH	6.5 – 9.5	6.5 – 8.5	6.5 – 9.0[a]
Total Suspended Solids (mg/L)	30	50	N/A
Total Cu (mg/L)	0.3	0.6	0.007[b]
Dissolved Cu (mg/L)	0.05	0.15	0.008[c]
Dissolved Fe (mg/L)	0.5	2	0.35[d]
Dissolved Zn (mg/L)	0.2	0.2	0.0075[e]
Rainbow Trout Acute Lethality	≥ 50% survival in 100% concentration	≥ 50% survival in 100% concentration	N/A
Maximum Annual Discharge	2,600,000 m^3	Not specified	N/A

[a] BC MOE 2019a.

[b] Guideline for total Cu in Babine Lake, approved by the BC MOE (Glencore 2014).

[c] Guideline for dissolved Cu in Babine Lake, as defined by Glencore (2019).

[d] Acute effects guideline for dissolved Fe; chronic effects guidelines do not exist (BC MOE 2019a).

[e] Guideline for total Zn; guidelines for dissolved Zn do not exist (BC MOE 2019a).

N/A = Not applicable

TABLE 2. MONITORING FREQUENCY REQUIREMENTS FOR POLISHING POND OUTFLOW (PPO) AND 8D DISCHARGES FROM BELL MINE TO BABINE LAKE. (ADAPTED FROM GLENCORE 2018A.)

<table>
<tr><th>Parameter</th><th>PPO Discharge</th><th>8D Discharge</th></tr>
<tr><td>Surface Flow</td><td rowspan="2">Continuous (while actively discharging)</td><td rowspan="6">Bi-weekly (Mar 15-May 31)/ Monthly (Jun 1-Mar 14)</td></tr>
<tr><td>Field pH</td></tr>
<tr><td>Conventional Parameters (e.g., hardness, conductivity, etc.)</td><td rowspan="4">Weekly (while actively discharging)</td></tr>
<tr><td>Sulphate</td></tr>
<tr><td>Total Suspended Solids</td></tr>
<tr><td>Total & Dissolved Metals</td></tr>
<tr><td>Rainbow Trout Acute Lethality[a]</td><td>Bi-annually</td><td>Annually</td></tr>
<tr><td>Ceriodaphnia dubia Reproduction & Survival</td><td>Monthly (while actively discharging)</td><td>NM</td></tr>
</table>

[a] Additional rainbow trout lethality testing is required if ever discharge water quality does not meet the quality standards in Table 1.
NM = Not monitored

Granisle Mine Discharges

Granisle mine site has three different areas categorized as passively draining untreated surface flow and/or shallow seepage, all potentially containing ARD, into Babine Lake (Figure 3):

i. North Dump – Consistent seasonal surface flow to Babine Lake northeast of the mine site (Glencore 2018b; BC MOE 2019b).

ii. Mill Area – Contains three separate discharge sources, two of which have relatively consistent seasonal surface flows (Glencore 2018b; BC MOE 2019b). Discharge drains to Babine Lake northwest of the mine site.

iii. Settling Pond – Glencore (2018b) categorizes this site as potentially releasing shallow seepage to Babine Lake west of the mine site.

There are no volume or quality permit limits on any Granisle mine discharges, despite being untreated, potentially containing ARD, and often having surface flows into Babine Lake (Glencore 2018b). Permits do require Glencore to sample discharge quality from each area in Spring, Summer, and Autumn. Surface flows at North Dump and Mill Area are documented qualitatively using photographs, but actual discharge volumes are not quantified. Lethality of some Granisle mine discharges to aquatic invertebrates (i.e., *Daphnia magna*) is tested, but none of Granisle's discharges are tested for lethality to rainbow trout or other fishes (Glencore 2018b).

FIGURE 3. PASSIVE MINE-IMPACTED WATER DISCHARGES (RED ARROWS) FROM GRANISLE MINE INTO BABINE LAKE.

BABINE LAKE AQUATIC MONITORING PROGRAMS

We investigated monitoring efforts by Glencore of water quality, sediment quality, and fish health and tissue metals in Babine Lake (though monitoring of other indicators, such as groundwater quality and aquatic invertebrates, also is performed). Monitoring requirements for these indicators are regulated by BC MOE permits. Mine-exposed receiving areas (i.e., areas of Babine Lake that have received historical or current mine water discharges) in which aquatic monitoring is performed include: Bell Diffuser Area, Hagan Arm, and Granisle vicinity (Figure 4). Hagan Arm consists of three sites: North Hagan Arm, Woolverton Bay, and Rum Bay. North Hagan Arm receives ongoing 8D discharge, whereas Woolverton Bay and Rum Bay are sites of historical discharges from Bell mine. Granisle vicinity consists of Granisle East and Granisle West, on either side of the tailings impoundment.

Babine Lake is long and narrow, containing multiple basins; its mean depth is 55 m and maximum depth is 186 m, though depth in much of the lake is in the 10-20 m range (Johnson 1965). The lake is oligotrophic (i.e., low in nutrients, particularly phosphorous), and naturally contains high levels of organic matter, low levels of suspended solids and trace metals, and slightly basic acidity (Remington 1996). Glencore compares mine-affected conditions in Babine Lake receiving areas to conditions at reference sites (i.e., areas of Babine Lake unlikely to be affected by mine activities), provincial guidelines – which can be insensitive to sublethal effects and/or effects of combined contaminants on salmonids (Price 2013), and historical site conditions.

FIGURE 4. RECEIVING AREA SITES IN BABINE LAKE WHERE AQUATIC MONITORING IS PERFORMED: BELL DIFFUSER AREA (BDA); NORTH HAGAN ARM (NORTH HA), WOOLVERTON BAY, AND RUM BAY IN THE HAGAN ARM RECEIVING AREA; AND GRANISLE EAST AND GRANISLE WEST IN THE GRANISLE VICINITY RECEIVING AREA. RED ARROWS INDICATE SOURCES OF CURRENT MINE DISCHARGES INTO BABINE LAKE.

Water Quality

The Bell Diffuser Area is a 500 m mixing zone extending from the point of Polishing Pond Outflow discharge. Dilution capacity of lake environments can often be uncertain due to changing flow conditions; however, Glencore's discharge permitting is based on the assumption that mine-impacted water will progressively dilute until it becomes no different from reference site water quality at the 500 m perimeter of the Bell Diffuser Area mixing zone (Glencore 2015). In 2014 (i.e., before any Polishing Pond Ouflow discharge), Glencore collected two water samples on the same day from the mixing zone to characterize baseline water quality (Glencore 2014). Currently, Glencore samples Bell Diffuser Area water quality at 20 m, 150 m, and 500 m downstream of the point of discharge; a single sample from each site is obtained once per year (Glencore 2018a). Overall, these monitoring efforts lack adequate sampling replication in time and space both for baseline and ongoing data.

Hagan Arm water quality is monitored infrequently as part of Glencore’s Aquatic Effects Monitoring Program. This program is conducted every five years (beginning in 2009), and a different selection of receiving areas, as approved by the BC MOE, are monitored each period (Glencore 2014). Water quality in Hagan Arm was last sampled in 2014, and the next scheduled sampling event in Hagan Arm is planned for 2024 at the earliest, leaving a minimum ten-year gap in monitoring effort (Glencore 2014). Importantly, insufficient sampling replication was performed in 2014, with a single surface depth and a single bottom depth water sample acquired from each of the three Hagan Arm locations.

Granisle vicinity sites are sampled for water quality via a single water sample from each site obtained in Spring, Summer, and Autumn (Glencore 2018b), which means that sampling replication occurs throughout the year, but not for each sampling period. While these monitoring locations may capture the effects of seepage from the Settling Pond and/or the tailings dams, other areas of Babine Lake receiving Granisle mine’s untreated discharges (i.e., from North Dump and Mill Area) are never monitored for water quality (Glencore 2018b).

Sediment Quality

Sediment quality monitoring is a component of Glencore's Aquatic Effects Monitoring Program, which occurs every five years. In 2014, Glencore monitored surficial (i.e., top 3 cm) sediment in Hagan Arm and Granisle vicinity (Table 3). The Granisle East sampling area was expanded to include one sample obtained near the North Dump discharge location, and an additional two samples were obtained near Mill Area discharges (i.e., Granisle Northwest; Table 3). While this translates to at least one sediment sample collected from each area receiving Granisle mine water discharges, sampling replication near both North Dump and Mill Area has been insufficient to fully characterize any potential change in sediment quality. A minimum ten-year gap will occur in Hagan Arm and Granisle vicinity sediment quality monitoring efforts, with the next sampling event planned for 2024 at the earliest (Glencore 2014). Surficial sediment quality in Bell Diffuser Area also was monitored in 2014 to provide baseline (i.e., pre-Polishing Pond Outflow discharge) data, and again in 2019 to assess the effects of Polishing Pond Outflow (Table 3). Sediment monitoring in Bell Diffuser Area is scheduled to occur again in 2024 (Glencore 2019).

TABLE 3. STUDY SITES AND SAMPLE SIZES IN GLENCORE'S 2014 & 2019 AQUATIC EFFECTS MONITORING PROGRAM FOR SEDIMENT AND FISH TISSUE MONITORING (GLENCORE 2014, 2019).

Year	Site Type	Study Site	Surficial Sediment (# samples)	Sculpin Tissue (# fish)[a]	Lake Trout Tissue (# fish)[a]
2014	Mine-Exposed	North HA	5	5	5[b]
		Woolverton Bay	5	5	
		Rum Bay	5	5	
		Granisle East	5[c]	5	NS
		Granisle West	5	5	NS
		Granisle Northwest[d]	2	NS	NS
	Reference	Snowshoe Island	5	5	NS
		Char Bay	5	5	5
	Baseline	BDA	5	NS	NS
2019	Mine-Exposed	BDA	5	5	10
	Reference	Char Bay	5	5	10

[a] Number of individual fish for which tissue samples were sent for metals content analysis. (In some cases, Glencore retained tissues from more individuals, but did not analyze them.)

[b] This set of lake trout was collected from the Hagan Arm area; Glencore does not specify which sites were sampled.

[c] This set of sediment samples extended from Granisle East northward to offshore from North Dump.

[d] This site is offshore from Mill Area discharges.

North HA = North Hagan Arm; BDA = Bell Diffuser Area; NS = Not sampled.

Fish Health and Tissue Metals

Monitoring of fish is a component of Glencore's Aquatic Effects Monitoring Program, which occurs every five years. A number of species, including prickly sculpin (*Cottus asper*), lake trout (*Salvelinus namaycush*), and non-anadromous sockeye salmon (commonly known as kokanee) are monitored for general body condition, based on non-lethal sampling of any individuals caught in the selected sampling areas. General body condition is measured as Fulton's K (Ricker 1975),

$$K = \frac{W}{L^3}$$

a factor of fish length and weight, where W = fish weight and L = fish length; a scaling factor is also usually applied to bring the value of K close to 1.00. Higher values of K (i.e., > 1.00) indicate greater well-being and/or nourishment (Williams 2000). However, there are a number of shortcomings associated with Fulton's K, making it a relatively imprecise measure of fish health (Froese 2006).

Some lake trout liver and muscle tissues, and prickly sculpin whole-body samples, also are collected and analyzed for tissue metals content (Glencore 2014, 2019). Sculpin are bottom-dwelling fish occupying small home ranges (maximum ~500 m); therefore, these fish demonstrate localized effects of mine-related discharges (Gray et al. 2018). By contrast, lake trout may visit the same locations repeatedly but have home ranges of 60 km to 70 km (Schmalz & Hansen 2002), which easily covers the distance between mine-exposed and reference sites in Babine Lake; given their mobility, lake trout monitoring may better demonstrate mining-related impacts to salmonids throughout Babine Lake, as opposed to impacts at specific locations. Additionally, lake trout have diverse prey, which may affect individual metal accumulation (Madenjian et al. 1993, Vander Zanden et al. 2000); however, Glencore does not currently investigate the diet of lake trout.

In 2014, Glencore monitored fish in Hagan Arm and Granisle vicinity (Table 3); some sampling was very limited (i.e., low overall sampling of lake trout tissues), or non-existent (i.e., sculpin monitoring was not performed near Granisle mine's North Dump and Mill Area discharges). In 2019, Glencore monitored fish in Bell Diffuser Area (Table 3). Both years, Glencore retained a surplus of fish tissue samples that were not analyzed for metal content (Glencore 2014, 2019). Sculpin and lake trout also were monitored in Bell Diffuser Area in 2012, providing some baseline (i.e., pre-Polishing Pond Outflow discharge) data; however, lake trout tissue metals were omitted during this effort (Glencore 2019). There are no reports of Glencore ever monitoring lake trout in Granisle vicinity. Hagan Arm and Granisle vicinity fish monitoring has not occurred since 2014, and is not planned until 2024 at the earliest, leaving a ten-year monitoring gap (Glencore 2014). Fish monitoring in Bell Diffuser Area is scheduled to occur again in 2024 (Glencore 2019).

PHOTO CREDIT: SKEENAWILD
OPEN PIT AT GRANISLE MINE (BABINE LAKE, BC), WHICH STORES MINE-IMPACTED WATER THAT WILL EVENTUALLY REQUIRE TREATMENT BEFORE DISCHARGE TO BABINE LAKE

MINE DISCHARGE & BABINE LAKE MONITORING RESULTS

We assessed the results of Glencore's water quality monitoring of mine discharges and Babine Lake from 2013-2019 (depending on data availability), and results of sediment and fish monitoring from Glencore's 2014 and 2019 Aquatic Effects Monitoring Programs (as these indicators are monitored only every five years). For all aquatic indicators, sampling from receiving areas and reference areas mostly occurred at similar times, though not always on the same day; water quality sampling generally occurred from May to October, and sediment and fish sampling occurred in late August. Not all reports and raw data related to monitoring of these indicators are publicly available; we obtained information for this assessment both from public government websites and directly from Glencore. We focused on metal contaminants, such as Al, Cd, Cu, Fe, Zn, silver (Ag), arsenic (As), mercury (Hg), manganese (Mn), nickel (Ni), lead (Pb), and selenium (Se); metals are displayed for each indicator (i.e., water quality, sediment quality, or fish tissue metals content) when there are relevant results associated with them (e.g., exceedances of effect thresholds, or elevations in mine-exposed compared to reference areas). We also assessed other relevant parameters such as pH, conductivity, hardness, SO_4, and total suspended solids (TSS). We compared conditions in Babine Lake mine-affected receiving areas to reference areas (using independent two-sample t-tests and a significance threshold of $p < 0.10$, the threshold used by Glencore in their own monitoring), available baseline and historical site data, provincial guidelines for chronic aquatic impacts, and other thresholds for impacts to fish obtained from the best available science.

PHOTO CREDIT: SKEENAWILD
DISCHARGE PIPE FOR UNTREATED MINE-IMPACTED WATER AT GRANISLE MINE

Water Quality

Copper (Cu) is the contaminant of greatest concern in Babine Lake. When comparing water quality results to provincial chronic effect guidelines, we observed a potential discrepancy in the threshold for chronic effects used by Glencore to monitor dissolved Cu concentrations. Glencore applies a threshold of 0.008 mg/L dissolved Cu, but does not provide any rationale for this value (Glencore 2019). Based on provincial guidelines (BC MOE 2019c), associated public tools (i.e., the "Copper Water Quality Guideline Look-Up Table"; BC MOE 2020), and data we collected regarding water parameters for Babine Lake, we estimated a much lower chronic effect threshold of 0.0022 mg/L dissolved Cu (Table 4). In this assessment, we used our estimate as it is more conservative. We also compared water quality results to general thresholds for sublethal-effects to salmonids (Price 2013), and to thresholds for sublethal- and lethal-effects to sockeye salmon that have been derived specifically for total Cu in Babine Lake (Remington 1996; Table 5). These thresholds can indicate cause for concern where BC guidelines do not.

TABLE 4. BABINE LAKE WATER PARAMETERS, INPUT TO THE "COPPER WATER QUALITY GUIDELINE LOOK-UP TABLE" (BC MOE 2020), AND THE RESULTING PROVINCIAL DISSOLVED COPPER WATER QUALITY GUIDELINE FOR CHRONIC AQUATIC EFFECTS.

Babine Lake Parameters			BC Dissolved Copper Water Quality Guideline (mg/L)
pH	Dissolved Organic Carbon (mg/L)	Hardness (mg/L)	
7.6[a]	7[b]	40[a]	0.0022

[a]Average conditions based on Glencore water quality monitoring from 2013-2019 across mine-exposed
and reference sites, and rounded to accommodate look-up table restrictions.
[b]Glencore 2019.

TABLE 5. CHRONIC AQUATIC EFFECTS THRESHOLDS USED IN ASSESSING BELL AND GRANISLE MINE WATER DISCHARGE QUALITY AND BABINE LAKE WATER QUALITY. WHERE PROVINCIAL GUIDELINES DIFFER BASED ON RECEIVING AREA PARAMETERS (E.G., HARDNESS), THRESHOLDS ARE PRESENTED ACCORDING TO RECEIVING AREA (BDA = BELL DIFFUSER AREA; HA/G = HAGAN ARM AND GRANISLE VICINITY).

Parameter	BC Guideline[a]	Sublethal-Effect Limit[b]	Lethal-Effect Limit
pH	6.5-9.0	-	-
Total SO_4 (mg/L)	218.0[c]	-	-
Dissolved Metals (mg/L)			
Ag	-	0.00010	-
Al	0.050	0.006	-
Cd	BDA: 0.00014 HA/G: 0.00011	-	-
Cu	0.0022[d]	0.0007	-
Fe	0.35[e]	-	-
Pb	-	0.0030	-
Zn	-	0.0086	-
Total Metals (mg/L)			
Ag	0.00005	-	-
Al	-	0.030	-
As	0.0050	-	-
Cu	0.0070[f]	0.1090[g]	0.2100[g]
Fe	1.00[e]	-	-
Mn	BDA: 0.8590 HA/G: 0.7930	-	-
Ni	0.0250[h]	0.0060	-
Pb	BDA: 0.0049 HA/G: 0.0044	-	-
Se	0.0020	-	-
Zn	0.0075	-	-

[a] Provincial guidelines from BC MOE (2019a), unless otherwise referenced.

[b] Thresholds for sublethal-effects to salmonids from Price (2013), unless otherwise referenced.

[c] We compared Glencore's reporting of dissolved SO_4 to the guideline for total SO_4 as a guideline for dissolved SO_4 does not exist.

[d] Based on potential discrepancy in calculation of the BC chronic effects guideline for dissolved Cu, we compared water quality data to our estimate (0.0022 mg/L) as opposed to Glencore's estimate (0.008 mg/L) of the guideline.

[e] Acute effects guideline for dissolved Fe; chronic effects guidelines do not exist.

[f] Guideline for total Cu in Babine Lake, approved by the BC MOE (Glencore 2014).

[g] Effect limit for total Cu, estimated specifically for sockeye salmon in Babine Lake (Remington 1996).

[h] Working chronic effects water quality guideline for total Ni (BC MOE 2017).

"-" = Not available

Mining Discharge

We report summaries of Bell and Granisle mine water discharges (i.e., Polishing Pond Outflow, which releases to Bell Diffuser Area; 8D discharge, which releases to North Hagan Arm; and North Dump, Mill Area, and Settling Pond discharges which release in various directions surrounding Granisle mine) in Appendix A. In the years we assessed, on average, mine discharges exceeded background (i.e., reference site) levels for essentially all contaminants, and exceeded BC guidelines and/or sublethal-effect limits for a number of contaminants, including Al, Cd, Cu, Fe, Mn, Ni, Zn, and SO_4. Concerningly, Polishing Pond Outflow, North Dump, and Mill Area discharges all at times exceeded, or approached, the Babine-specific sockeye salmon lethal-effect limit for total Cu. Some discharges appeared to be improving over time; in particular, 8D discharge showed reduced concentrations of many metals from 2017-2019 compared to 2013-2016, and North Dump discharge increased in pH over time (with associated decreases in metal concentrations). Concerningly, however, Cu concentrations appeared to be increasing in both 8D and Mill Area discharges over time. In 2018, a total 1,486,922 m^3 of Polishing Pond Outflow was released, resulting in approximately 4 kg of dissolved Cu and 53 kg of total Cu deposited into Babine Lake by this discharge alone (Glencore 2018a). An estimated 50,212 m^3 of contaminated water also was released by 8D discharge (Glencore 2018a). Flow volumes of Granisle mine discharges (i.e., North Dump, Mill Area, and Settling Pond discharges) are unknown because they are not monitored.

Despite poor discharge quality, lethal effects to rainbow trout have not been observed during testing of Polishing Pond Outflow or 8D discharges (Glencore 2018a); however, the sensitivity of other fish residing in Babine Lake, such as sockeye salmon, to Bell mine discharges remains unknown. Toxicity of Granisle mine discharges to salmonids also is not known because it is not tested. Testing of Polishing Pond Outflow, North Dump, and Mill Area discharges has shown lethal effects to aquatic invertebrates (Glencore 2017a, 2017b).

Bell Diffuser Area

Monitoring of Bell Diffuser Area water quality in 2016-2019, years during which Polishing Pond Outflow was discharged, indicated that contaminant concentrations did not consistently decrease with distance from the source of Polishing Pond Outflow; this observation suggests that discharge dilution may not be occurring as expected and/or that the mixing zone (i.e., the area of potential impacts) may be larger or more dynamic than defined. Compared to baseline data from 2014, Bell Diffuser Area water overall appeared to increase in a number of contaminants after Polishing Pond Outflow discharge began (Table 6). In 2016-2019, water at Bell Diffuser Area contained significantly greater conductivity, hardness, Al, Cu, Mn, Ni, and SO_4 compared to reference sites (though elevations in Cu and Ni were minimal; Table 6); importantly, elevations of Al and SO_4 extended to the outer edge of the mixing zone, providing further support that contaminants are not diluting entirely. Based on maximum values, Bell Diffuser Area water also was occasionally elevated in Fe, Cd, Zn, and TSS compared to water at reference sites (Table 6). Water quality at Bell Diffuser Area mostly remained below effect thresholds; however, both Bell Diffuser Area and reference site waters consistently exceeded the sublethal-effect limit for dissolved Cu, and intermittently exceeded sublethal-effect limits for Al (dissolved and total). Compared to conditions in the 1970s-1990s, Bell Diffuser Area water in 2016-2019 contained lower Cu and Fe; however, it contained greater hardness and SO_4, seemingly as a result of Polishing Pond Outflow (Remington 1996, BC MOE 2019b).

PHOTO CREDIT: SKEENAWILD
WATER TREATMENT PLANT AND POLISHING POND AT BELL MINE

TABLE 6. BABINE LAKE WATER QUALITY AT BELL DIFFUSER AREA (BDA) IN 2014 (I.E., PRE-POLISHING POND OUTFLOW DISCHARGE), AND AT BDA AND REFERENCE SITES IN 2016-2019 (I.E., DURING POLISHING POND OUTFLOW DISCHARGE). STATISTICALLY SIGNIFICANT ELEVATIONS AT BDA COMPARED TO REFERENCE SITES IN 2016-2019 ARE IN **BOLD** ($P < 0.10$).

	2014	2016-2019					
	BDA	BDA			Reference		
Sample Size	n=2	n=12			n=15		
Parameter	**Mean ± SD[a]**	**Min.**	**Max.**	**Mean ± SD**	**Min.**	**Max.**	**Mean ± SD**
Field pH	NM	7.3	7.9	7.6 ± 0.3	7.0	8.1	7.7 ± 0.3
Field Conductivity (uS/cm)	NM	85	154	**114 ± 28**	81	96	86 ± 5
pH	NM	7.6	7.7	7.7 ± 0.02	7.7	7.9	7.8 ± 0.1
Conductivity (uS/cm)	NM	87	160	**122 ± 31**	81	90	86 ± 3
Hardness (mg/L)	41.4 ± 0.4	40.5	75.6	**57.7 ± 14.1**	39.0	42.2	40.8 ± 1.0
Dissolved SO_4 (mg/L)	0.5	4.7	39.3	**20.9 ± 14.0**	4.2	4.8	4.5 ± 0.2
TSS (mg/L)	<3.0	<3.0	6.4	BDLs	<3.0	3.0	BDLs
Dissolved Metals (mg/L)							
Al	0.002 ± 0.0004	0.004	0.007	0.006 ± 0.001	0.003	0.014	0.005 ± 0.003
Cd	<5.0E-6	<5.0E-6	6.4E-6	BDLs	<5.0E-6	<5.0E-6	BDLs
Cu	0.0020 ± 0.0003	0.0016	0.0020	0.0017 ± 0.0001	0.0015	0.0020	0.0017 ± 0.0001
Fe	<0.03	<0.03	<0.03	BDLs	0.01	<0.03	BDLs
Mn	0.0004	0.0003	0.0076	**0.0027 ± 0.0028**	<0.0002	0.0013	0.0004 ± 0.0003
Ni	0.0005 ± 0.00001	<0.0005	0.0006	BDLs	0.0004	0.0005	0.0005 ± 0.0001
Zn	0.0028	<0.0010	0.0061	BDLs	<0.0010	0.0034	BDLs
Total Metals (mg/L)							
Al	0.006 ± 0.003	0.008	0.082	**0.021 ± 0.021**	0.004	0.033	0.010 ± 0.007
Cd	<5.0E-6	<5.0E-6	0.00001	5.0E-6 ± 2.0E-6	<5.0E-6	0.00003	BDLs
Cu	0.0019 ± 1.4E-6	0.0018	0.0035	**0.0023 ± 0.0005**	0.0014	0.0030	0.0019 ± 0.0004
Fe	<0.03	<0.03	0.15	BDLs	0.01	0.05	0.02 ± 0.01
Mn	0.0010 ± 0.0003	0.0013	0.0091	**0.0051 ± 0.0032**	0.0007	0.0027	0.0011 ± 0.0005
Ni	0.0005 ± 0.00001	0.0005	0.0006	**0.0006 ± 0.00004**	0.0004	0.0007	0.0005 ± 0.0001
Zn	<0.0030	<0.0030	<0.0030	BDLs	0.0003	<0.0030	BDLs

[a] Two water samples were collected from BDA in 2014. If one sample was below the detection limit, the higher result is shown.

SD = Standard deviation; NM = Parameter not monitored; BDLs = Too many readings below detection limit to calculate mean

Hagan Arm

Water quality sampling at Hagan Arm has not been performed since 2014. Because sampling at this time was minimal, we assessed water quality for all Hagan Arm sites combined, and could not perform statistical analyses. However, water quality at Hagan Arm was not noticeably different from reference sites (Appendix A). Water quality at Hagan Arm mostly remained below effect thresholds, except both Hagan Arm and reference sites waters consistently exceeded the sublethal-effect limit for dissolved Cu. Compared to water quality in the 1970s-1990s, Hagan Arm in 2014 contained lower Cu, Fe, and Zn (Remington 1996).

Granisle Vicinity

There are no in-lake water quality monitoring sites near North Dump or Mill Area discharge sources in the vicinity of Granisle mine; thus, water quality monitoring likely only reflects impacts of seepage from the Settling Pond and/or tailings impoundment. Compared to reference locations, water at Granisle vicinity sites in 2013-2018 contained significantly greater conductivity, hardness, Cu, Fe, Mn, and SO_4 (Table 7); dissolved Zn concentrations also appeared elevated in Granisle vicinity as they were mostly above the detection limit at Granisle mine-exposed sites, but below the detection limit at reference sites (Table 7). On average, Granisle East water exceeded our estimate of the BC guideline for dissolved Cu, whereas reference waters did not, indicating the potential for mine-related chronic effects. Additionally, both Granisle vicinity and reference site waters consistently exceeded the sublethal-effect limit for dissolved Cu, and intermittently exceeded sublethal-effect limits for Al (dissolved and total). Compared to conditions in the 1970s-1990s, Granisle vicinity water in 2013-2018 contained lower Cu and SO_4 (Remington 1996).

TABLE 7. WATER QUALITY AT GRANISLE VICINITY AND REFERENCE SITES IN 2013-2018. STATISTICALLY SIGNIFICANT ELEVATIONS AT GRANISLE VICINITY COMPARED TO REFERENCE SITES ARE IN **BOLD** (P < 0.10).

	Granisle East			Granisle West			Reference		
Sample Size	n=20			n=20			n=27		
Parameter	**Min.**	**Max.**	**Mean ± SD**	**Min.**	**Max.**	**Mean ± SD**	**Min.**	**Max.**	**Mean ± SD**
Field pH	7.0	8.0	7.6 ± 0.3	7.1	8.0	7.6 ± 0.3	7.0	8.1	7.7 ± 0.4
Field Conductivity (uS/cm)	83	134	**95 ± 16**	82	118	**94 ± 12**	81	96	86 ± 5
pH	7.3	8.3	7.8 ± 0.2	7.4	8.3	7.8 ± 0.2	7.4	8.4	7.8 ± 0.2
Conductivity (uS/cm)	55	105	84 ± 12	56	98	84 ± 11	51	105	85 ± 11
Hardness (mg/L)	39.5	47.7	**42.4 ± 2.0**	39.5	55.1	**43.4 ± 4.0**	39.0	44.8	41.4 ± 1.3
Dissolved SO_4 (mg/L)	0.8	6.0	4.5 ± 1.4	0.6	17.1	**5.6 ± 3.2**	<0.5	5.5	3.8 ± 1.5
TSS (mg/L)	<1.0	<3.0	BDLs	<1.0	5.7	BDLs	<1.0	3.0	BDLs
Dissolved Metals (mg/L)									
Al	0.002	0.021	0.006 ± 0.002	0.002	0.007	0.004 ± 0.002	0.001	0.014	0.004 ± 0.003
Cd	<5.0E-6	0.00002	BDLs	<5.0E-6	0.00001	BDLs	<5.0E-6	0.00001	BDLs
Cu[a]	0.0017	0.0037	**0.0024 ± 0.0004**	0.0017	0.0033	**0.0021 ± 0.0004**	0.0015	0.0024	0.0018 ± 0.0002
Fe	<0.01	0.03	BDLs	<0.01	<0.03	BDLs	<0.01	<0.03	BDLs
Mn	0.0003	0.0035	**0.0010 ± 0.0008**	<0.0002	0.0025	0.0005 ± 0.0005	<0.0002	0.0013	0.0004 ± 0.0003
Ni	<0.0002	0.0006	0.0005 ± 0.0001	<0.0002	0.0007	0.0005 ± 0.0002	<0.0002	0.0006	0.0004 ± 0.0001
Zn	<0.0010	0.0070	0.0022 ± 0.0020	<0.0010	0.0065	0.0021 ± 0.0017	<0.0008	0.0060	BDLs
Total Metals (mg/L)									
Al	0.004	0.043	0.013 ± 0.012	0.003	0.038	0.010 ± 0.008	0.003	0.033	0.009 ± 0.006
Cd	<5.0E-6	0.00002	BDLs	<5.0E-6	<0.00001	BDLs	<5.0E-6	0.00003	BDLs
Cu	0.0019	0.0034	**0.0025 ± 0.0004**	0.0017	0.0042	**0.0024 ± 0.0008**	0.0014	0.0030	0.0020 ± 0.0004
Fe	0.02	0.05	**0.03 ± 0.01**	0.01	0.03	0.02 ± 0.01	0.01	0.05	0.02 ± 0.01
Mn	0.0010	0.0047	**0.0021 ± 0.0012**	0.0003	0.0031	0.0011 ± 0.0006	0.0007	0.0027	0.0010 ± 0.0004
Ni	<0.0002	0.0006	0.0005 ± 0.0002	<0.0002	0.0008	0.0005 ± 0.0002	<0.0002	0.0007	0.0005 ± 0.0002
Zn	0.0010	0.0030	0.0018 ± 0.0005	0.0008	0.0048	0.0019 ± 0.0011	0.0003	0.0040	BDLs[b]

[a] One dissolved Cu outlier removed from reference site data.

[b] Detection limit for reference site total Zn is <0.003 mg/L.

SD = Standard deviation; BDLs = Too many readings below detection limit to calculate mean.

Sediment Quality

We assessed pH and metals content both for full sediment samples and the < 63 µm sediment fraction (i.e., the fraction with greater bioavailability to aquatic life) obtained from Babine Lake in 2014 and 2019. We used BC Working Sediment Quality Guidelines (BCWSQGs) as chronic effect thresholds; Lower BCWSQGs occasionally are associated with adverse biological effects, and Upper BCWSQGs frequently are associated with adverse biological effects (BC MOE 2017; Table 8).

TABLE 8. PROVINCIAL CHRONIC AQUATIC EFFECTS THRESHOLDS USED IN ASSESSING SEDIMENT QUALITY IN BABINE LAKE (BC WORKING SEDIMENT QUALITY GUIDELINES; BC MOE 2017). LOWER THRESHOLDS OCCASIONALLY ARE ASSOCIATED WITH ADVERSE BIOLOGICAL EFFECTS; UPPER THRESHOLDS FREQUENTLY ARE ASSOCIATED WITH ADVERSE BIOLOGICAL EFFECTS.

Parameter	Lower BC Guideline (mg/kg)	Upper BC Guideline (mg/kg)
Ag	0.50	-
Cu	36	197
Hg	0.170	0.486
Ni	16.0	75.0
Pb	35.0	91.3
Se	2.00[a]	-
Zn	123	315

[a] BC MOE 2019a.

"-" = Not available

Bell Diffuser Area

In 2014, before Polishing Pond Outflow discharge began, sediments at Bell Diffuser Area compared to reference sites had significantly elevated concentrations of Ag, Al, Ni, and Pb, as well as noticeable, but non-significant, elevations of Cu and Zn (Table 9). In 2019, after Polishing Pond Outflow discharge had been occurring, all of the above metals except Ni showed significantly elevated concentrations at Bell Diffuser Area compared to reference sediments (Table 9). However, from 2014 to 2019, sediment quality appears to have remained similar or improved at both mine-exposed and reference sites (Table 9), suggesting that contaminant elevations in Bell Diffuser Area sediments are due to historical mining activities and not the result of Polishing Pond Outflow. In 2014 and 2019, Bell Diffuser Area sediments on average exceeded the Lower BCWSQGs for Cu, Ni, and Zn, whereas reference sediments either did not exceed the guideline at all (i.e., for Zn) or exceeded the guideline by a lesser amount (i.e., for Cu and Ni), indicating the potential for ongoing mine-related chronic effects. Data prior to 2014 were not available to assess whether these historical impacts to Bell Diffuser Area sediments have improved from previous decades.

TABLE 9. SEDIMENT QUALITY AT BELL DIFFUSER AREA (BDA) AND CHAR BAY REFERENCE SITE IN BABINE LAKE IN 2014 AND 2019. RESULTS ARE SHOWN FOR FULL SEDIMENT SAMPLES AND THE < 63µM SEDIMENT FRACTION (I.E., THE FRACTION WITH GREATER BIOAVAILABILITY TO AQUATIC LIFE). STATISTICALLY SIGNIFICANT ELEVATIONS IN METALS AT BDA COMPARED TO THE REFERENCE SITE IN EACH YEAR ARE IN **BOLD** (P < 0.10).

	2014				2019			
	BDA		Reference		BDA		Reference	
Sample Size	n=5		n=5		n=5		n=5	
Parameter	**Mean ± SD (full)**	**Mean ± SD (< 63)**	**Mean ± SD (full)**	**Mean ± SD (< 63)**	**Mean ± SD (full)**	**Mean ± SD (< 63)**	**Mean ± SD (full)**	**Mean ± SD (< 63)**
pH	7.0 ± 0.1	6.9 ± 0.2	7.0 ± 0.2	6.8 ± 0.3	6.8 ± 0.1	6.8 ± 0.1	6.9 ± 0.3	6.9 ± 0.3
Metals (mg/kg)								
Ag	**0.32 ± 0.04**	**0.33 ± 0.03**	0.23 ± 0.02	0.22 ± 0.02	**0.30 ± 0.04**	**0.30 ± 0.03**	0.20 ± 0.03	0.20 ± 0.03
Al	20640 ± 3928	**23820 ± 3285**	19580 ± 2845	19260 ± 2463	**21880 ± 2071**	22240 ± 3219	18620 ± 2809	19880 ± 1821
Cu	120 ± 84	129 ± 94	64 ± 6	59 ± 5	**92 ± 19**	**83 ± 13**	52 ± 9	55 ± 3
Hg	0.107 ± 0.009	0.093 ± 0.006	0.105 ± 0.013	0.101 ± 0.016	0.085 ± 0.009	0.079 ± 0.015	0.079 ± 0.008	0.086 ± 0.019
Ni	36.4 ± 4.7	**40.7 ± 4.0**	34.2 ± 2.5	32.7 ± 2.6	37.5 ± 4.7	37.6 ± 6.6	32.5 ± 5.1	34.1 ± 4.7
Pb	13.2 ± 1.3	**13.6 ± 1.1**	11.4 ± 0.8	10.6 ± 0.7	**12.5 ± 1.9**	**11.7 ± 1.1**	8.9 ± 0.5	9.3 ± 1.3
Se	0.77 ± 0.28	0.79 ± 0.30	0.88 ± 0.18	0.82 ± 0.20	0.73 ± 0.31	0.70 ± 0.20	0.80 ± 0.13	0.81 ± 0.12
Zn	128 ± 15	137 ± 13	114 ± 10	108 ± 6	**128 ± 15**	**136 ± 14**	108 ± 14	110 ± 6

SD = Standard deviation

Hagan Arm

In 2014, sediments at all Hagan Arm sites showed a slight depression in pH compared to reference sediments (Table 10). Woolverton Bay and Rum Bay sediments also contained significantly greater Ag, Al, Cu, Hg, Ni, Pb, Se, and Zn than reference sediments (Table 10). On average, sediments at Woolverton Bay and Rum Bay exceeded Lower BCWSQGs for Hg, Ni, and Zn, and the Upper BCWSQG for Cu, whereas reference sediments either did not exceed these guidelines at all (i.e., for Hg and Cu) or exceeded the guideline by a lesser amount (i.e., for Ni and Zn), indicating the potential for mine-related chronic effects. These elevated concentrations likely are persisting due to historical mining activities because they have been reported in previous monitoring efforts (Glencore 2014) and are not present in the vicinity of current discharges from 8D. However, North Hagan Arm sediments did contain smaller, but noticeable, elevations of some metals (e.g., Ag and Cu), which may not have been statistically significant due to high variation among samples. Some long-term impact recovery is evident in Hagan Arm sediments, as Cu and Zn concentrations were in some cases much lower in 2014 than they were in 1992 (Glencore 2014).

Granisle Vicinity

Sediments at Granisle East and Granisle West in 2014 had clear elevations in metal concentrations compared to reference sediments (e.g., of Ag, Cu, Pb, and Se); however, none were statistically significant, likely due to limited sample sizes in large collection areas, and high variation among samples (Table 11). Notably, Granisle East sediments contained up to 20 times greater Cu than reference sediments (Granisle East maximum = 1420 mg/kg Cu; reference site maximum = 69.2 mg/kg Cu). Granisle Northwest sediments (which are exposed to Mill Area discharges) also contained elevated Cu (maximum = 631 mg/kg; Glencore 2014). On average, sediments near Granisle mine exceeded the Upper BCWSQG for Cu, whereas reference sediments did not, indicating the potential for mine-related chronic effects. These Cu elevations are ongoing, and have been observed in previous monitoring efforts (Glencore 2014); however, there also is evidence of very recent decline. For example, sediment Cu concentrations near Granisle mine increased noticeably from 2009 to 2014 (Glencore 2014), and some 2014 samples were similar to levels observed in 1992 (Remington 1996).

TABLE 10. SEDIMENT QUALITY AT HAGAN ARM AND TWO REFERENCE SITES IN BABINE LAKE IN 2014. RESULTS ARE SHOWN FOR FULL SEDIMENT SAMPLES AND THE < 63 µM SEDIMENT FRACTION (I.E., THE FRACTION WITH GREATER BIOAVAILABILITY TO AQUATIC LIFE). STATISTICALLY SIGNIFICANT ELEVATIONS IN METALS OR DECLINES IN PH AT HAGAN ARM COMPARED TO THE REFERENCE SITES ARE IN **BOLD** (P < 0.10).

	North HA		Woolverton Bay		Rum Bay		Reference	
Sample Size	n=5		n=5		n=5		n=10	
Parameter	Mean ± SD (full)	Mean ± SD (< 63)	Mean ± SD (full)	Mean ± SD (< 63)	Mean ± SD (full)	Mean ± SD (< 63)	Mean ± SD (full)	Mean ± SD (< 63)
pH	**6.6 ± 0.4**	**6.4 ± 0.4**	**6.7 ± 0.2**	**6.5 ± 0.3**	**6.7 ± 0.1**	6.7 ± 0.1	7.0 ± 0.2	6.8 ± 0.2
Metals (mg/kg)								
Ag	0.29 ± 0.32	0.35 ± 0.33	0.25 ± 0.07	**0.25 ± 0.07**	**0.29 ± 0.03**	**0.29 ± 0.03**	0.19 ± 0.07	0.18 ± 0.06
Al	16488 ± 4682	17580 ± 2799	18140 ± 2223	18600 ± 2281	**21740 ± 1865**	**21900 ± 1351**	17048 ± 6174	17808 ± 4215
Cu	74 ± 37	81 ± 30	**390 ± 201**	**382 ± 256**	**133 ± 58**	**102 ± 14**	55 ± 21	57 ± 9
Hg	0.099 ± 0.025	0.131 ± 0.073	0.212 ± 0.165	0.099 ± 0.016	0.138 ± 0.054	**0.115 ± 0.008**	0.089 ± 0.031	0.083 ± 0.024
Ni	28.1 ± 7.4	35.6 ± 5.6	**37.1** ± 4.0	43.5 ± 4.6	**40.3 ± 2.8**	39.6 ± 3.5	29.7 ± 11.4	37.9 ± 9.0
Pb	7.1 ± 2.0	7.7 ± 1.3	10.7 ± 2.1	10.6 ± 1.7	11.1 ± 1.7	**11.3 ± 1.3**	9.6 ± 3.0	9.8 ± 1.5
Se	0.47 ± 0.14	0.52 ± 0.07	0.94 ± 0.36	0.94 ± 0.31	**1.23 ± 0.20**	**1.19 ± 0.31**	0.69 ± 0.36	0.69 ± 0.28
Zn	105 ± 28	111 ± 20	**132 ± 14**	**134 ± 12**	**128 ± 7**	125 ± 9	110 ± 23	117 ± 11

North HA = North Hagan Arm; SD = Standard deviation

TABLE 11. SEDIMENT QUALITY AT GRANISLE VICINITY AND TWO REFERENCE SITES IN BABINE LAKE IN 2014. RESULTS ARE SHOWN FOR FULL SEDIMENT SAMPLES AND THE < 63 µM SEDIMENT FRACTION (I.E., THE FRACTION WITH GREATER BIOAVAILABILITY TO AQUATIC LIFE). NO SIGNIFICANT DIFFERENCES BETWEEN GRANISLE VICINITY AND REFERENCE SITE SEDIMENTS WERE FOUND.

	Granisle East[a]		Granisle West		Reference	
Sample Size	n=5		n=5		n=10	
Parameter	Mean ± SD (full)	Mean ± SD (< 63)	Mean ± SD (full)	Mean ± SD (< 63)	Mean ± SD (full)	Mean ± SD (< 63)
pH	7.2 ± 0.5	7.1 ± 0.6	6.9 ± 0.2	6.8 ± 0.2	7.0 ± 0.2	6.8 ± 0.2
Metals (mg/kg)						
Ag	0.31 ± 0.31	0.34 ± 0.33	0.35 ± 0.24	0.38 ± 0.25	0.19 ± 0.07	0.18 ± 0.06
Al	15804 ± 6513	20240 ± 2870	17198 ± 5306	18000 ± 3920	17048 ± 6174	17808 ± 4215
Cu	425 ± 560	440 ± 572	468 ± 456	528 ± 525	55 ± 21	57 ± 9
Hg	0.076 ± 0.046	0.070 ± 0.030	0.093 ± 0.030	0.093 ± 0.024	0.089 ± 0.031	0.083 ± 0.024
Ni	26.3 ± 13.9	39.9 ± 5.4	29.7 ± 9.9	31.8 ± 7.9	29.7 ± 11.4	37.9 ± 9.0
Pb	10.8 ± 7.4	12.5 ± 6.8	11.4 ± 4.9	12.5 ± 4.6	9.6 ± 3.0	9.8 ± 1.5
Se	0.87 ± 0.85	0.88 ± 0.67	0.81 ± 0.47	0.87 ± 0.43	0.69 ± 0.36	0.69 ± 0.28
Zn	95 ± 34	120 ± 13	101 ± 25	107 ± 17	110 ± 23	117 ± 11

[a] This set of sediment samples extended from Granisle East northward to offshore from North Dump.
SD = Standard deviation

Fish Health and Tissue Metals

We assessed prickly sculpin and lake trout body condition and tissue metal concentrations, both in dry and wet tissue samples, as monitored in 2014 and 2019. Despite Fulton's K condition factor being a relatively crude analysis of fish health, we assessed Glencore's reporting of this statistic due to a lack of any alternative monitoring information regarding overall fish health and/or body condition. We compared sculpin tissue metal concentrations between mine-exposed and reference sites. However, given that lake trout likely travel repeatedly between mine-exposed and reference locations, we quantified trends for lake trout across Babine Lake as a whole by comparing between sampling years, using site-specific data to inform conclusions about whether observed impacts are mine-related or not. Additionally, we compared sculpin and lake trout tissue metal concentrations to available thresholds from the scientific literature that are known to be associated with sublethal-effects in salmonids, which we call tissue sublethal-effect limits (Table 12). Insufficient data have been collected through Glencore's sampling of kokanee, making it impossible for us to perform any assessment regarding mine-related impacts to sockeye salmon.

TABLE 12. TISSUE SUBLETHAL-EFFECT LIMITS, WHICH ARE TISSUE METAL CONCENTRATIONS KNOWN TO BE ASSOCIATED WITH ADVERSE CHRONIC EFFECTS IN SALMONIDS, USED AS THRESHOLDS IN ASSESSING METAL CONTENT OF DRY AND WET FISH TISSUE SAMPLES IN BABINE LAKE.

	Tissue Sublethal-Effect Limit (µg/g)					
	Whole-Body		Muscle		Liver	
Parameter	Dry	Wet	Dry	Wet	Dry	Wet
As	-	1.100[a]	-	-	-	0.700[b]
Cd	0.162[a]	0.012[a]	-	-	-	0.010[a]
Cu	6.00[a]	1.20[c]	-	-	170.00[d]	36.00[a]
Hg	-	1.20[a]	-	-	-	-
Se	4.00[e]	0.54[a]	4.00[e]	1.50[f]	-	13.14[f]

[a] Environmental Residue-Effects Database 2019.

[b] Oladimeji et al. 1984.

[c] Meador 2015.

[d] Bernttsen et al. 1999.

[e] BC guideline for fish tissue Se content (BC MOE 2019a).

[f] Holm et al. 2003.

"-" = Not available

Sculpin – Bell Diffuser Area

In 2019, body condition of sculpin, according to Fulton's K, was significantly lower at Bell Diffuser Area (mean K = 1.01) than the reference site (mean K = 1.07; p = 0.002), and whole-body tissue concentrations of Cu, Pb, and Se were significantly greater in sculpin at Bell Diffuser Area than the reference site (Table 13). Non-significant elevations in Bell Diffuser Area sculpin tissues also were apparent for Al and Fe (Table 13). Sculpin tissue concentrations of Cu at Bell Diffuser Area exceeded tissue sublethal-effect limits, whereas reference sculpin tissues did not, indicating the potential for mine-related chronic effects. Both Bell Diffuser Area and reference site sculpin also on average exceeded the tissue sublethal-effect limit for Cd. Mine-related exceedances generally appear to have derived from historical impacts, as sculpin condition and most tissue metals concentrations at Bell Diffuser Area either have remained the same or have improved since previous monitoring efforts in 2012 (Glencore 2019). However, Fe concentrations in Bell Diffuser Area sculpin tissues increased from 2012 to 2019, suggesting that this is a recent impact that could be linked to Polishing Pond Outflow (Glencore 2019).

TABLE 13. METAL CONCENTRATIONS IN DRY AND WET WHOLE-BODY TISSUES OF PRICKLY SCULPIN (*COTTUS ASPER*) FROM BELL DIFFUSER AREA (BDA) AND CHAR BAY REFERENCE SITE IN BABINE LAKE IN 2019. STATISTICALLY SIGNIFICANT ELEVATIONS AT BDA COMPARED TO THE REFERENCE SITE ARE IN **BOLD** (P < 0.10).

	BDA		Reference	
Sample Size	n=5		n=5	
Whole-Body Metals (µg/g)	**Mean ± SD (Dry)**	**Mean ± SD (Wet)**	**Mean ± SD (Dry)**	**Mean ± SD (Wet)**
Al	31.7 ± 30.6	7.4 ± 7.0	16.5 ± 8.6	3.8 ± 2.0
Cd	0.122 ± 0.033	0.028 ± 0.006	0.099 ± 0.027	0.023 ± 0.006
Cu	**14.60 ± 5.05**	**3.46 ± 1.26**	3.48 ± 0.80	0.81 ± 0.18
Fe	174.1 ± 111.7	41.0 ± 26.3	83.9 ± 14.7	19.4 ± 3.1
Ni[a]	<0.200-0.260	<0.040-0.064	<0.200-0.360	<0.040-0.092
Pb	**0.132 ± 0.065**	**0.031 ± 0.014**	0.037 ± 0.003	0.009 ± 0.001
Se	**1.23 ± 0.22**	**0.29 ± 0.05**	0.86 ± 0.08	0.20 ± 0.02

[a] Where there are some samples above detection limits, but too many samples below to calculate a mean, the range of tissue concentrations is displayed instead.

SD = Standard deviation

Sculpin – Hagan Arm

In 2014, Fulton's K of sculpin was similar between Hagan Arm (mean K = 1.22) and reference sites (mean K = 1.24). However, sculpin at Hagan Arm showed significantly elevated concentrations of Cd and Se in their tissues compared to sculpin at reference sites, and apparent, but not statistically significant, elevations of Al (Table 14). Average tissue concentrations of Cd and Cu in sculpin at Hagan Arm exceeded tissue sublethal-effect limits by more (and more frequently) than fish at reference sites, indicating the potential for mine-related chronic effects. However, these impacts did not occur at the current discharge location (i.e., North Hagan Arm), and some were observed during previous monitoring efforts (Glencore 2014); therefore, they likely are a legacy from historical mining activities.

Sculpin – Granisle Vicinity

In 2014, Fulton's K of sculpin was similar between Granisle vicinity (mean K = 1.26) and reference sites (mean K = 1.24). However, sculpin at Granisle vicinity showed significantly elevated concentrations of Cd, Cu, and Se, and not statistically significant but noticeable elevations of Fe, Ni, and Pb in their tissues compared to sculpin at reference sites (Table 15). Based on wet tissue concentrations, sculpin at Granisle vicinity contained up to 3 times more Cu (Granisle East maximum = 4.73 µg/g), 14 times more Fe (Granisle West maximum = 711 µg/g) and 10 times more Pb (Granisle West maximum = 0.504 µg/g) than sculpin at reference sites (maximums = 1.61 µg/g Cu, 49.1 µg/g Fe, and 0.050 µg/g Pb). Average tissue concentrations of Cd and Cu in sculpin exceeded tissue sublethal-effect limits by more (and more frequently) at Granisle vicinity than at reference sites, indicating the potential for mine-related chronic effects. Many of these impacts likely are historical, as they have been observed in previous monitoring efforts (Glencore 2014). However, there also is evidence of worsening impacts recently to sculpin from Granisle vicinity; from 2009 to 2014, the elevation of Se in their tissues compared to reference fish increased, and they also experienced a marked increase in tissue concentrations of Pb that was not observed in fish from reference sites (Glencore 2014).

TABLE 14. METAL CONCENTRATIONS IN DRY AND WET WHOLE-BODY TISSUES OF PRICKLY SCULPIN (*COTTUS ASPER*) FROM HAGAN ARM AND TWO REFERENCE SITES IN BABINE LAKE IN 2014. STATISTICALLY SIGNIFICANT ELEVATIONS AT HAGAN ARM COMPARED TO REFERENCE SITES ARE IN **BOLD** ($P < 0.10$).

	North HA		Woolverton Bay		Rum Bay		Reference	
Sample Size	n=5		n=5		n=5		n=10	
Whole-Body Metals (µg/g)	**Mean ± SD (Dry)**	**Mean ± SD (Wet)**	**Mean ± SD (Dry)**	**Mean ± SD (Wet)**	**Mean ± SD (Dry)**	**Mean ± SD (Wet)**	**Mean ± SD (Dry)**	**Mean ± SD (Wet)**
Al	61.2 ± 96.2	15.1 ± 24.7	64.2 ± 45.5	15.2 ± 11.1	44.2 ± 47.0	9.5 ± 9.3	39.9 ± 42.4	8.6 ± 9.1
Cd	0.078 ± 0.036	0.019 ± 0.009	0.136 ± 0.091	0.033 ± 0.025	**0.180 ± 0.069**	**0.041 ± 0.018**	0.106 ± 0.045	0.023 ± 0.009
Cu	5.25 ± 1.58	1.24 ± 0.44	6.86 ± 2.28	1.62 ± 0.69	7.08 ± 2.37	1.62 ± 0.63	5.12 ± 1.60	1.12 ± 0.31
Fe	127.7 ± 93.6	30.7 ± 24.6	133.2 ± 45.3	30.7 ± 10.3	109.3 ± 54.0	24.0 ± 9.9	115.7 ± 57.7	25.2 ± 11.9
Ni[a]	<0.200-0.370	<0.040-0.094	<0.200-0.210	<0.040-0.046	<0.200-0.250	<0.040-0.059	<0.200-0.290	<0.040-0.062
Pb	0.055 ± 0.030	0.013 ± 0.008	0.086 ± 0.042	0.020 ± 0.009	0.045 ± 0.029	0.010 ± 0.006	0.095 ± 0.033	0.018 ± 0.009
Se	0.75 ± 0.10	0.18 ± 0.02	**1.10 ± 0.23**	**0.25 ± 0.06**	**1.23 ± 0.14**	**0.28 ± 0.04**	0.88 ± 0.12	0.20 ± 0.02

[a] Where there are some samples above detection limits, but too many samples below to calculate a mean, the range of tissue concentrations is displayed instead.

North HA = North Hagan Arm; SD = Standard deviation

TABLE 15. METAL CONCENTRATIONS IN DRY AND WET WHOLE-BODY TISSUE SAMPLES OF PRICKLY SCULPIN (*COTTUS ASPER*) FROM GRANISLE VICINITY AND TWO REFERENCE SITES IN BABINE LAKE IN 2014. STATISTICALLY SIGNIFICANT ELEVATIONS AT GRANISLE VICINITY COMPARED TO REFERENCE SITES ARE IN **BOLD** ($P < 0.10$).

	Granisle East		Granisle West		Reference	
Sample Size	n=5		n=5		n=10	
Whole-Body Metals (µg/g)	**Mean ± SD (Dry)**	**Mean ± SD (Wet)**	**Mean ± SD (Dry)**	**Mean ± SD (Wet)**	**Mean ± SD (Dry)**	**Mean ± SD (Wet)**
Al	47.2 ± 44.7	12.1 ± 12.3	41.0 ± 39.4	10.9 ± 11.3	39.9 ± 42.4	8.6 ± 9.1
Cd	**0.169 ± 0.047**	**0.042 ± 0.009**	**0.241 ± 0.086**	**0.061 ± 0.020**	0.106 ± 0.045	0.023 ± 0.009
Cu	**10.64 ± 5.43**	**2.73 ± 1.53**	6.84 ± 2.08	**1.76 ± 0.64**	5.12 ± 1.60	1.12 ± 0.31
Fe	258.2 ± 199.6	64.6 ± 50.6	749.1 ± 1182.7	192.5 ± 298.1	115.7 ± 57.7	25.2 ± 11.9
Ni[a]	<0.200-0.450	<0.040-0.113	<0.200-0.940	<0.040-0.237	<0.200-0.290	<0.040-0.062
Pb	0.054 ± 0.023	0.014 ± 0.007	0.760 ± 0.760	0.196 ± 0.194	0.095 ± 0.033	0.018 ± 0.009
Se	**1.66 ± 0.18**	**0.42 ± 0.05**	**1.95 ± 0.39**	**0.50 ± 0.10**	0.88 ± 0.12	0.20 ± 0.02

[a] Where there are some samples above detection limits, but too many samples below to calculate a mean, the range of tissue concentrations is displayed instead.

SD = Standard deviation

Lake Trout – Babine Lake

Assessing lake trout by sampling year (i.e., lake trout collected in Hagan Arm and the reference site in 2014 vs. lake trout collected in Bell Diffuser Area and the reference site in 2019) indicated that Fulton's K of lake trout in Babine Lake as a whole was significantly lower in 2019 (mean K = 0.94; p = 0.001) than in 2014 (mean K = 1.05). Additionally, Glencore (2014) reported that lake trout body condition in Babine Lake already had declined from 2012 to 2014. Metal concentrations in tissues of lake trout in Babine Lake generally were higher in both 2014 and 2019 than those previously observed in unpolluted BC lakes (Rieberger 1992). Importantly, lake trout tissue concentrations of As, Cu, Fe, Mn, Se, and Zn increased significantly from 2014 to 2019 (Table 16); it also appears that lake trout muscle content of Al increased, with samples in 2019 reading above detection limits, whereas 2014 samples did not (Table 16). In 2019, lake trout in Babine Lake on average exceeded liver tissue sublethal-effect limits for Cu, indicating the potential for chronic effects; some individuals even hosted liver Cu concentrations in the range of, or exceeding those observed in 1992 (Remington 1996).

From 2014 to 2019, we observed that increases to tissue metals content were apparent in lake trout sampled from the same location (i.e., the reference site), suggesting that these trends likely represent Babine Lake's population as a whole. Individual differences in diet may have impacted the tissue metal concentrations reported between years. However, many metals that increased in lake trout tissues over time (such as As, Cu, Fe, Se, and Zn) often were found in higher concentrations in fish collected from mine-exposed sites (i.e., Bell Diffuser Area and Hagan Arm) compared to the reference site (Appendix A); such evidence suggests that the Bell and Granisle mines are contributing factors to the recently elevated concentrations of contaminants observed in lake trout throughout Babine Lake.

TABLE 16. METAL CONCENTRATIONS IN DRY AND WET MUSCLE AND LIVER TISSUE SAMPLES OF LAKE TROUT (*SALVELINUS NAMAYCUSH*) FROM HAGAN ARM AND CHAR BAY REFERENCE SITE IN BABINE LAKE IN 2014, AND BELL DIFFUSER AREA AND CHAR BAY REFERENCE SITE IN BABINE LAKE IN 2019. STATISTICALLY SIGNIFICANT ELEVATIONS IN 2019 COMPARED TO 2014 ARE IN **BOLD** (P < 0.10).

	2014				**2019**			
Sample Size	n=10				n=20			
Tissue Metals (µg/g)	**Muscle**		**Liver**		**Muscle**		**Liver**	
	Mean ± SD (Dry)	**Mean ± SD (Wet)**	**Mean ± SD (Dry)**	**Mean ± SD (Wet)**	**Mean ± SD (Dry)**	**Mean ± SD (Wet)**	**Mean ± SD (Dry)**	**Mean ± SD (Wet)**
Al[a]	<2.0	<0.4	<2.0-6.4	<0.4-1.6	2.7 ± 2.1	0.7 ± 0.5	<2.0-4.6	0.5 ± 0.2
As	0.184 ± 0.079	0.043 ± 0.020	0.690 ± 0.560	0.180 ± 0.150	**0.442 ± 0.174**	**0.119 ± 0.055**	0.940 ± 0.470	0.225 ± 0.115
Cd	<0.005	<0.001	0.349 ± 0.135	0.084 ± 0.031	<0.005	<0.001	0.368 ± 0.181	0.085 ± 0.038
Cu	1.22 ± 0.36	0.28 ± 0.07	119.30 ± 64.20	29.66 ± 17.94	**1.48 ± 0.28**	**0.39 ± 0.09**	**342.28 ± 446.09**	**80.55 ± 101.84**
Fe	8.8 ± 3.6	2.0 ± 0.8	274.5 ± 96.6	66.6 ± 21.8	**16.2 ± 5.7**	**4.2 ± 1.2**	310.1 ± 142.0	73.2 ± 32.4
Hg	1.01 ± 0.44	0.23 ± 0.10	1.39 ± 0.75	0.33 ± 0.16	0.80 ± 0.35	0.20 ± 0.07	1.13 ± 0.56	0.26 ± 0.12
Mn	0.365 ± 0.079	0.084 ± 0.018	5.734 ± 1.691	1.383 ± 0.330	**0.524 ± 0.354**	**0.135 ± 0.086**	6.353 ± 2.024	1.478 ± 0.380
Se	0.52 ± 0.06	0.12 ± 0.01	2.97 ± 0.40	0.73 ± 0.15	0.51 ± 0.06	**0.13 ± 0.01**	**3.58 ± 1.38**	0.85 ± 0.31
Zn	11.5 ± 2.4	2.6 ± 0.5	136.5 ± 10.8	33.4 ± 3.8	11.9 ± 1.3	**3.1 ± 0.3**	**174.7 ± 50.4**	**41.0 ± 11.0**

[a] Where there are some samples above detection limits, but too many samples below to calculate a mean, the range of tissue concentrations is displayed instead.

SD = Standard deviation

DISCUSSION & RECOMMENDATIONS

Bell and Granisle mines have discharged mine-impacted water into the ecologically and culturally significant waters of Babine Lake for decades. Historically, these discharges have not received sufficient regulatory oversight to prevent elevated concentrations of contaminants from entering Babine Lake or its aquatic community. Our assessment of Bell and Granisle mines demonstrates that current permits regulating their mine-impacted water discharges remain limited in thoroughness and stringency. The Granisle mine site, which contains multiple discharge sources, has no limits on the volume or quality of its discharges, nor is monitoring required to test discharge toxicity to salmonids. Discharge permits for Bell mine allow high concentrations of some harmful contaminants (i.e., Cu, Fe, and Zn), and disregard a number of other contaminants (e.g., Al, Ag, As, Cd, Hg, Mn, Ni, Pb, Se, and SO_4), many of which are known to harm salmon at elevated concentrations. Additionally, the combination of contaminants in mine discharges may exert amplified negative effects on salmon, most of which are not well scientifically understood (Price 2013). Under current regulation, Bell and Granisle mines are permitted to continue discharging mine water into Babine Lake that exhibits lethal negative effects to aquatic invertebrates during toxicity tests, and contains metal concentrations that are well above the lake's background levels and/or levels known to cause chronic (i.e., sublethal), and sometimes lethal, effects to salmonids. Importantly, some mine discharges have increased their output of Cu recently. Lenient regulation of Bell and Granisle mine discharges is especially concerning, given our observation that Babine Lake already contains lake-wide water concentrations of some metal contaminants (e.g., Cu and Al) that could be causing chronic negative effects to salmonids.

Of similar concern are the gaps in scientific rigour and information obtained through the aquatic monitoring program of Babine Lake, which inhibit examination of potential negative mine-related impacts, and the tracking of their persistence and/or recovery. In several instances, especially for water, sediment and salmonid fishes in the area affected by Bell's water treatment plant, sufficient baseline and/or historical data have not been collected. Monitoring efforts surrounding Bell and Granisle mines also entirely omit key receiving areas (e.g., fish and water quality monitoring is lacking near several Granisle mine discharges) and disregard others (e.g., all aquatic monitoring in Hagan Arm) for ten years at a time. Additionally, the mixing zone near Bell mine appears to be inaccurately defined and/or monitored for discharge movement and dilution in the lake; similar challenges with relying on mixing zones in lake environments have been noted by other mining companies (e.g., Mount Polley Mining Corporation 2018), suggesting this is not responsible practice.

Where monitoring is performed, sampling replication often is insufficient to provide scientifically robust information, leading to too few samples, or too high variation among samples, with which to statistically detect effects; this is particularly true for monitoring of water quality in Hagan Arm and sediment quality in Granisle vicinity. Furthermore, sockeye salmon, particularly anadramous sockeye, are not a focal monitoring species. The distribution of juvenile sockeye in mine-affected areas has not been investigated and/or reported, only minimal sampling has been performed on kokanee (i.e., non-anadromous sockeye) and mine-related impacts to plankton (a primary food source of juvenile sockeye) have not been monitored, leaving gaps in knowledge of the risks and/or occurrences of mining impacts to anadromous sockeye. Other gaps exist related to the transparency and scientific accuracy of Babine Lake monitoring; not all monitoring data and reports are publicly available, there are potential discrepancies in Glencore's definition of water quality guidelines (e.g., for dissolved Cu), only provincial guidelines for determining chronic effects are used despite more protective and/or extensive thresholds being reported in the scientific literature, only crude indices for fish body condition (i.e., Fulton's K) are reported to indicate fish health, and highly mobile fish, such as lake trout, are not considered indicators of lake-wide impacts. Lastly, additional follow-up monitoring is not performed even when aquatic impacts are identified. In essence, full awareness of ongoing and recently occuring mine-related impacts to Babine Lake will not be possible without more exhaustive, consistent, and accurate data collection and impact analysis for all aquatic indicators at all mine-exposed receiving areas.

PHOTO CREDIT: SKEENAWILD
MINE-IMPACTED WATER AT BELL MINE NEAR THE TAILINGS IMPOUNDMENT

Despite such gaps in aquatic monitoring, our assessment demonstrates evidence of a number of aquatic impacts in Babine Lake linked to historical and/or recent mining activities. Persisting impacts that clearly are associated with past discharges from Bell and Granisle mines include elevated concentrations of a number of metals in sediments and sculpin tissues surrounding both mine locations – some of which (especially Cu) likely are associated with adverse biological effects. More recently, some of these persistent impacts have worsened, with increases to already elevated metal concentrations both in mine-affected sediments (i.e., Cu) and sculpin tissues (i.e., Se). There also is evidence of newly arising impacts to water quality (i.e., increased Al and SO_4 in water near Bell mine, and increased Cu – potentially exceeding the provincial guideline for chronic aquatic impacts – in water near Granisle mine) and sculpin (i.e., new elevations of Fe and Pb in mine-exposed sculpin tissues).

Lastly, salmonids appear to have been affected by Bell and Granisle mines. Lake trout in Babine Lake continue to host tissue metal concentrations that exceed those found in unpolluted BC lakes. Over the last 5-6 years, the body condition of lake trout has declined, and metal concentrations in lake trout tissues have increased. Copper concentrations in the liver of lake trout now far exceed those known to cause sublethal effects and, in some cases, are as high as they were at the beginning of mine closure and environmental reclamation efforts. The role of lake trout diet in these trends is unclear; however, such impacts likely are at least partially mine-related given that the highest metal concentrations in the tissue of lake trout are observed in individuals collected from mine-affected areas. To date, these potential impacts to lake trout have been overlooked by Glencore. Regrettably, any impacts to sockeye salmon in Babine Lake remain unknown due to insufficient monitoring. Such mine-related deteriorations to the aquatic environment in Babine Lake likely will persist given that both Bell and Granisle mines will continue to discharge mine-impacted water far into the foreseeable future.

Regulatory stringency, scientific rigour in environmental monitoring, and effective mitigation of ongoing and recent environmental impacts are essential to minimize further mine-related damage to Babine Lake and its aquatic community. We recommend the following actions to address current shortcomings in mine regulation and aquatic monitoring related to Bell and Granisle mines:

Discharge permits should:

- Apply to *all* water discharges at mine sites, however small;
- Limit discharge concentrations to
  - a) cover *all* potentially harmful contaminants,
  - b) not exceed Babine Lake natural background levels and/or known salmonid sublethal- or lethal-effect limits;
- Limit discharge volume, including instantaneous discharge volume, and require continuous flow monitoring to calculate accurate annual discharge volumes;
- Eliminate reliance on mixing zones in Babine Lake, or at least significantly reduce allowable mixing zone size;
- Require salmonid lethal and sublethal toxicity testing, performed multiple times throughout the year/discharge period, using sensitive fish species such as juvenile sockeye salmon rearing in Babine Lake;
- Include thresholds for toxicity testing of sublethal and lethal impacts to aquatic invertebrates and fishes, and additional measures to be taken when thresholds are surpassed.

Aquatic monitoring in Babine Lake should:

- Be performed in *all* receiving areas of current and historical mine discharges, including Bell Diffuser Area, North Hagan Arm, Woolverton Bay, Rum Bay, Granisle East, Granisle West, and areas in the vicinity of Granisle mine discharges that currently are overlooked (i.e., areas receiving North Dump and Mill Area discharges);
- Be performed on *all* indicators in *all* receiving areas during every monitoring cycle (i.e., annual monitoring of water quality, and monitoring every five years of sediment and fish);
- (If not eliminated) include additional studies to evaluate mixing zone dynamics in Bell Diffuser Area (e.g., related to discharge magnitude, temperature, and wind), so as to accurately delineate this receiving area, adjust monitoring sites accordingly, and ensure that contaminated discharge does indeed dilute fully to background water quality at the perimeter;
- Compare water quality, sediment quality, and fish tissue metal concentration data to thresholds for chronic effects obtained from the best available science (regardless of provincial guidelines);
- Use the results of improved baseline and regularly occurring monitoring (as recommended below) to more accurately categorize recent vs. historical impacts, and track the persistence and/or recovery of impacts;
- Include follow-up monitoring and additional measures, such as revising discharge permits to be more protective, in the event of identified impacts, particularly where thresholds related to chronic effects are surpassed;
- Be made fully transparent to the public, including all raw data and monitoring reports uploaded to BC government websites (e.g., BC Mine Information and BC Environmental Monitoring System).

Specifically, water quality monitoring efforts in Babine Lake should include:

- Greater sampling replication in space and time, such as
  - a minimum of 5 samples per receiving area (including each monitoring site within Bell Diffuser Area) during every collection effort, and
  - monthly collection efforts during the ice-free season, including months that mine discharges are not active;
- Publicly available, detailed rationales/calculations for any site-specific water quality guidelines used (e.g., for dissolved Cu).

Specifically, sediment quality and fish monitoring efforts in Babine Lake should include:

- Analysis of fish tissue metal concentrations for all samples collected;
- Lake-wide assessment of mobile fish (e.g., salmonid) health and tissue metals content, using site-specific data to support conclusions regarding whether observed impacts are mine-related;
- Assessment of individual lake trout diet, using stable isotope analysis, in conjunction with tissue metals content analysis;
- Assessment to determine juvenile sockeye presence in mine-exposed areas (i.e., Bell Diffuser Area, Hagan Arm, and Granisle vicinity);
- Performance of holding experiments on juvenile sockeye salmon to determine potential sublethal-effects using a variety of water qualities obtained from mine-impacted and reference sites;
- Assessment of mine-related impacts to juvenile sockeye salmon food sources, including plankton;

- Use of more robust indicators of general fish health and/or body condition (see Froese 2006);
- Collection of fish for lethal and non-lethal sampling *not* during spawning periods;
- Greater sampling replication in space and time, such as
  - 10 surficial sediment samples per receiving area site,
  - 10 prickly sculpin samples for whole-body tissue analysis per receiving area site,
  - 30 lake trout samples for tissue analyses of metal concentrations and diet, collected across mine-exposed and reference areas, and
  - if present, 15-20 non-lethal juvenile sockeye salmon samples for assessment of general health and/or body condition, collected across mine-exposed and reference areas.

Specifically, baseline monitoring in Babine Lake, in preparation for future changes to mine-related discharges, should include:

- Sampling of all aquatic indicators in receiving areas potentially affected by the change;
- Replicated sampling, generally following the recommendations for water quality, sediment quality, and fish as described above;
- Additional collection efforts, if required, to ensure that baseline characterization is based on 3-5 years of monitoring data.

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APPENDIX A: SUPPLEMENTARY TABLES

TABLE A1. QUALITY OF POLISHING POND OUTFLOW (PPO) DISCHARGE FROM BELL MINE, 2015-2019. DISCHARGE ENTERS BELL DIFFUSER AREA IN BABINE LAKE.

Parameter	PPO Discharge 2015-2019		
	Min.	**Max.**	**Mean ± SD**
Field pH	7.2	9.4	8.8 ± 0.5
Field Conductivity (uS/cm)	624	4391	3713 ± 582
pH	6.7	8.6	7.4 ± 0.5
Conductivity (uS/cm)	3420	4290	3955 ± 210
Hardness (mg/L)	2645.2	3467.9	3068.0 ± 214.4
Dissolved SO_4 (mg/L)	2010.0	3480.0	3000.7 ± 264.0
TSS (mg/L)	<2.0	25.3	8.7 ± 6.9
Dissolved Metals (mg/L)			
Ag	<0.00001	<0.00005	BDLs
Al	0.004	0.590	0.054 ± 0.111
As	<0.0002	<0.0005	BDLs
Cd	0.00012	0.00040	0.00026 ± 0.00007
Cu	<0.0010	0.0439	0.0040 ± 0.0064
Fe	<0.01	<0.06	BDLs
Hg	<5.0E-6	<0.00002	BDLs
Mn	0.0737	1.3400	0.4265 ± 0.2655
Ni	0.0010	0.0041	0.0014 ± 0.0008
Pb	<0.0001	0.0009	BDLs
Se	0.0008	0.0015	0.0012 ± 0.0002
Zn	<0.0010	0.0059	BDLs
Total Metals (mg/L)			
Ag	<0.00001	<0.00005	BDLs
Al	0.011	0.598	0.141 ± 0.116
As	<0.0002	<0.0005	BDLs
Cd	0.00015	0.00045	0.00029 ± 0.00007
Cu	0.0059	0.2070	0.0637 ± 0.0463
Fe	<0.01	0.11	BDLs
Hg	<5.0E-6	<0.00002	BDLs
Mn	0.0814	1.3300	0.4794 ± 0.2815
Ni	0.0014	0.0084	0.0035 ± 0.0018
Pb	<0.0001	0.0008	BDLs
Se	0.0009	0.0017	0.0012 ± 0.0002
Zn	0.0030	0.0215	0.0075 ± 0.0048

SD = Standard deviation; BDLs = Too many samples below detection limit to calculate mean

TABLE A2. QUALITY OF 8D DISCHARGE FROM BELL MINE, 2013-2016 AND 2017-2019. DISCHARGE ENTERS NORTH HAGAN ARM IN BABINE LAKE.

	8D Discharge					
	2013-2016			2017-2019		
Parameter	**Min.**	**Max.**	**Mean ± SD**	**Min.**	**Max.**	**Mean ± SD**
Field pH	6.4	7.5	6.7 ± 0.4	6.5	8.7	7.2 ± 0.6
Field Conductivity (uS/cm)	974	1402	1212 ± 203	459	1965	1012 ± 369
pH	6.7	7.9	7.3 ± 0.3	6.5	7.9	7.3 ± 0.3
Conductivity (uS/cm)	538	2020	1193 ± 415	678	1830	1072 ± 287
Hardness (mg/L)	448.0	1510.0	832.7 ± 266.1	376.2	1209.8	641.5 ± 202.2
Dissolved SO_4 (mg/L)	303.0	1220.0	693.3 ± 269.9	317.0	1190.0	579.7 ± 209.0
TSS (mg/L)	<1.0	14.0	3.1 ± 2.9	<3.0	5.1	BDLs
Dissolved Metals (mg/L)						
Ag	<0.00001	<0.00005	BDLs	<0.00001	0.00001	BDLs
Al	0.001	0.292	0.096 ± 0.074	0.038	0.148	0.089 ± 0.035
As	<0.0005	0.0013	BDLs	0.0002	0.0004	0.0003 ± 0.0001
Cd	0.00001	0.00855	0.00053 ± 0.00189	0.00002	0.00007	0.00004 ± 0.00002
Cu	<0.0002	0.0174	0.0036 ± 0.0033	0.0026	0.0082	0.0050 ± 0.0016
Fe	<0.03	1.58	0.52 ± 0.42	0.04	0.25	0.13 ± 0.07
Hg	<5.0E-6	0.00003	BDLs	NM	NM	NM
Mn	0.0105	4.9900	1.2468 ± 1.8637	0.0013	0.1360	0.0553 ± 0.0497
Ni	0.0016	0.0084	0.0028 ± 0.0014	0.0015	0.0026	0.0020 ± 0.0003
Pb	<0.00005	0.0384	BDLs	<0.00005	0.0001	BDLs
Se	<0.0002	0.0006	BDLs	0.0001	0.0002	0.0001 ± 0.00003
Zn	0.0012	0.0680	0.0090 ± 0.0120	0.0030	0.0125	0.0062 ± 0.0032
Total Metals (mg/L)						
Ag	<0.00001	0.00008	BDLs	<0.00001	0.00002	BDLs
Al	0.005	0.553	0.244 ± 0.202	0.049	0.482	0.197 ± 0.149
As	<0.0005	0.0014	BDLs	0.0002	0.0005	0.0004 ± 0.0001
Cd	0.00001	0.00040	0.00010 ± 0.00009	0.00002	0.00008	0.00005 ± 0.00002
Cu	0.00014	0.0227	0.0043 ± 0.0041	0.0033	0.0112	0.0057 ± 0.0022
Fe	<0.03	2.36	0.73 ± 0.66	0.05	0.64	0.25 ± 0.18
Hg	<0.00002	0.00006	BDLs	NM	NM	NM
Mn	0.0109	4.8200	1.2885 ± 1.8969	0.0015	0.1450	0.0583 ± 0.0514
Ni	0.0020	0.0088	0.0032 ± 0.0016	0.0016	0.0027	0.0022 ± 0.0004
Pb	<0.00005	0.0002	BDLs	<0.00005	0.0001	BDLs
Se	<0.0005	0.0017	BDLs	0.0001	0.0002	0.0001 ± 0.00004
Zn	0.0010	0.0730	0.0138 ± 0.0152	0.0031	0.0134	0.0071 ± 0.0035

SD = Standard deviation; BDLs = Too many readings below detection limit to calculate mean; NM = Parameter not monitored

TABLE A3. QUALITY OF SURFACE FLOWS AND SHALLOW SEEPAGE FROM GRANISLE MINE, 2013-2019. DISCHARGES ENTER BABINE LAKE TO THE NORTHEAST, NORTHWEST, AND WEST OF THE GRANISLE MINE SITE.

	North Dump 2013-2018			Mill Area 2013-2019			Settling Pond 2013-2019		
Parameter	**Min.**	**Max.**	**Mean ± SD**	**Min.**	**Max.**	**Mean ± SD**	**Min.**	**Max.**	**Mean ± SD**
Field pH	5.2	5.8	5.5 ± 0.3	6.8	7.8	7.3 ± 0.3	6.9	8.2	7.7 ± 0.4
Field Conductivity (uS/cm)	645	795	709 ± 77	783	1729	1357 ± 235	161	364	259 ± 66
pH	4.9	6.8	5.8 ± 0.5	7.3	8.3	7.9 ± 0.2	7.5	8.2	7.8 ± 0.2
Conductivity (uS/cm)	299	1090	709 ± 261	661	1860	1464 ± 248	159	346	241 ± 51
Hardness (mg/L)	316.8	732.0	509.1 ± 151.7	322.7	1740.0	920.9 ± 214.1	76.0	166.6	119.0 ± 23.9
Dissolved SO_4 (mg/L)	302.0	690.0	479.0 ± 140.3	261.0	1440.0	730.2 ± 207.4	38.6	122.0	67.8 ± 21.7
TSS (mg/L)	<1.0	13.0	BDLs	<1.0	17.0	4.7 ± 3.6	<1.0	3.3	BDLs
Dissolved Metals (mg/L)									
Ag	<5.0E-6	0.00001	BDLs	<5.0E-6	<0.00005	BDLs	<0.00001	<0.00005	BDLs
Al	0.238	0.638	0.427 ± 0.175	<0.001	0.065	0.005 ± 0.010	<0.005	0.038	0.020 ± 0.012
As	<0.0005	<0.0005	BDLs	<0.0001	0.0007	0.0003 ± 0.0002	<0.0001	<0.0005	BDLs
Cd	0.00014	0.00040	0.00030 ± 0.00011	<0.00001	0.00069	0.00011 ± 0.00015	0.00003	0.00006	0.00004 ± 0.00001
Cu	0.1120	0.2810	0.1730 ± 0.0587	0.0010	0.8140	0.0483 ± 0.1230	0.0355	0.0634	0.0517 ± 0.0073
Fe	0.08	0.19	0.11 ± 0.03	<0.01	0.51	BDLs	<0.01	0.03	BDLs
Hg	<0.00002	<0.00002	BDLs	<5.0E-6	0.00005	BDLs	<5.0E-6	<0.00002	BDLs
Mn	0.1020	0.3280	0.2261 ± 0.0987	0.0003	1.7000	0.3218 ± 0.4665	0.0004	0.0196	0.0067 ± 0.0059
Ni	0.0076	0.0205	0.0154 ± 0.0058	<0.0002	0.0194	0.0042 ± 0.0043	0.0008	0.0036	0.0020 ± 0.0009
Pb	<0.00005	<0.0001	BDLs	<0.00005	0.0009	BDLs	<0.00005	<0.0001	BDLs
Se	<0.0005	<0.0005	BDLs	<0.0005	0.0011	0.0003 ± 0.0002	<0.0005	0.0006	0.0003 ± 0.0002
Zn	0.0130	0.0420	0.0298 ± 0.0121	0.0010	0.1420	0.0187 ± 0.0261	0.0017	0.0110	0.0051 ± 0.0024
Total Metals (mg/L)									
Ag	<0.00001	<0.00001	BDLs	<0.00001	0.00005	BDLs	<0.00001	0.00002	0.00002 ± 5.7E-6
Al	0.234	0.597	0.404 ± 0.154	<0.003	0.144	0.016 ± 0.024	0.007	0.064	0.033 ± 0.018
As	<0.0005	<0.0005	BDLs	<0.0001	0.0009	0.0003 ± 0.0002	<0.0005	0.0002	0.0002 ± 0.0001
Cd	0.00015	0.00041	0.00030 ± 0.00011	0.00001	0.00071	0.00012 ± 0.00016	0.00002	0.00005	0.00004 ± 0.00001
Cu[a]	0.1100	0.2150	0.1633 ± 0.0461	0.0036	0.3400	0.0572 ± 0.0644	0.0417	0.0714	0.0563 ± 0.0085
Fe	0.09	0.16	0.12 ± 0.02	<0.01	0.53	0.06 ± 0.09	0.01	0.10	BDLs[b]
Hg	<0.00002	<0.00002	BDLs	<5.0E-6	0.00006	BDLs	<5.0E-6	<0.00002	BDLs
Mn	0.1030	0.3390	0.2310 ± 0.1019	0.0017	1.8800	0.3684 ± 0.4723	0.0010	0.0205	0.0075 ± 0.0056
Ni	0.0075	0.0217	0.0159 ± 0.0061	0.0003	0.0193	0.0047 ± 0.0046	0.0009	0.0037	0.0021 ± 0.0009
Pb	<0.00005	<0.0001	BDLs	<0.00003	0.0005	BDLs	<0.00005	0.0001	BDLs
Se	<0.0005	<0.0005	BDLs	<0.0002	0.0015	0.0003 ± 0.0003	<0.0005	0.0009	0.0003 ± 0.0002
Zn	0.0134	0.0430	0.0297 ± 0.0123	<0.0030	0.1390	0.0236 ± 0.0294	<0.0030	0.0089	0.0055 ± 0.0020

[a] One total Cu outlier removed from Mill Area discharge data.

[b] Detection limit for Settling Pond total Fe is <0.03 mg/L.

SD = Standard deviation; BDLs = Too many readings below detection limit to calculate mean

TABLE A4. BABINE LAKE WATER QUALITY AT HAGAN ARM AND REFERENCE SITES IN 2014.

	Hagan Arm[a]			Reference		
Sample Size	n=6			n=4		
Parameter	**Min.**	**Max.**	**Mean ± SD**	**Min.**	**Max.**	**Mean ± SD**
Field pH	NM	NM	NM	NM	NM	NM
Field Conductivity (uS/cm)	NM	NM	NM	NM	NM	NM
pH	NM	NM	NM	NM	NM	NM
Conductivity (uS/cm)	NM	NM	NM	NM	NM	NM
Hardness (mg/L)	42.4	43.0	42.8 ± 0.2	42.0	42.2	42.1 ± 0.1
Dissolved SO_4 (mg/L)	1.0	1.6	1.2 ± 0.2	<0.5	0.5	0.5 ± 0.1
TSS (mg/L)	<3.0	<3.0	BDLs	<3.0	<3.0	BDLs
Dissolved Metals (mg/L)						
Al	0.002	0.003	0.002 ± 0.0004	0.001	0.003	0.002 ± 0.001
Cd	<5.0E-6	<5.0E-6	BDLs	<5.0E-6	<5.0E-6	BDLs
Cu	0.0019	0.0021	0.0020 ± 0.0001	0.0016	0.0018	0.0017 ± 0.0001
Fe	<0.03	<0.03	BDLs	<0.03	<0.03	BDLs
Mn	<0.0002	0.0007	0.0004 ± 0.0002	<0.0002	0.0005	0.0003 ± 0.0001
Ni	0.0005	0.0006	0.0005 ± 0.00005	0.0005	0.0005	0.0005 ± 0.00002
Zn	<0.0010	0.0014	BDLs	<0.0010	<0.0010	BDLs
Total Metals (mg/L						
Al	0.004	0.008	0.005 ± 0.002	0.004	0.006	0.005 ± 0.001
Cd	<5.0E-6	<5.0E-6	BDLs	<5.0E-6	<5.0E-6	BDLs
Cu	0.0019	0.0022	0.0020 ± 0.0001	0.0017	0.0018	0.0017 ± 0.00002
Fe	<0.03	<0.03	BDLs	<0.03	<0.03	BDLs
Mn	0.0007	0.0013	0.0009 ± 0.0002	0.0007	0.0008	0.0007 ± 0.00005
Ni	0.0005	0.0005	0.0005 ± 0.00001	0.0004	0.0005	0.0005 ± 0.00003
Zn	<0.0030	<0.0030	BDLs	<0.0030	<0.0030	BDLs

[a] Monitoring data for North Hagan Arm, Woolverton Bay, and Rum Bay are summarized together due to minimal sampling.

SD = Standard deviation; NM = Parameter not monitored; BDLs = Too many readings below detection limit to calculate mean

TABLE A5. METAL CONCENTRATIONS IN DRY AND WET MUSCLE AND LIVER TISSUE SAMPLES OF LAKE TROUT (*SALVELINUS NAMAYCUSH*) FROM BELL DIFFUSER AREA (BDA) AND CHAR BAY REFERENCE SITE IN BABINE LAKE, 2019. SIGNIFICANT ELEVATIONS AT BDA COMPARED TO REFERENCE ARE SHOWN IN **BOLD** (P < 0.10).

	BDA				Reference			
Sample Size	n=10				n=10			
Tissue	**Muscle**		**Liver**		**Muscle**		**Liver**	
Metals (µg/g)	**Mean ± SD (Dry)**	**Mean ± SD (Wet)**	**Mean ± SD (Dry)**	**Mean ± SD (Wet)**	**Mean ± SD (Dry)**	**Mean ± SD (Wet)**	**Mean ± SD (Dry)**	**Mean ± SD (Wet)**
Al[a]	3.1 ± 1.9	0.8 ± 0.5	<2.0-3.6	0.5 ± 0.2	<2.0-8.0	0.6 ± 0.5	<2.0-4.6	0.5 ± 0.2
As	0.487 ± 0.120	0.131 ± 0.041	1.051 ± 0.539	0.252 ± 0.132	0.397 ± 0.212	0.107 ± 0.066	0.825 ± 0.392	0.197 ± 0.094
Cd	<0.005	<0.001	0.311 ± 0.185	0.072 ± 0.037	<0.005	<0.001	0.425 ± 0.166	0.099 ± 0.035
Cu	**1.60 ± 0.19**	0.42 ± 0.07	483.30 ± 588.96	112.89 ± 133.33	1.35 ± 0.31	0.36 ± 0.10	201.25 ± 170.40	48.21 ± 42.39
Fe	17.9 ± 6.1	4.6 ± 1.1	332.3 ± 129.2	77.3 ± 24.1	14.6 ± 5.0	3.8 ± 1.3	287.9 ± 157.5	69.2 ± 40.0
Hg	0.74 ± 0.30	0.19 ± 0.06	1.11 ± 0.55	0.26 ± 0.12	0.86 ± 0.40	0.22 ± 0.08	1.14 ± 0.60	0.27 ± 0.13
Mn	0.411 ± 0.105	0.107 ± 0.026	5.816 ± 1.585	1.348 ± 0.258	0.638 ± 0.474	0.164 ± 0.114	6.889 ± 2.344	1.607 ± 0.449
Se	0.52 ± 0.08	0.14 ± 0.01	4.05 ± 1.77	0.95 ± 0.39	0.50 ± 0.05	0.13 ± 0.01	3.12 ± 0.62	0.74 ± 0.16
Zn	12.0 ± 1.6	3.1 ± 0.3	182.3 ± 54.3	42.4 ± 10.0	11.9 ± 1.0	3.1 ± 0.3	167.0 ± 48.7	39.6 ± 12.2

[a] Where there are some samples above detection limits, but too many samples below to calculate a mean, the range of tissue concentrations is displayed instead.

SD = Standard deviation

TABLE A6. METAL CONCENTRATIONS IN DRY AND WET MUSCLE AND LIVER TISSUE SAMPLES OF LAKE TROUT (*SALVELINUS NAMAYCUSH*) FROM HAGAN ARM AND CHAR BAY REFERENCE SITE IN BABINE LAKE, 2014. NO SIGNIFICANT DIFFERENCES WERE FOUND BETWEEN SITES.

	Hagan Arm				**Reference**			
Sample Size	n=5				n=5			
Tissue	**Muscle**		**Liver**		**Muscle**		**Liver**	
Metals (µg/g)	**Mean ± SD (Dry)**	**Mean ± SD (Wet)**	**Mean ± SD (Dry)**	**Mean ± SD (Wet)**	**Mean ± SD (Dry)**	**Mean ± SD (Wet)**	**Mean ± SD (Dry)**	**Mean ± SD (Wet)**
Al[a]	<2.0	<0.4	<2.0-6.4	<0.4-1.6	<2.0	<0.4	<2.0-3.4	<0.4-0.7
As	0.157 ± 0.087	0.036 ± 0.021	0.752 ± 0.789	0.196 ± 0.217	0.211 ± 0.067	0.050 ± 0.018	0.632 ± 0.280	0.155 ± 0.077
Cd	<0.005	<0.001	0.349 ± 0.132	0.088 ± 0.037	<0.005	<0.001	0.349 ± 0.153	0.080 ± 0.027
Cu	1.27 ± 0.45	0.29 ± 0.10	122.20 ± 95.49	31.38 ± 26.41	1.18 ± 0.29	0.27 ± 0.05	116.40 ± 11.59	27.94 ± 4.40
Fe	9.7 ± 5.1	2.2 ± 1.1	276.4 ± 125.9	68.3 ± 29.2	7.9 ± 1.1	1.8 ± 0.2	272.6 ± 71.7	64.8 ± 14.5
Hg	1.12 ± 0.53	0.25 ± 0.11	1.56 ± 0.79	0.38 ± 0.17	0.90 ± 0.37	0.21 ± 0.10	1.22 ± 0.76	0.28 ± 0.15
Mn	0.329 ± 0.059	0.074 ± 0.011	5.310 ± 1.774	1.316 ± 0.387	0.402 ± 0.084	0.094 ± 0.019	6.158 ± 1.686	1.450 ± 0.290
Se	0.52 ± 0.03	0.12 ± 0.01	3.01 ± 0.56	0.76 ± 0.17	0.52 ± 0.08	0.12 ± 0.01	2.93 ± 0.23	0.71 ± 0.15
Zn	12.4 ± 2.9	2.8 ± 0.6	132.8 ± 12.6	33.3 ± 4.3	10.6 ± 1.4	2.5 ± 0.2	140.2 ± 8.3	33.5 ± 3.6

[a] Where there are some samples above detection limits, but too many samples below to calculate a mean, the range of tissue concentrations is displayed instead.

SD = Standard deviation