ABSTRACT

The historic Bralorne-Takla mercury mine is located north of Fort St. James, B.C. within the traditional territory of the Takla Lake First Nation (TLFN). The wastes, equipment, and other materials remained until B.C.’s Crown Contaminated Sites Program (CCSP) began investigations in 2005. Working in partnership with TLFN, remediation and reclamation was completed in 2017.

Investigation confirmed the presence of unacceptable risks to human health and ecological receptors. The CCSP and the TLFN collaboratively identified remedial objectives including protecting of human health and the environment and returning the mine site to forest ecosystem.

The remedial approach included capping mine openings, demolition of structures, off-site disposal of Hazardous Waste; consolidation of non-Hazardous Waste into two on-site landfills; revegetation; and implementation of administrative risk controls to protect future site users. The cover design included innovative elements to support forest growth. Selection of native species for seed mix, shrub and trees replanting focused on returning the mine site to a forest ecosystem and supporting traditional use of the land.

Monitoring of covers, drainage systems, landfill gases, water quality, vegetation performance, and administrative (land use) risk controls is ongoing. Additional monitoring includes ambient mercury vapour monitoring and biomonitoring.

Keywords: contamination, remediation, historic mine, Takla, closure, waste
INTRODUCTION AND BACKGROUND

The historic Bralorne-Takla mercury mine is located ~150 km north of Fort St. James, B.C. (Figure 1) within the traditional territory of the Takla Lake First Nation (TLFN). Cinnabar ore was roasted to extract liquid mercury during World War II. The mine wastes, processing equipment, and other materials remained abandoned until B.C.’s Crown Contaminated Sites Program (CCSP), part of the Ministry of Forests, Lands, Natural Resource Operations and Rural Development, began investigations in 2005, after the mine site was prioritized through the CCSP risk ranking methodology (CCSP, 2018). The core project team for the work described here consisted of the various authors’ organizations.

Figure 1: The Bralorne-Takla mine is located along the Pinchi fault in the Omineca Mountains approximately 40 km from Takla Landing, British Columbia.

Site assessment by the CCSP to characterize risks posed by environmental media and wastes at the mine site was halted due to concerns raised by the TLFN in 2007. An engagement strategy was designed collaboratively with the TLFN and implemented from 2011 to present. A Technical Working Group (TWG) made up of representatives from the CCSP and the TLFN, along with their supporting consultants, guided subsequent site assessment, remediation, and monitoring activities.

The relationship between the CCSP and the TLFN strengthened throughout the assessment and planning phases of the project. Using feedback from community workshops, a detailed options analysis was carried out to identify the key objectives and values of both the CCSP and the TLFN, and to understand what options would deliver the most value. Consensus was reached in 2014, as documented in a Conceptual Remediation Plan (SNC-Lavalin, 2014a) that detailed remediation design involving a commitment to construct a novel landfill which would support a forest ecosystem.
In summary, the remediation works involved abatement of asbestos and liquid mercury, off-site disposal of all Hazardous Waste, on-site consolidation of non-Hazardous Waste contaminated soil and mine wastes, landfill construction, and installation of drainage structures designed to maintain the integrity of the landfills and roadways. Construction at the remote site occurred during the short summer and fall seasons of 2015 and 2016 following detailed engineering and design. Planting of shrubs and trees was carried out in Spring 2017 and vegetation performance assessment is ongoing as part of Long Term Monitoring and Maintenance (LTMM) commitments.

While this project involved all the aspects typical of mine closure, there were many novel aspects and challenges faced during reclamation of this mine site. This paper describes how the many facets of the project evolved to achieve the desired remedial objectives and end land use.

**HUMAN AND ECOLOGICAL RISK ASSESSMENT**

Once the CCSP prioritized the mine site for characterization and before the investigations were completed, the risk assessment and risk management process was initiated – earlier than is typical – to understand the mine site’s liabilities associated with contamination. A preliminary human health risk assessment was conducted which concluded the off-site risks would likely be acceptable, but that mine site remediation and risk management were required. Signage and a fence were installed to delineate the relatively small area where access was potentially unsafe. A detailed quantitative ecological risk assessment (Azimuth, 2008) was conducted which confirmed the mine site required remediation. Importantly, it was found that the small lakes adjacent to the mine site did not require remediation or risk management measures; instead the focus was on surface soils, vapours, groundwater and on-site ephemeral surface waters.

Engagement with the TLFN was prioritized to ensure that the concerns of community members were addressed in risk management planning. Data and information to supplement future (post-remediation) risk assessment were collected alongside the extensive site characterization effort necessary to support remediation planning. For example:

- Traditional knowledge about the mine site and the region was collected by the community and communicated to the project team for application in the risk assessment.
- Sampling of country foods was conducted, directed by TLFN members.
- Additional wildlife species were identified for evaluation beyond those used in the initial ecological risk assessment.
- Community members were encouraged to submit tissue samples from game for chemical analysis to address concerns about country foods.
- A two-day “camp” was held for community members, the TLFN’s consultants and the project team to learn about the mine site and to share knowledge. Located in a wildlands setting, the camp provided an opportunity to deepen understanding of the risks and potential solutions.
CONCEPTUAL DESIGN

The requirements of governing regulations under the BC *Environmental Management Act* and the *Mines Act* set standards for site remediation and reclamation; the project team recognized that a successful remediation strategy would address the objectives of both the CCSP and the TLFN. Working in the collaborative forum of the TWG, the CCSP and the TLFN identified site specific remedial objectives within four categories (SNC-Lavalin, 2014b), as outlined in Table 1.

Table 1: Site-specific remedial objectives, organized by objective type.

<table>
<thead>
<tr>
<th>Objective Type</th>
<th>Remedial Objective</th>
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</thead>
<tbody>
<tr>
<td>Environmental Improvement Objectives</td>
<td>- Make site safe for use by humans, animals, and plants</td>
</tr>
<tr>
<td></td>
<td>- Remove contamination at the site caused by mining activities</td>
</tr>
<tr>
<td></td>
<td>- Minimize environmental impacts of remediation through sustainable clean-up and planning</td>
</tr>
<tr>
<td>Technical Feasibility Objectives</td>
<td>- Technically feasible, scientifically supported, and timely remedial solution(s)</td>
</tr>
<tr>
<td>Community Benefits Objectives</td>
<td>- TLFN benefits from and is involved in remediation</td>
</tr>
<tr>
<td></td>
<td>- Restores TLFN traditional land use (forest habitat)</td>
</tr>
<tr>
<td>Cost and Liability Management Objectives</td>
<td>- Manage provincial responsibilities in the long term</td>
</tr>
<tr>
<td></td>
<td>- Is cost effective and considers short and long term costs</td>
</tr>
</tbody>
</table>

The project team prepared a long-list of management strategies and treatment technologies for mercury contaminated mine sites for review by the TWG. The TWG then agreed on a short-list of strategies based on the identified remedial objectives. The project team defined Management Areas, grouping site areas with similar soil characteristics, receptors of concern, contamination levels, and construction requirements to facilitate further evaluation of management strategies. Short-listed management strategies were assembled into remedial options for each Management Area and the evaluation criteria were used to further screen how well a particular strategy met the objectives for a given Management Area. Through this collaborative process, the CCSP and the TLFN, supported by their consultants, arrived at a preferred remedial plan consisting of the following elements (SNC-Lavalin, 2014a):

- Recover and dispose all Hazardous Waste materials, cleaned metal and garbage off-site.
- Stabilize leachable wastes prior to shipment.
- Manage non-Hazardous Waste mine contaminated soil, mine waste and demolition debris by consolidation into on-site landfills.
- Address unexpected contamination encountered during remediation through a transparent adaptive management approach.
- Manage surface water to convey shallow groundwater and surface water from the engineered landfills to protect the covers. Promote re-infiltration downhill of the landfills.
- Place simple soil covers over most excavated areas to eliminate exposure to soil or bedrock with naturally high metals concentrations (as needed to meet risk management objectives).
- Secure mine openings by installing concrete caps with simple soil covers.
Following remediation, decommission secondary roads and maintain the Fall-Dream Forest Service Road (FSR) for future site access and public use.

Reclaim disturbed areas, landfill covers and decommissioned roads to forest habitat using native species. Exceptions to forest habitat end-goal were the FSR, surface water swales, and capped mine openings which would be planted with native shrubs and plant species.

Risk manage isolated contamination within reforested areas surrounding the mine site.

Implement an education and recognition program with the TLFN community about the Bralorne-Takla Mine Site remediation work and risk-based land use restrictions (Photo 1).

IMPLEMENTATION / CONSTRUCTION

The remedial objectives developed by the TWG were addressed by a remedial approach that combined physical remediation and risk management actions. As involvement with the TLFN throughout project delivery was critical for project success, a TLFN representative took part in procurement of the remedial contractor. Contractors were evaluated, in part, on how they involved the TLFN in the work. The winning design-build team used heavy equipment and operators, along with labourer support, provided by the TLFN and/or member-owned companies. While a specialized crew was required for some activities such as asbestos abatement, operators and labourers were trained to work safely around the abatement activities, either remaining outside of exclusion zones or in appropriate personal protective equipment. In addition, at least one of the on-site environmental monitoring crew was a member of the TLFN. This approach to implementation and construction supported a team approach to safety and environmental management during remediation.

In addition to meeting the objectives of the TWG, the project team had to ensure that regulatory requirements were met, including permits and authorizations for landfiling, mine reclamation, road use, water use, waste discharge, tree falling, wildlife salvage and Hazardous Waste shipping. There were many challenges associated with remediation and reclamation – key examples follow:

- Bedrock and shallow undisturbed native soils along the Pinchi Fault contain concentrations of mercury and other metals in excess of the B.C. Contaminated Site Regulation numeric standards. The localized nature of the mineralization was not representative of regional background concentrations. The risk assessment process indicated unacceptable risks to human health at these locations proximate to the mine site. Shallow soil covers over these areas were used for risk management in combination with signage to restrict future use (Photo 2).

- The presence of naturally elevated metals concentrations created challenges around confirmatory sampling. This was partly addressed by siting of the landfills over the worst areas of contamination.

- The abandoned mill equipment contained both asbestos and liquid mercury and required special measures for abatement and disposal. Some mercury contaminated materials required trucking across the country to a processing and disposal facility.

- Due to health and safety concerns, limited sampling of the soils below the mill equipment had been completed prior to remediation. The volume of liquid mercury and soils with leachable mercury was much higher than anticipated, significantly impacting both costs and schedule. Due to this change and other delays, an additional year was required to implement the remedial plan.
As discussed below, the desired end land use required designing landfill covers to support a future forest ecosystem. Aspects such as cover thickness were balanced against material availability, prevention of burrowing animals, and cost.

Photos 1 and 2: Site use (risk control) signage posted on a panel in the on-site kiosk (left). Risk control signage posted at the former cement shack where highly mineralized materials are present at surface (right).

REVEGETATION

The TLFN provided feedback on reclamation and revegetation objectives throughout the planning phases of the project, including at community workshops. The desired end land use is forested wildlife habitat and, importantly, the disturbance footprint will return over time to a forest ecosystem like the surrounding lands. The Conceptual Remediation Plan (SNC-Lavalin, 2014a) and detailed engineering accommodated this by designing the landfill morphology to fit into the surrounding landscape (Figure 2) and a capillary-break layer underlaying the ~1 m thick till cover to prevent burrowing animals or deep roots from penetrating the light-density polyethylene cover into the waste (CH2M Hill, 2015a).
Revegetation Planning

Selection of native tree, shrub, and herbaceous species for establishment at the mine site used an ecosystem-specific approach, with input from the TLFN. Selection considered dominant trees and shrub species observed proximate to the mine site, species identified for the Mossvale moist cool variant of the Suboreal Spruce zone (SBSmk1), and species known as traditionally valued by members of the TLFN. Tree species selected include lodgepole pine (\textit{Pinus contorta} var. \textit{latifolia}), subalpine fir (\textit{Abies lasiocarpa}) and hybrid white spruce (\textit{Picea engelmannii} \textit{x glauca}). The recommended stocking rate for tree and shrub seedlings at the mine site was 1,300 stems/ha and was based on a target stocking standard at free growing for preferred and acceptable species (TSSpa) for site series 02 of the SBSmk1 variant (1200 stem/ha; [BCMOF, 2000]) and a recommended stocking rate of 100 stems/ha for selected shrub species (CH2M Hill, 2015b, CH2M Hill, 2016 and SNC-Lavalin, 2017a).

In 2014, the collection of local seed was carried out with the support of TLFN members at locations in the general vicinity of the mine site, with propagation of the shrub species carried out by a commercial nursery. Tree seedlings were grown at the same commercial nursery and were originally scheduled for outplanting in Fall 2015 or Spring 2016. Due to construction delays and other complications, some of the shrub stock and tree seedlings had to be augmented to address the impacts of an additional growing season on seedling quality.
Summary of Revegetation Activities

Following construction activities in 2016, all disturbed (reclaimed) areas of the mine site (4.7 ha) were seeded with a cover crop of fall rye as an erosion control and soil building measure. In June 2017, a total of approximately 80 kg of upland seed mix (36 kg/ha) and 8 kg of lowland seed mix (4 kg/ha) were applied to the mine site. The custom upland and lowland seed mixes were developed for the mine site, as follows:

- **Upland Seed Mix** – 30% Coated Smooth Wild Rye, 30% Mountain Bromegrass, 20% Rocky Mountain Fescue, 12% Slender Wheatgrass, 6% Tall Fescue, 2% Alsike Clover.
- **Lowland Seed Mix** – 33% Tufted Hairgrass, 20% Ticklegrass, 20% Coated Common Blue Wild Rye, 14% Fowl Bluejoint, and 3% Alsike Clover.

The application of the lowland seed mix targeted drainage swales and low-lying and wet areas of the mine site. Except for drainage swales, all areas were fertilized following seeding using a slow release 20-12-16 NPK fertilizer (250 kg/ha).

Tree and shrub planting was carried out in June 2017. The tree planting prescription (CH2M Hill, 2015b, CH2M Hill, 2016 and SNC-Lavalin, 2017a) was based on three planting zones identified across the mine site: lodge pole pine leading, hybrid white spruce leading, and sub-alpine fir leading. Each zone was characterized based on aspect, drainage, and moisture. Leading species made up 70% of the trees planted in a given area. The two remaining subdominant tree species each made up 15% of the planted trees to protect against potential variation in site conditions and weather. To meet the stocking standards and provide a uniform spread of trees, approximately three metre spacing was implemented. Three shrub species were planted across the mine site including black gooseberry (*Ribes lacustre*), thimbleberry (*Rubus parviflorus*), and willow (*Salix* sp.) harvested locally prior to the planting.

Photo 3: Facing east from atop the main landfill, showing surface conditions at time of planting including placement of coarse woody debris and “rough and loose” surface preparation.
All shrubs, hybrid white spruce, and sub-alpine fir were planted alongside a 20 g fertilizer “teabag” (14-4-4 NPK). Microsites created by the coarse woody debris and the “rough and loose” surface preparation (Photo 3) were utilized during planting.

**POST-REMEDICATION RISK ASSESSMENT**

Risk assessment was iterative with site investigation, remediation planning and, to some extent, implementation. When questions and concerns arose, the risk assessors responded and sometimes needed to collect new data or information. The aquatic ecological risk assessment (Azimuth, 2013) was completed first, to address uncertainties that were identified in the earlier risk assessment. The human health risk assessment (SNC-Lavalin, 2017b) was completed after post-remediation data became available. During construction, ecological risk assessment assumptions were repeatedly revisited to compare them to post-remediation data.

Based on the risk assessment findings, monitoring requirements (detailed in the LTMM Plan [SNC-Lavalin, 2018a]) are being used to confirm some of the assumptions that underpin the risk assessment; examples include:

- On-site vegetation sampling to be carried out when edible plants have re-established at the mine site. Concentrations of mercury in plant tissues will be evaluated for potential human health and ecological risks. Favourable results would allow removal of related land use restrictions.
- Semi-annual off-site “biomonitoring”. Radial concentric sampling of vegetation (moss and needles, annual growth only) outside the remediated area analyzed for mercury concentrations as a surrogate for vapour emissions over time. Comparison against pre-remediation conditions will confirm if exposure to mercury vapours is stable or improving.
- Semi-annual fish tissue monitoring at Lakes (L4 and L5) to monitor effects of remediation. Mercury concentrations in fish in the vicinity of the site did not pose risks to human health; however, some of the TLFN community members have expressed concerns about impacts to fish.
- Annual on-site mercury vapour monitoring. Pre-remediation mercury vapour levels on-site did not pose human health risk; however, data may indicate effects of remediation.

**LONG TERM MONITORING AND MAINTENANCE**

The LTMM plan for the mine site is designed to ensure that risk controls remain effective and satisfy landfill permit and Mines Act requirements. Risk controls established at the mine site and associated monitoring activities are summarized in Table 2 (SNC-Lavalin, 2018a).

The monitoring activities are carried out semi-annually and reported annually. The project team will evaluate potential refinements to the LTMM plan (e.g., monitoring frequency and scope) based on future monitoring results.
### Table 2: Risk Controls and Monitoring Requirements

<table>
<thead>
<tr>
<th>Risk Control</th>
<th>Monitoring Activity</th>
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<tbody>
<tr>
<td><strong>Engineered Risk Controls</strong></td>
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</table>
| Landfill Covers                       | • Landfill gas monitoring  
• Surface and groundwater monitoring and sampling  
• Geotechnical inspection (erosion, slope failure) |
| Simple Soil Covers                    | • Geotechnical inspection (erosion, slope failure)                                   |
| Drainage network                      | • Geo-hydrotechnical inspection (erosion, failure, armouring, capacity)              |
| Former Seasonally West Area           | • Ensure groundwater not at ground surface                                          |
| **Vegetation Establishment**          |                                                                                     |
|                                       | • Annual inspection of vegetation re-growth and health satisfies performance targets  
• Photo point monitoring               |
| **Roadways**                          | • Confirm FSR is maintained, no vegetation encroachment                              |
| **Mine Openings**                     | • Geotechnical inspection of caps/soil covers (erosion, slope failure, undermining) |
| **Administrative Risk Controls**      |                                                                                     |
| Land Use Restriction Signage*         | • Ensure signage is present/legible  
• Inspect for adherence to land use restrictions (no camping, no digging, no groundwater use, no buildings, no harvesting plants, no off-road traffic) |
| Worker Health and Safety Plans        | • Ensure Health and Safety Program addresses potential exposure to contaminants for workers on-site (future excavations) |
| Map Reserve                           | • Check records to ensure map reserve remains in place so site is not disturbed       |

* The land use restrictions as well as information regarding site and project history are displayed in a timber kiosk on signage designed in collaboration with the TWG, partially fulfilling the TLFN’s objectives for site related educational information.

**LTMM - Vegetation Performance and Maintenance**

In Fall 2017, as part of the LTMM program, a total of 16 reclamation monitoring plots (3 m radius) were established to observe seed and seedling establishment and development. This included 12 plots selected at random in advance of the field visit within each of the different seeding and planting zones at the mine site. The remainder were installed in areas to ensure shrub clusters were captured, and also where notable decreased vegetative coverage was observed. Each plot was photographed in a standard direction for ease of comparison in the future. The vegetation performance metrics were chosen to satisfy the LTMM requirements and to evaluate compliance with the *Health, Safety, and Reclamation Code for Mines in British Columbia*. These included: plot total percent cover; and seedling (shrub and conifer) survivorship, height, and relative vigour (relying on colour, crown volume, needle size and density). Species composition and the presence of noxious or nuisance weeds were documented for each plot.
Early monitoring results indicate acceptable tree and shrub performance based on survivorship (>95%), relative vigour (<10% poor or medium vigour), and ground cover (19%) after one growing season and meets or exceeds the LTMM targets (SNC-Lavalin, 2018b) (Photo 4).

![Photo 4: Vegetation conditions on landfills in September 2017, after one season of growth.](image)

**CONCLUSIONS**

Remediation and reclamation of the Bralorne-Takla mine site presented a variety of challenges requiring innovative approaches.

- The continued engagement of the TLFN community is a critical component of the successful project. Key aspects included incorporating the TLFN objectives into the remedial design and involving TLFN personnel and resources throughout the investigation, remediation, and monitoring programs. This success was demonstrated when members of the TLFN hosted a closure ceremony and related potlatch. As part of the educational objectives, a video was prepared and is available on YouTube (https://www.youtube.com/watch?v=wveuqFlL1-e4).
- Human and ecological risk assessment was integral to assessing and managing risks related to site contamination. An iterative approach was used to address uncertainties and revise risk assessments using new data and information.
- The design and construction of landfill covers to accommodate re-growth of a forest ecosystem was a novel challenge.
- Posting educational information (about administrative controls) at the mine site to advise users of land use restrictions to minimize potential exposure to contaminants (including naturally occurring mineralized bedrock) was necessary to address the remedial objectives.
- Remedial construction faced several challenges, including the discovery of significant quantities of additional contaminated soil that required extending the construction schedule over two work
seasons. Risk assessment assumptions were revisited continually during the remediation program, and the remediation work was adjusted as needed to ensure that post-remediation conditions would satisfy risk-based requirements.

- Early vegetation performance monitoring results indicate that the re-vegetation efforts using native species selected for the mine site has largely been successful after one growing season.
- Site monitoring is currently underway in accordance with the LTMM plan developed for the mine site. The LTMM plan is designed to ensure that risk controls established for the mine site remain effective as well as to satisfy the landfill permit and *Mines Act* requirements.

REFERENCES


