

# DESIGN, CONSTRUCTION AND PERFORMANCE OF A PASSIVE WATER MANAGEMENT SYSTEM AT THE ABANDONED ATLIN RUFFNER MINE

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## ABSTRACT

Water management is an important component of mine closure and reclamation. Successful water management requires consideration of wide variety of factors including: climate, site accessibility, hydrogeology, geochemistry, and engineering feasibility. This case study focuses on the design, construction, performance, and initial monitoring results for a passive water management system at a remote abandoned mine site.

The primary design challenges included: cold climate, steep slopes, remoteness, slope stability, and a low potential for revegetation. An innovative design including an automatic siphon combined with an integrated geomembrane cover and interceptor trench system was designed and constructed to prevent clean water from contacting the tailings and becoming contaminated.

Post- remediation monitoring indicates that the passive system is functional and has reduced loading of metals to the shallow groundwater flow system. A total of 58,874 m<sup>3</sup> of water is collected and conveyed around the tailings on an annual basis. The contaminant plume downgradient of tailings pond has begun to shrink, and annual contaminant loads have been reduced by an estimated 11,562 kg of sulphate and 505 kg of zinc in addition to other metals. A long-term monitoring and maintenance plan that uses an automated data collection system has been developed to ensure that risk controls remain effective and satisfy the provincial and federal regulations.

**Keyword:** Abandoned mine, remote, cold climate, passive water management, low maintenance design

## SITE BACKGROUND AND OVERALL PROJECT OBJECTIVES

The Atlin Ruffner Mine is an abandoned mine site located in northern British Columbia (BC), approximately 28 km northeast of the community of Atlin and is accessible by road only via the Yukon on Atlin Road (Figure 1). Mining operations commenced in 1900 and continued intermittently until 1981. A total of 3,535 tonnes of ore were milled, with recovery of 138,493 kg lead, 13,540 kg zinc, 2,079 kg silver, 920 kg copper, 15 kg cadmium and 3.4 kg gold (MINFILE, 2010).

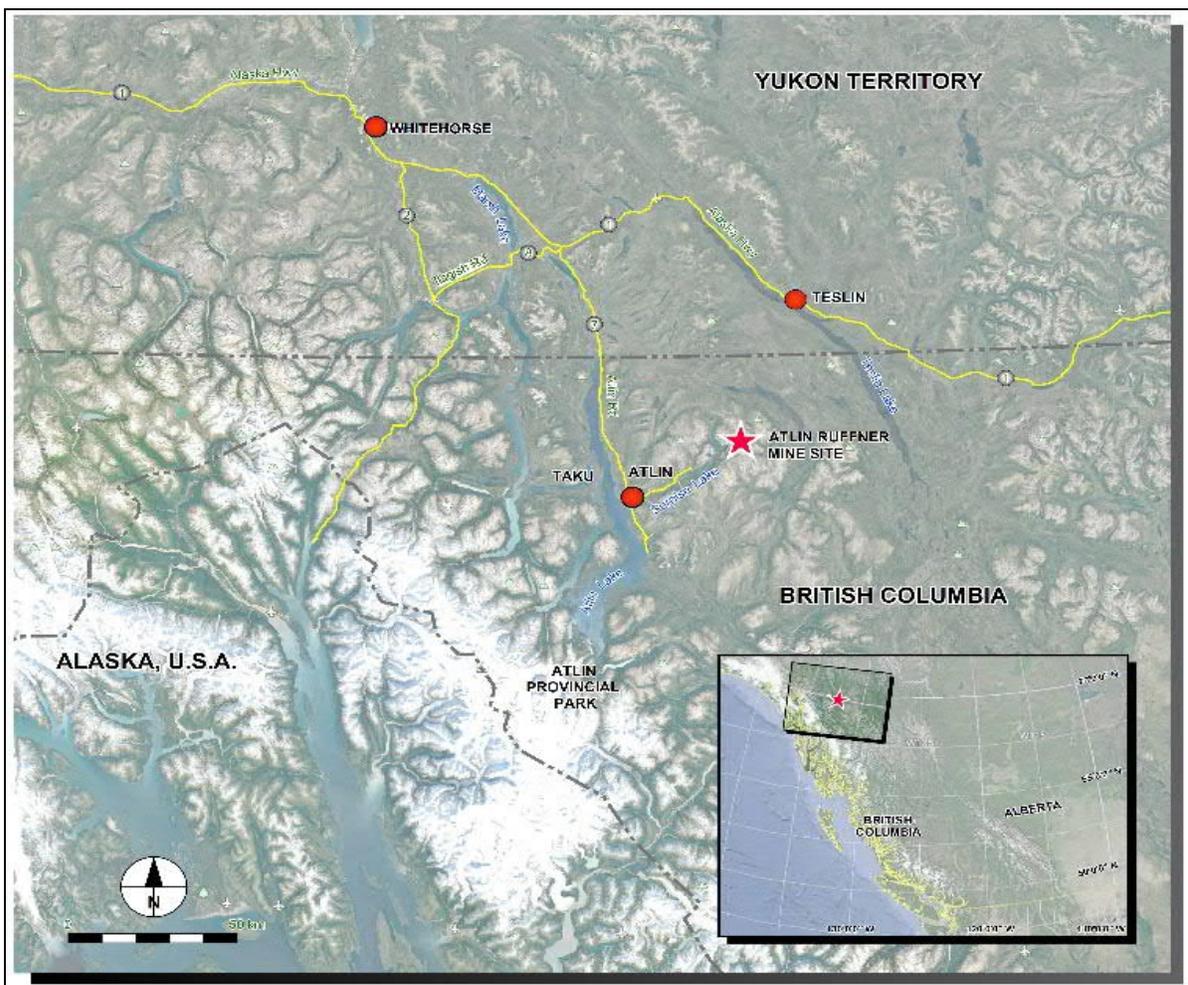


Figure 1. Site Location. The Mine site is located approximately 28 kilometers northeast of Town of Atlin, British Columbia (BC), Canada.

The mine consisted of an onsite mill facility, several underground mine adits, several small waste rock piles, a tailings pond, and one borehole that was purposefully drilled to provide a continuous supply of

groundwater to the mill to meet mineral processing needs (adit drainage). When the mine was abandoned, these groundwater flows continued to passively discharge from the adit, presenting a risk to the physical and chemical stability of the site.

### **Project objectives and guiding principles of remedial plan**

The Crown Contaminated Sites Program (CCSP) of the BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development leads the management of contaminated sites on provincial land to ensure the protection of human health and the environment. CCSP uses a science-based risk assessment to identify sites and prioritize them for remediation. The Atlin Ruffner Mill and Tailings Site was classified through the CCSP risk ranking process as a high priority site (Power 2009), and this designation led to the development of the Remedial Plan (AECOM, 2012). The purpose of the plan was to:

- Mitigate contaminant concentrations in open, high-significant, exposure pathways, and
- Reduce long term risk related to chemical contaminants at the abandoned mine site.

The guiding principles the CCSP provided for the Remedial Plan included the following:

- Provide a robust, long term, risk-based remedial solution that is cost-effective and achievable,
- Consider innovative approaches and potential alternative delivery methods to ensure project efficiencies and cost effectiveness, and
- Comply with the standards and guidelines defined in the B.C. *Environmental Management Act*, Contaminated Sites Regulation and Hazardous Waste Regulations (HWR) and the BC Ministry of Environment and Climate Change Strategy protocols on contaminated sites. The site qualifies for a Historical Hazardous Waste Contaminated Site Exemption under the HWR.

### **MONITORING, PLANNING, AND PHASE ONE REMEDIAL ACTIVITIES**

Remedial planning commenced in 2009 to support development of the remediation plan for the mill and tailings pond. Field investigations have included surface water monitoring, groundwater monitoring, surveying, soil sampling, geotechnical slope stability assessment, hazardous waste assessments, and volumetric assessments.

Phase One Remedial Works were completed in 2012 and included the demolition of the mill, removal or containment of onsite disposal of hazardous waste, and the installation of a 1 m thick capping layer over the accessible contaminated areas of the site including the mill facility, tailings pond, two sedimentation ponds, and access/connection roads. The cap was constructed using non-contaminated onsite material to physically isolate contaminated soils to mitigate risks to human health and the environment. A geotextile layer was used to visually demarcate the clean cap materials from the underlying visually similar contaminated materials.

## **WATER MANAGEMENT: PHASE TWO REMEDIAL WORKS DESIGN CONSIDERATIONS**

This case study focuses on the Phase Two Remedial Works, which had the objective of preventing interaction between contaminated materials (i.e. soil, waste rock, and tailings) and three sources of water found at the site (i.e. surface water, groundwater, and adit drainage). The overall approach was to avoid water treatment at this remote site off the electrical power grid by separation of clean water and contaminated materials to minimize contaminant loads to the environment.

### **Site constraints and challenges**

Drainage from the adit originates from a collapsed underground mine portal. Prior to Phase One Remedial Works, water flowed from the adit through both the Former Sedimentation Ponds prior to infiltrating to ground. After the Phase One Remedial Works, the water was directed into a drainage channel, and diverted around the site. Upon completion, it was determined that 20 to 50% of the adit flow was seasonally infiltrating to a shallow perched aquifer and the Former Tailings Pond, resulting in metal loading to the downstream portion of the perched aquifer and receiving environment.

The primary challenges that constrained the design were:

- Requirement for passive methods to manage surface water and groundwater,
- Freezing issues associated with low winter flows in cold climates,
- Possibility of rockfall and slope failure,
- Presence of high permeability soils resulting in rapid infiltration of surface water,
- Desire to minimize disturbance due to marginal potential for revegetation at this sensitive, cold, subalpine, north-facing, nutrient deficient site,
- Steep slopes upwards of 30% grade, and
- Desire for redundancy and a long-term objective to limit or eliminate the need for annual maintenance and inspection.

Monitoring data could not verify the minimum seasonal discharge from the adit because water level readings were affected by ice formation during a portion of the monitoring period. However, over-winter measurements indicated continuous above zero temperatures, suggesting continuous discharge throughout the winter.

A detailed and comprehensive Remedial Option Evaluation was undertaken. We used the evaluation to compare seven separate remedial options against CCSP's guiding principles for the site. Using the Remedial Options Evaluation, we selected the option involving diversion of clean water around the Former Tailings Pond (Remedial Option 2) and isolation of tailings from infiltrating water. Many of the other options were deemed not feasible for technical, operational, schedule, and financial reasons. The selection option included provisions for prevention/conveyance of water around the site, diversion of lateral groundwater

flows in the perched aquifer around the tailings, and isolation of tailings from infiltration using an engineered cover.

### **Design variants for adit drainage diversion**

The design of the Phase Two Remedial Works considered preventing drainage of groundwater from the adit by making attempts to install a hydraulic plug. The collapsed portal and limited information on the layout and stability of the historic mine workings was deemed a significant cost and safety risk. Further, there was high uncertainty with respect to achieving the desired outcome due to limited information being available on the configuration and stability of the underground workings. As a result, installation of a hydraulic plug was not pursued.

The second design variant considered construction of a lined open channel to divert discharge from the adit around the Former Tailings and Sedimentation Ponds. The design challenges included risk of obstruction from rockslides, treefall, freezing, and erosion of stream banks due to high flow velocities. Routing the channel through the site with sufficient depth and definition to mitigate the risk of icing was deemed undesirable due to the volume of contaminated materials which would require relocation. Locating the channel adjacent to the steep mountain slopes exposed it to risk of obstruction from rockslides.

The final design variant considered a buried pipeline control that would collect drainage from the adit and divert flows around the Former Tailings and Sedimentation Ponds. The design challenges included risk of pipe freezing and obstruction due to very low winter discharge and cold climate driven frost potential. Protecting the buried piping by means of insulation was not considered sufficient without additional mitigation for freezing. The depth of frost penetration was conservatively estimated to be up to 5.8 m assuming a 2,500 °C-day freezing index, 3% soil moisture, granular backfill material, and no snow cover on ground surface. The heat loss through the pipeline was determined based on the flow velocity and residence time. The adit drainage pipe would likely freeze during periods of low discharge during late winter. When an automatic siphon was combined with foam board insulation above the pipeline, the design was able to mitigate the potential for freezing using the siphon to accumulate discharge from the adit, and subsequently release the stored volume to the buried and insulated pipeline. Based on a review of the design variants, diversion of the adit drainage pipeline using an automatic siphon and a buried, insulated pipeline was determined to be the most cost effective and reliable option.

### **Automatic siphon and adit diversion pipeline**

Automatic siphons are not a new technology and have been in use for over 100 years. They continue to be used to flush livestock yards, dose trickling filters in sewage treatment plants, and to dose recirculating sand filters (Ball 1996). A dosing system provides for the periodic discharge of a determined volume of effluent. In the application for the Atlin Ruffner project, a passive system without the requirement for electrical power or mechanical parts facilitated the temporary storage of adit flows followed by the automatic discharge of the stored water less susceptible to freezing. Based on an assumed minimum flow rate of 0.2

L/s, the maximum cycle of the 660 L siphon chamber was once every 55 minutes. Based on the hydraulic properties of the section of the pipeline with the least grade, the flow capacity of the pipe was calculated to be 29.3 L/s in comparison to the 26.6 L/s maximum discharge of the siphon.

A minimum burial depth of 1.5 m was selected to situate the pipeline below the influence of extreme daily temperatures. A maximum burial depth of 2.5 m was selected for constructability reasons. Where possible, the slope of the pipe was matched to the slope of the existing ground surface.

The maximum potential velocities within the pipeline were calculated as 4.1 m/s in part due to the steep site grades. Energy dissipation and limiting of the flow rate were reviewed to limit the maximum pipe velocity. However, the low sediment load of the discharge reduced the risk of pipe scour and an increased wall thickness was selected to provide sacrificial material meanwhile providing freeze-thaw cycle resilience. A pipe anchoring system was implemented along the pipeline to maintain the physical integrity of the system.

### **Geomembrane cover system and interceptor trenches**

The adit diversion pipeline prevents infiltration of a significant volume of water to the perched aquifer, and the volume of groundwater reporting to the Former Tailings and Sedimentation Ponds is therefore reduced. However, infiltration due to precipitation and snowmelt upslope of the Former Tailings and Sedimentation Ponds provided a secondary source of water to the perched aquifer that required management using groundwater interceptor trenches. Further, infiltration of precipitation to the tailings required management using an engineered geomembrane cover.

A water balance was developed which incorporated groundwater inputs based on Darcy's Law and precipitation. The groundwater reporting to the interceptor trenches was anticipated to range from 0.2 to 5.3 L/s based on a water balance model sensitivity analysis that considered precipitation, hydraulic conductivity, and saturated thickness of the perched aquifer. The predicted range of flows was compared to seepage losses from the adit drainage and was in general agreement.

The interceptor trenches and geomembrane covers were designed as an integrated system. The interceptor trenches are located on the upgradient side of the Former Tailings and Sedimentation Ponds. The system consists of a low permeability near vertical bituminous geomembrane (BGM) liner on the downgradient walls combined with a perforated HDPE pipe at the base of the trench surrounded by high permeability drainage rock to collect and convey water downslope and away from the Former Tailings and Sedimentation Ponds. To increase the redundancy of the design, separate piping systems were included for each trench. The bituminous geomembrane liner on top of the Former Tailings and Sedimentation Ponds was designed to integrate with the interceptor trench liners to minimize ingress of groundwater, moisture and oxygen to the tailings. The Phase Two Remedial Works were constructed in 2017 and 2018. Photographs taken prior to Phase One Remedial Works and after Phase Two Remedial Works are shown below (Figure 2).



Figure 2. Site photo (left, 2010) taken prior to remedial activities showing mill building left and uncovered tailings pond right. Site photo (right, 2017) taken during remedial activities showing mill building demolished, site capped, and liner being installed on tailings and sedimentation ponds.

## **POST REMEDIATION RESULTS**

### **Groundwater flow**

Implementation of the Phase 2 Remedial Works isolated the tailings from surficial recharge and lateral groundwater flow. This resulted in desaturation of the tailings in the Former Tailings and Sedimentation Ponds, and reduced groundwater levels in select monitoring wells screened in the downgradient portion of the perched aquifer. Following implementation of the Phase 2 Remedial Works, all monitoring wells completed in the Former Tailings and Sedimentation Ponds (i.e., MW14-12-I2, MW14-15S, MW14-15D, and MW14-17) were dry (Figure 3).

Monitoring wells further downgradient and screened in the perched aquifer were dry for prolonged periods of time following completion of the Phase 2 Remedial Works. The response of groundwater levels to spring snowmelt and freshet was also dampened. Lateral groundwater flow velocities in the perched aquifer for July 2018 were estimated to be 478 m/yr, which represents a decrease of approximately 30% compared to 2017. Groundwater levels and the groundwater flow pattern in the deep unconsolidated aquifer was consistent with previous years, and it was unaffected by the Phase 2 Remedial Works.

### **Surface water flow**

Flow rates were highest at the adit drainage pipeline outlet (Figure 3) in 2018, with average flows of approximately 2.77 L/s over the summer months. Discharge occurred in pulses of up to 21 L/s every 4.5 minutes. Flow conveyed through the interceptor trench upgradient of the Former Sedimentation Ponds was negligible and ranged from 0 to 0.01 L/s. Flows conveyed through the interceptor trench upgradient of the Former Tailings Pond in July and September 2018 were 0.005 L/s and 0.02 L/s, respectively.

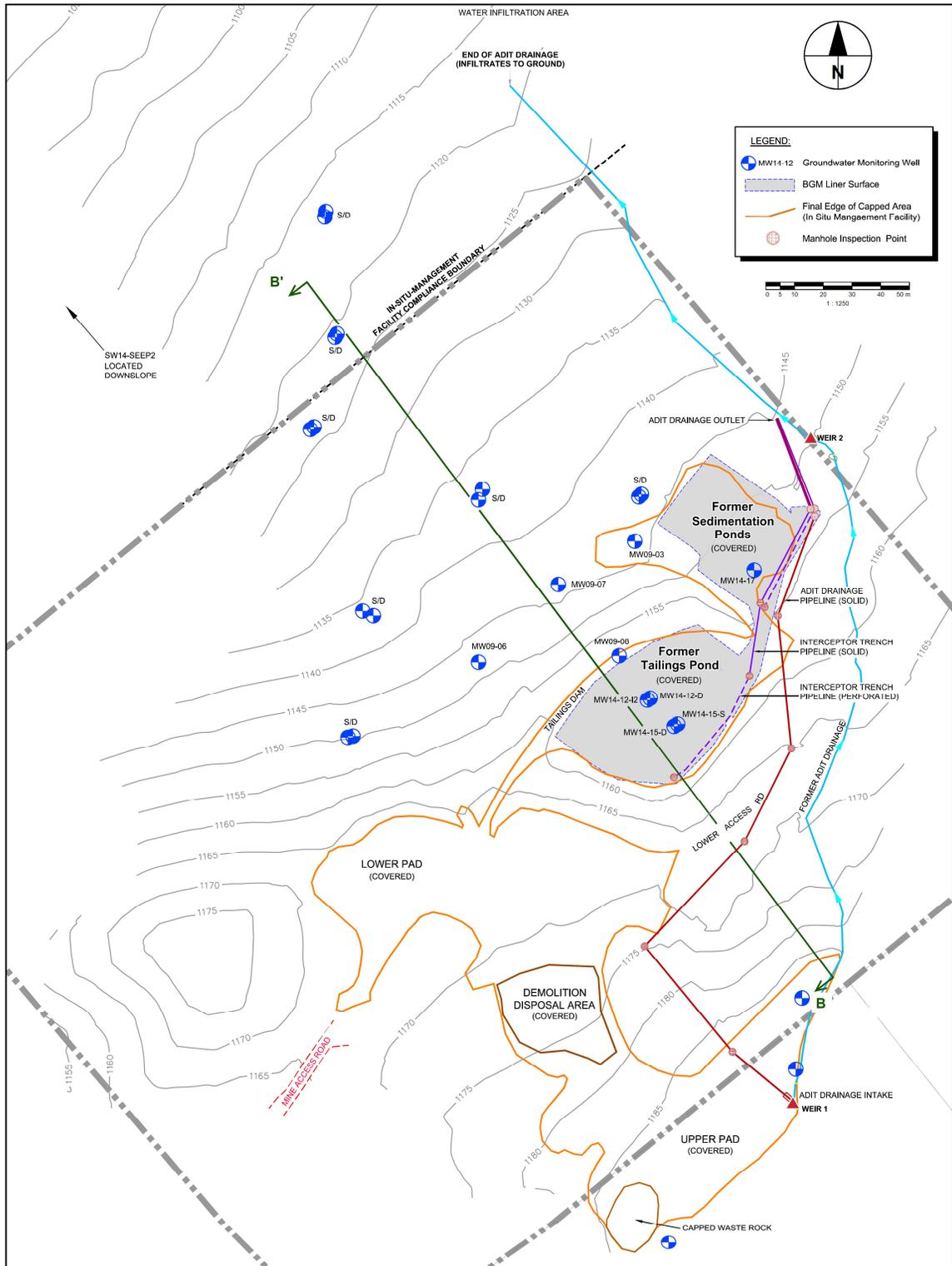


Figure 3. Groundwater and surface water monitoring locations. S/D refers to shallow/deep monitoring wells drilled on Site.

The adit drainage diversion pipeline collected and conveyed over 99% of the historical flows in the adit drainage. The interceptor trenches captured a small amount of residual seepage upslope of the Former Tailings and Sedimentation Ponds.

The siphon was observed to cycle at a rate of approximately once every 4.5 minutes during the summer months, for an estimated discharge of 187 m<sup>3</sup>/d. The total flow volume captured by the adit drainage diversion over the summer season (early April to late October) was estimated to be 39,780 m<sup>3</sup>. It was estimated that a further 19,094 m<sup>3</sup> of water was captured during the winter season. It is estimated that a total of 58,874 m<sup>3</sup> of water will be collected and conveyed around the Former Tailings and Sedimentation Ponds each year (Table 1).

Table 1. Estimated Flow Captured by Siphon

<b>Measured Flows Captured by Siphon</b>				
<b>Date</b>	<b>Number of Days</b>	<b>Volume Captured per Cycle (m<sup>3</sup>)</b>	<b>Cycle Numbers per Day</b>	<b>Total Volume Captured by Siphon (m<sup>3</sup>)</b>
Oct 6, 2017 - Nov 2, 2017	27	0.58	322	5,043
Jul 14, 2018 - Aug 11, 2018	28	0.58	322	5,229
Average Flow (m <sup>3</sup> /d)	187			
<b>Estimated Seasonal Flows Captured by Siphon</b>				
<b>Period</b>	<b>Number of Days</b>	<b>Estimated Total Volume Captured by Siphon (m<sup>3</sup>)</b>		
April to October (Summer)	213	39,780		
November to March (Winter)	152	19,094*		

\* Winter Flow Estimated Based on Historical Measurements Using V-Notch Weir and Pressure Transducers (Winter Flow = Summer Flow ×48%)

### **Groundwater quality**

Following implementation of the Phase 2 Remedial Works, the extent of the ARD/ML plume in the perched aquifer downgradient of Former Tailings and Sedimentation Ponds stabilized and reduced in extents at the downgradient boundary. The deep aquifer remains unimpacted by the overlying ARD/ML plume. Concentrations at the time of sampling in 2018 were generally lower than those measured in 2016 and 2017, which may reflect improvements due to implementation of the Phase 2 Remedial Works.

**Tailings Area:** Prior to the Phase Two Remedial Works, the quality of emergent groundwater near the Former Tailings Pond was mildly influenced by ARD/ML as it travelled across the top of the tailings. Water quality historically degraded as it migrated vertically downward through both the oxidized and unoxidized tailings, with increased hardness, conductivity, sulphate, and dissolved metal concentrations. After completion of the Phase 2 Remedial Works in 2018, all monitoring wells completed in the Former Tailings and Sedimentation Ponds became dry, indicating the adit drainage diversion pipeline, interceptor trenches and bituminous geomembrane cover on the Former Tailings Pond and Sedimentation Ponds are functioning as intended.

Sulphide oxidation in the Former Tailings and Sedimentation Ponds was historically strongly affected by wetting and drying cycles, with seasonal loadings of sulphide to groundwater driven by snowmelt and downward infiltration of ARD/ML products to the underlying perched aquifer. These cyclic effects have not been observed since the Phase 2 Remedial Works were completed.

**Downgradient Perched Aquifer:** Groundwater quality has been affected by ARD/ML processes at monitoring well MW09-08, located approximately five metres downgradient of the Former Tailings Pond since August 2012. Groundwater quality at this location continued to exhibit the highest concentrations of ARD/ML indicator parameters of any well at the site, indicating that the tailings are the primary cause of impacts to groundwater quality in the perched aquifer. Groundwater quality at this location has improved slightly following completion of the Phase 2 Remedial Works, with the lower conductivity, fluoride, aluminum, cadmium, manganese and zinc concentrations.

Monitoring wells completed in the perched aquifer downgradient of the Former Tailings Pond continued to be impacted by the ARD/ML plume. At the southern extent of the plume, groundwater quality in monitoring well MW09-06 remained relatively stable. Along the northwestern extent of the plume, groundwater quality exhibited decreasing trends in fluoride, cadmium and zinc, indicating slightly improved groundwater quality. Arsenic concentrations in the perched aquifer remained low and generally close to detection limits. The inconsistency between concentrations of arsenic and other ARD/ML parameters indicates that arsenic may be involved in secondary redox reactions (i.e., adsorption). Concentrations of arsenic are very low in groundwater monitoring wells that are impacted by the ARD/ML plume. Based on measured discharge from the adit drainage diversion pipeline and the interceptor trenches, the Phase 2 Remedial Works are anticipated to prevent an estimated total of 11,562 kg of sulphate and 505 kg of zinc from entering the perched aquifer each year.

**Deep Unconsolidated Aquifer:** Monitoring wells completed in the deep aquifer met applicable water quality standards in 2018 for all ARD/ML plume indicator parameters. Most of the parameters associated with ARD/ML remained at or near detection limits except for arsenic. Arsenic is found in several surface water bodies upgradient of the Site, and in groundwater emanating from the underground mine workings. Arsenic is therefore considered to be naturally elevated due to proximity to mineralized bedrock and the historic sulphidic ore body.

### **Surface water quality**

**Adit Drainage Diversion:** Background surface water quality in the upstream adit drainage is very similar to that observed for the past several years and is not impacted by mining waste. Samples collected from the upstream and downstream extremities of the adit drainage diversion pipeline and interceptor trench generally met applicable surface water quality guidelines. Exceedances for total arsenic concentrations at upstream and downstream adit drainage diversion pipeline are consistent with historical results and are considered to reflect the elevated background concentrations associated with the ore deposit. Water quality in samples from the outlet of the interceptor trenches generally met applicable surface water quality guidelines, indicating good separation between clean groundwater and tailings was achieved.

**Receiving Environment:** The point of discharge to the receiving environment (SW14-SEEP2) is located approximately 400 m down slope of the Former Tailings Pond. Water quality was generally compliant with applicable groundwater standards and surface water quality guidelines for ARD/ML parameters prior to discharge to the marsh but exhibited concentrations of arsenic consistent with background levels.

A wetland is located approximately 700 m down slope of the Former Tailings Pond. Water quality was consistent with historical concentrations and continued to meet applicable surface water quality guidelines, with the exception of arsenic. The concentrations of all ARD/ML related constituents including arsenic, cadmium, copper, uranium and zinc have remained relatively stable since September 2016. Elevated concentrations of arsenic are not indicative of impacts from the ARD/ML plume downgradient of the Former Tailings Pond, but more likely reflects water quality impacts from the mineralized bedrock in the region and the nearby ore body.

### **CONCLUSIONS**

The case study presented was selected due to its combination of unique design challenges related to design and implementation of water management solutions at remote, abandoned mine sites in cold climates that are not connected to an electrical power distribution grid. The combination of an automatic siphon designed to manage surface water, and an integrated interceptor trench and bituminous geomembrane liner system to manage groundwater have been demonstrated to meet the remedial objectives outlined in the Remedial Plan. The simple, passive, low maintenance solution has been shown to be effective and reliable over the first two years of operation. Engineered redundancy and ongoing automated monitoring of water levels, water quality and site use will improve confidence in system performance and may allow for reduced inspections in the future.

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