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Reclamation and remediation of the Tom Property, Macmillan Pass, Canada

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Abstract

The Tom Property, owned by Hudson Bay Exploration and Development Company Limited, a subsidiary of Hudson Bay Mining and Smelting Co. Limited (HBMS), is located in the Macmillan Pass area, near the Yukon-Northwest Territories border, about 400 km northeast of Whitehorse, Yukon, Canada. The property was discovered in 1951 and between 1951 and 1991 various exploration campaigns were carried out on the property, including extensive diamond drilling from surface and underground. Underground development on the property was done via an adit located at elevation 1,440 masl. Approximately 52,000 m^3 of waste rock and ore from the underground development was stockpiled on the slopes adjacent to the adit. In the early 1980s, the underground workings were extended to explore the West Zone via a decline which encountered significant inflows of water eventually forcing the decline excavation to be shut down in 1982.

Between 1992 and 1994 the property was closed and decommissioned. The adit was closed with granular fill and drainage pipes were installed to permit the water from the underground workings to drain out to surface. In the spring of 1999, a routine inspection by government inspectors found that the portal backfill had been breached by a torrent of water from the adit. It was hypothesised that the drainage pipes through the backfill in the portal had frozen and the hydraulic head developed behind the frozen face eventually overcame the resistance of the backfill and washed out. The mine water discharge had degraded since decommissioning and did not meet regulatory standards as it was acidic and contained elevated concentrations of metals.

To mitigate the environmental impacts associated with this situation, HBMS embarked on a multi-faceted programme of surface and underground reclamation between 2006 and 2010. This paper will describe the various components of the reclamation programme, which included the following major activities: baseline environmental studies, project alternatives assessment, environmental assessment and permitting, covering the waste rock with a high density polyethylene (HDPE) liner to reduce infiltration of runoff and precipitation, relocation of the ore stockpile into a lined disposal area, construction of a concrete water retention plug within the underground workings to flood the exposed rock surfaces and reduce acid rock drainage and metal leaching, and adaptive management plan and monitoring.

1 Introduction

The Tom Property is located in the Macmillan Pass area, near the Yukon-Northwest Territories border. The property was discovered in 1951 and between 1970 and 1982 3,523 m of underground development were done via an adit located at 1,440 masl (Abermin Corporation, 1986). Approximately 52,000 m^3 of waste rock and ore from the underground development was stockpiled on the slopes adjacent to the adit. The underground workings were extended to explore the West Zone via the decline to the 1,300 m level which encountered significant inflows of water eventually forcing the decline excavation to be shut down in 1982 (Gartner Lee Ltd, 2008). The portals were closed in between 1992 and 1994 with granular fill and drainage pipes were installed to permit the water from the underground workings to drain out to surface.

In the spring of 1999, a routine inspection by government inspectors found that the adit backfill had been breached by a torrent of water from the adit. It was hypothesised that the drainage pipes through the backfill

in the adit had frozen and the hydraulic head developed behind the frozen face eventually overcame the resistance of the backfill and washed out. The adit discharge had degraded since decommissioning and did not meet regulatory standards as it was acidic and contained elevated concentrations of metals.

To mitigate the environmental impacts associated with this situation, Hudson Bay Mining and Smelting Co. Limited (HBMS) embarked on a multi-faceted programme of surface and underground reclamation between 2006 and 2010, which included the collection of baseline environmental data, project alternative assessment, development of a reclamation plan to plug the Tom adit for the purposes of flooding the underground workings in efforts to reduce acid rock drainage and metal leaching, and improve water quality of the discharge from the adit. Further work included permitting of the reclamation plan, construction of the adit plug and associated workings, and monitoring of the site to assess the performance of the reclamation plan.

1.1 Project setting and background information

The Tom Property consists of a sedimentary-exhalative style lead-zinc deposit located in the Macmillan Pass area of Yukon Territory, near the border with the Northwest Territories. The estimated mineral resource (NI 43–101 compliant) for the Tom deposit is 4.98 million indicated tonnes of 6.6 % zinc, 4.4 % lead and 47.8 g/t silver, and 13.55 million inferred tonnes of 6.7% zinc, 3.1% lead and 31.8 g/t silver (HudBay, 2009). The site is located in the remote Selwyn Mountains and accessed seasonally via the North Canol Road typically open from mid to late June to late September. The Tom deposit is located at the northeast end of the North Canol Road, approximately 175 km northeast of Ross River.

As follow-up to the inspection by government inspectors in 1999, a site clean-up was conducted, signage was posted and a stainless steel barricade installed across the adit preventing access to the underground in 2000. Water Licence QZ99-046 for the site was issued on 17 December 2002 by the Yukon Territory Water Board and became effective 1 January 2003. The amended Water Licence, QZ09-087, requires that HBMS continue its monitoring programme as outlined in the Water Licence & Tom Valley Final Adaptive Management Plan (AMP), and submit a Final Closure Plan prior to 30 June 2013. Since the issuance of Water Licence QZ99-046, HBMS has conducted ten years of studies for the purposes of characterising anthropogenic and natural metal loading observed in the Upper South Macmillan River area (Figure 1). Water quality of the adit discharge frequently exceeds the Effluent Quality Standards (EQS) specified in the site's water licence, which are scheduled to come into effect on 30 September 2012 (Table 1) (Yukon Water Board, 2009). However, natural background conditions also frequently exceed EQS and this natural metal loading contributes the majority of zinc to the receiving environment, the South Macmillan River. Naturally elevated metals in the area have been well documented in studies completed in the past 20 years. Investigations and studies show the adit's contribution to metal loading at downstream locations with known fisheries presence is insignificant. In spite of this, discussions with various regulators and agencies suggested that the status quo of the adit discharge was not acceptable; therefore a remediation plan was developed.

Table 1 Effluent quality standards that come into effect 1 October 2012

Parameter	Concentration
Dissolved arsenic	1.0 mg/L
Total copper	1.4 mg/L
Total lead	0.4 mg/L
Total nickel	2.1 mg/L
Total zinc	12.6 mg/L

A remediation plan was developed following the identification of the preferred remediation option through the project alternative assessment. The remediation plan included the construction of an adit plug, bypass raise, sludge containment pond, waste rock cover and lined discharge channel. The remediation plan addresses specifically water and facilities that require active management to ensure that adequate environmental protection is provided in the short term (i.e. to 2013). A management strategy is therefore required to monitor the success of the remediation plan and if there is a potential degradation of conditions to

the point where active intervention might be necessary prior to the end of 2013. The AMP provided a framework and strategy for ensuring that appropriate management actions are implemented.

HBMS has adopted an AMP approach for ensuring the effectiveness of the installation of the adit plug and associated workings. Adaptive management begins by using predictive modelling based on present knowledge to inform management decisions. As new information is obtained through monitoring, the models will be updated and further actions will be proposed in response to the results obtained through the monitoring programme. Actions can then be implemented accordingly. Continued monitoring, as required in the existing Water Licence, with additional sampling noted in the Tom Final AMP (AECOM Canada Ltd. et al., 2010), is expected to be sufficient to determine whether the remediation plan is achieving its objective of improving adit and downstream receiving water quality, or if further corrective action is required.

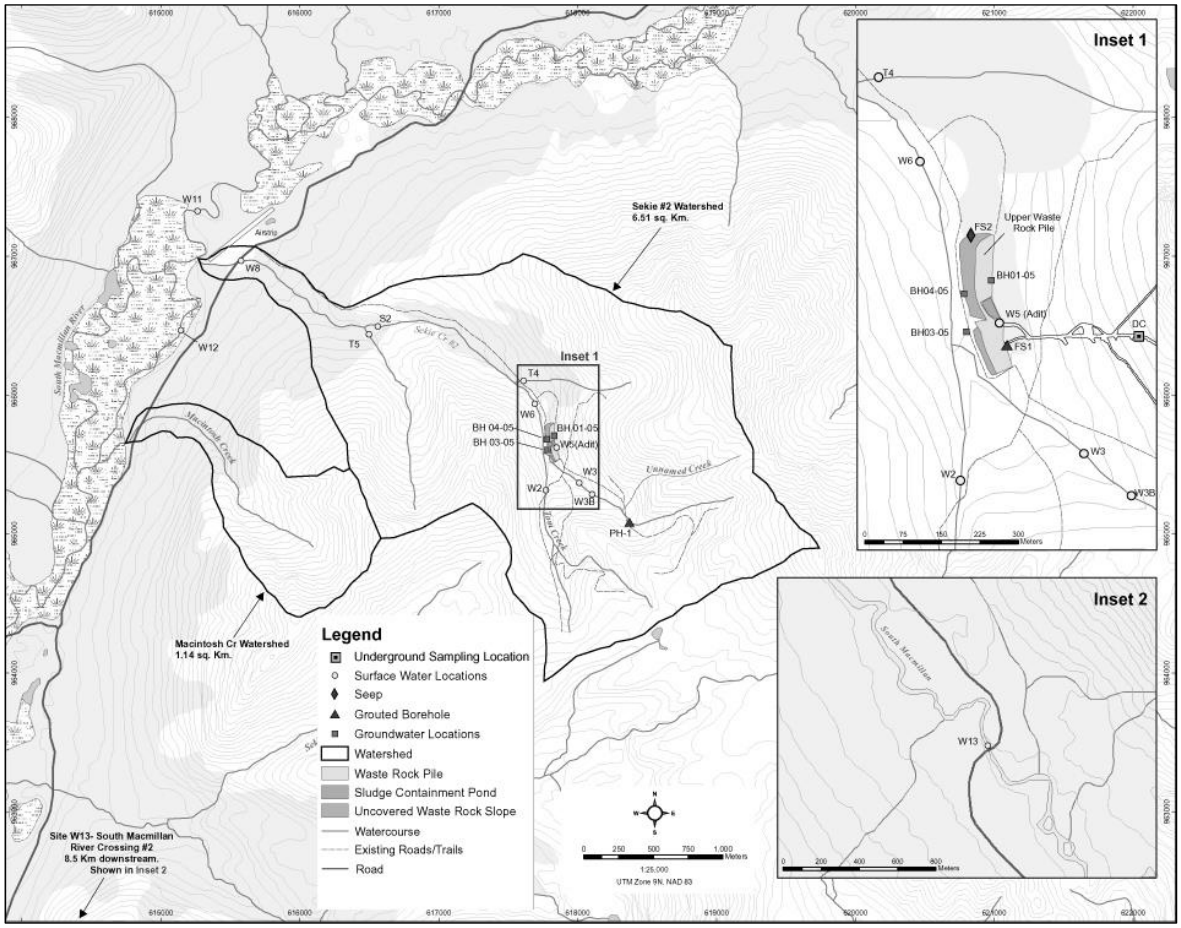

Figure 1 Tom Property monitoring locations

2 Project alternative assessment

Work was carried out in 2006 and 2007 to investigate various alternatives for mitigating the anthropogenic loadings from the Tom adit. The project alternative assessment evaluated five (5) remedial options to address the discharge from the Tom adit: high density sludge treatment, open limestone channels, caustic dosing tanks, hydraulic plug of the adit with lined discharge channel, and lined discharge channel.

These five alternatives were evaluated qualitatively based on effectiveness, implementation, environmental and socio-economic impacts. Based on this assessment, the preferred option for mitigating the discharge was these five alternatives were evaluated qualitatively based on effectiveness, implementation, environmental and socio-economic impacts. Based on this assessment, the preferred option for mitigating the discharge was the adit plug with the lined discharge channel. The preliminary design for this option assumed a plug length of 10 m would be required, at a point approximately 90 m from the portal. This design was based on the requirement to provide sufficient head to flood the mine workings, approximately 20 m. To protect against

the potential for hydraulic fracturing, this option includes a pressure relief system to limit the head of water behind the plug. This will be achieved by advancing an inclined raise to an elevation approximately 25 m above the existing adit floor. Once the workings are flooded and the water level reaches the drift exit, water will discharge out the raise to Sekie Creek #2 via a lined discharge channel. It is estimated that over time the water quality of the drainage water will be within the range of the naturally elevated background levels found in the area draining the rich pyrite shales of the Tom Sequence (Gartner Lee Ltd, 2007).

A summary of the alternatives assessment for the Tom adit mitigation is presented in Table 2 (Gartner Lee Ltd, 2007). Based on this qualitative assessment, taking into consideration equal weighting of the four criteria, the option that ranked the highest was the adit plug. The caustic dosing tank and the lined channel were next in the ranking. Given the potential regulatory issues associated with the lined channel and the possible perception of a "walk away / do nothing" option; it was felt this was not a viable option to carry forward. With respect to the caustic dosing tank, this technology is relatively unproven in the harsh winter conditions experienced at the site. This coupled with the issue of sludge generation and disposal resulted in this option also being dropped. The other two options ranked well below the adit plug and are considered not appropriate for the site. Therefore the preferred mitigation option was the adit plug with a lined discharge channel (Gartner Lee Ltd, 2007).

Table 2 Summary of alternative assessment for Tom adit mitigation

Criteria	HDS Treatment	Open Limestone Drain	Caustic Dosing Tank	Adit Plug	Lined Channel
Effectiveness	5	1	5	3	1
Implementation	1	2	2	4	5
Environmental impact	2	1	3	5	2
Socio-economic impact	3	4	3	5	5
Overall ranking	11	8	13	17	13

3 Environmental assessment and permitting

HBMS was issued Yukon Water Licence QZ99-46 on 17 December 2002 and it became effective on 1 January 2003 authorising HBMS to deposit waste in the form of discharge water from the Tom adit to Sekie Creek #2. HBMS completed several environmental studies (hydrology, surface and groundwater quality, fish quantity and habitat, and benthic invertebrate sampling) from 2003 to 2006 to support the project alternative assessment to identify a reclamation plan.

HBMS submitted a Project Proposal (Gartner Lee, 2008) that included an environmental assessment to the Yukon Environmental and Socio-economic Assessment Board (YESAB) on 2 February 2008 to install an adit plug and associated workings at the Tom property. HBMS received the decision document on 26 January 2009 from the Yukon Government to proceed with the Project Proposal to install the adit plug and associated workings. HBMS then submitted an amendment application to the Yukon Water Board for the installation of the adit plug and associated workings that included mitigations as outlined in the Decision Document. The current Water Licence, QZ09-087, expires on 31 December 2013. The Effluent Quality Standards are outlined in Table 1 and come into effect after 30 September 2012 for a grab sample of any waste discharge at station W5 (less than 10 m from adit portal).

4 Reclamation plan

The reclamation plan as outlined in the Project Proposal included the following reclamation activities: installation of an adit plug, construction of a bypass raise including shotcreting the downstream raise, construction of a temporary sludge containment pond, installation of a waste rock cover on the top of the waste rock pile and sludge pond, installation of a lined discharge channel, and grout artesian boreholes PH1 and FS1.

The construction of the adit plug was initially estimated to be completed in a 12 week period in 2009, but due to the delay in the opening of the North Canol Road in 2009 and the limited seasonal access to the site the construction was completed in 18 weeks and finished in September 2010. The adit plug construction was completed on 28 August 2010. Between 28 August and 13 September 2010 water flooded the underground workings with discharge resuming from the adit at approximately 1300 hrs on 13 September 2010. The adit discharge is now isolated from the waste rock dump and flows through a high density polyethylene (HDPE) lined channel. An impermeable cover consisting of HDPE liner and a 0.5 m of local material was installed over the top of the north and south waste rock dumps. The objective of the cover is to reduce the infiltration of surface runoff and precipitation into the waste rock dump, reducing potential non-point source metal loadings into the Sekie Creek #2 drainage. The construction of a sludge pond was initiated in July 2009 when it was dug out and lined with a 60 mm HDPE liner. The sludge pond was filled with ~1,000 m^3 of iron hydroxide sludge that was removed from the adit floor on 7 August 2009 and was left over winter to freeze dry.

In the summer of 2009, the location of the high grade ore pile was confirmed at the toe of the south waste rock dump. Upon confirmation of the location of the ore pile, a strategy to relocate it was determined to enhance the reclamation plan and address the material that poses the greatest ARD and metal leaching potential in the waste rock dump. It was decided the ore would be relocated into the sludge pond and at the top of the south waste rock pile. In July 2010 the sludge pond was dewatered to facilitate the relocation of the ore. The sludge pond was then filled to the top with approximately 1,000 m^3 of ore and then covered with a geotextile membrane. The remaining 600 m^3 of Tom ore was relocated to the top of the south waste rock dump. In September 2010, the sludge pond and the top of the south waste rock dump were covered with an HPDE liner and a protective layer composed of a 0.5 m of local talus material. Additionally, as part of the commitments made during the YESAB and Water Board processes, artesian boreholes FS1 and PH1 were grouted shut on 12 August 2010 and are no longer flowing, but will continue to be monitored for presence of seepage as outlined in the site's AMP.

4.1 Adit tunnel plug

4.1.1 Design

Between 2006 and 2008, investigations and design studies were undertaken for a tunnel plug to mitigate the adit discharge water quality. As a result, the following design considerations were identified:

- To avoid having to construct multiple plugs to seal each branch of the underground workings, the plug location had to be in the main drift, downstream of the three branches of the underground workings and upstream of the junction between the two portal drifts (Figure 2).
- The favoured location for the plug based on geometric considerations was downstream of a service bay excavated into the south sidewall (Figure 2). At this location, the drift had a section that tapered slightly in a downstream direction, providing a favourable "cork" effect for the plug.
- Subsequent inspection of the above location indicated that it also had favourable rock mass quality requiring minimal preparation for constructing a plug.
- Design guidelines prepared by the United Kingdom Health and Safety Executive (UKHSE, 2005) were used to size the dimensions of the plug. A mass concrete plug design was selected to simplify design and ensure a conservative length to resist the expected hydraulic head and seepage gradients. The length of the plug was based on the criterion of twice the dimensions of the tunnel opening. Since the average dimension of the drift at the proposed location was about 4.5 x 4.5.m, a plug length of 9 m was required (compared to the 10 m long preliminary design estimate). A concrete strength of 30 MPa at 28 days was specified.
- The minimum thickness of rock cover over the plug was estimated to be less than 30 m. Therefore the maximum hydraulic head behind the plug was limited to 20 m above top of plug level to prevent hydraulic jacking. A minimum head of 10 m was required to flood the remaining exposed underground workings.

- A bypass raise was provided to limit the head to a maximum of 20 m. The 2 m by 2 m raise was excavated into the south side of the main drift in the form of an inverted "V" (Figure 3). The upstream portion of the bypass raise was located at a vertical angle of 45° from the end of the service bay and was aligned parallel to the main drift. The downstream portion of the bypass raise was oriented at a vertical angle of 45o from a point about 15 m downstream of the plug, and aligned to intersect the upstream raise at a point 20 m above the top of the plug.
- Based on water pressure tests carried out in the sidewalls of the main drift at the plug location, the estimated hydraulic conductivity of the rock mass averaged 3.5–5.5 x 10–5 cm/s. The fractures were estimated to be relatively tight and contained no fillings that could wash out. The hydraulic conductivity values suggested a rock mass that was close to the limit of groutability using cement based grouts. Given these conditions, the potential fractured nature of the rock elsewhere around the flooded workings and the potential presence of numerous unsealed exploration boreholes; it was considered that an extensive radial grout curtain around the plug would not be effective in reducing seepage quantities through the rock mass. Instead, a programme of bedrock grouting was carried out to seal the potential higher seepage gradient bedrock-concrete interface zone around the plug to a radial depth of 2 m.

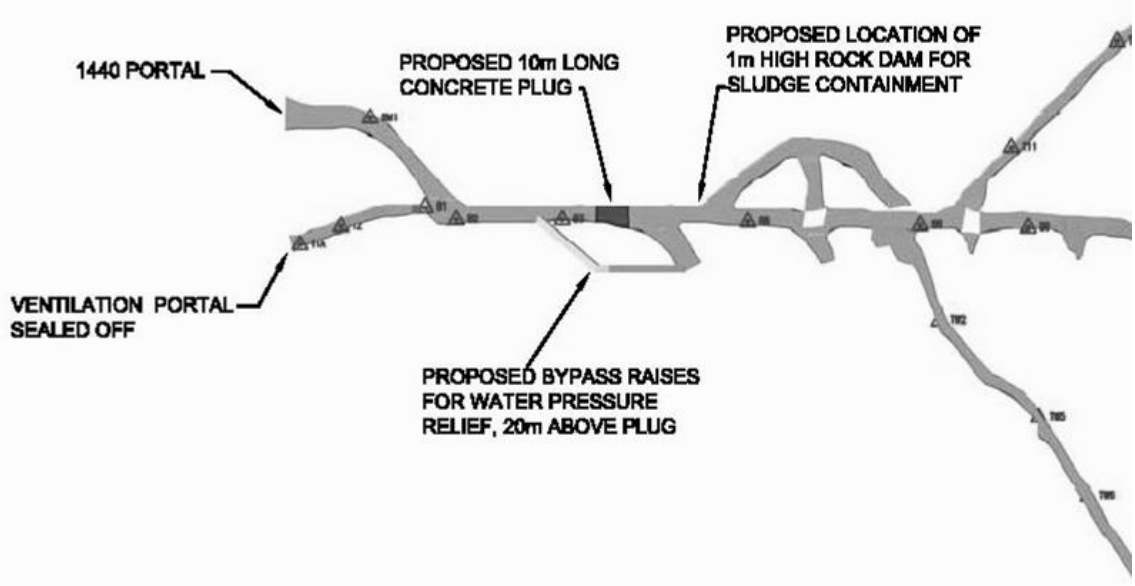

Figure 2 Tom Mine – plan view of underground workings and plug location

4.1.2 Plug construction

Plug construction was carried out over two construction seasons in 2009 and 2010. In 2009, most of the underground work involved establishing access into the main drift and starting the driving of the upstream and downstream segments of the bypass raise using jack-leg drills. The floor of the tunnel was covered by up to 1 m of colloidal iron hydroxide sludge, which was removed and placed into a HDPE lined sludge pond located in the north waste rock pile in front of the adit. Concrete aggregate was hauled 175 km to the Tom Property from a Yukon Department of Highways gravel pit and stockpiled on site.

In 2010, after excavation of the bypass raise was completed, preparations commenced for the construction of the plug. A small rock fill cofferdam was constructed upstream of the plug and a 200 mm diameter pipe was used to convey the adit seepage through the plug area. The perimeter of the tunnel within the limits of the plug was scaled and washed to remove loosened and decomposed rock. Heavy timber formwork for the plug concrete pour was erected and the interfaces with the rock surface sealed with shotcrete.

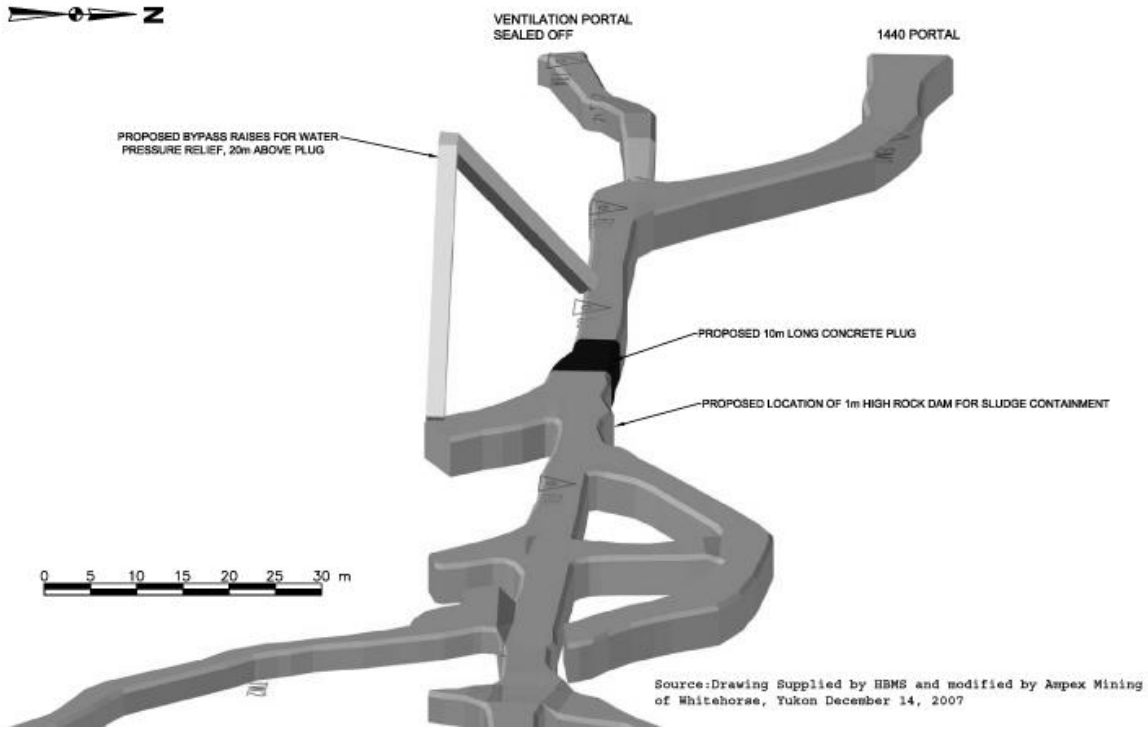

Figure 3 Tom Mine – 3D view of underground workings and plug location

The plug pour of about 190 to 200 m^3 was completed over a 10 hour period. Pre-mixed cement in 1 tonne bags were mixed on site with aggregate and other additives in a volumetric truck. Concrete cylinder samples were collected for strength testing every 50 m^3. Void grouting was carried out 10 days later, using left over bulk concrete mix pumped through the pipes installed into the high points in the crown. A total of 2 m^3 of additional concrete was placed under a pressure of 70 psi (483 kPa). Bedrock and contact grouting was carried out around the plug using microfine cement. Approximately 45 kg of grout was injected into the concrete-bedrock interface around the plug and 568 kg of grout was injected into the bedrock to seal the 2 m wide annulus of rock around the plug. The plug was commissioned 29 days after the pour was completed as water rose behind the plug. Upon completion of the grouting and plug commissioning, the bypass pipe through the plug was closed and sealed with grout backfill. Spill over the bypass raise occurred 16 days later when the water level reached 24 m above the adit floor. The hydrostatic pressure (water level) behind the plug is constantly being monitored by a vibrating wire piezometer connected to a data logger (Figure 4). To date, geotechnical performance of the adit plug has been deemed satisfactory.

4.2 Waste rock cover

For the purposes of reducing acid rock drainage and metal leaching within the waste rock dump, the top of the waste rock dump was covered with a 60 mm HDPE liner and a minimum thickness of 0.5 m protective barrier layer consisting of local talus material to minimise the infiltration of surface water into the dump and minimise erosion of the waste rock dump surface (Figure 5). The surface of the top of the waste rock dump was smoothed and compacted to remove sharp rocks before the HDPE liner was installed. The slopes of the waste rock dump were not covered as they were too steep and could not be recontoured due to the limited area adjacent to the adit and the concerns identified to not increase the project footprint. Three groundwater monitoring wells shown on Figure 1 will be monitored to evaluate the effectiveness of the waste rock cover.

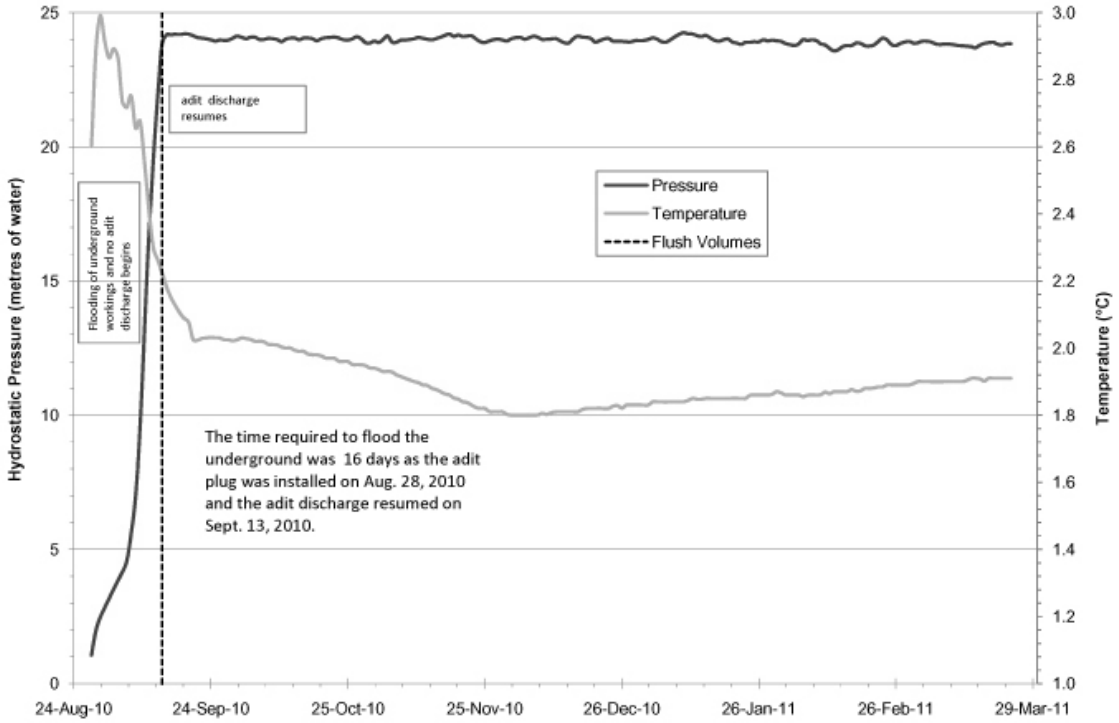

Figure 4 Hydrostatic pressure and water temperature behind the Tom adit plug

4.3 Lined discharge channel

A temporary lined discharge was installed in 2009 and was completed in early September 2010 when the underground workings where flooding and no discharge was present. The lined discharge channel as shown on Figure 5 begins at the bottom of downstream bypass raise and ends at the base of the waste rock dump. The lined discharge channel consists of a base geotextile layer with the 60 mm HDPE liner over top. The section of the lined discharge channel from the adit entrance to the crest of the top of the waste rock dump has been covered by a minimum thickness of 0.5 m of local talus material.

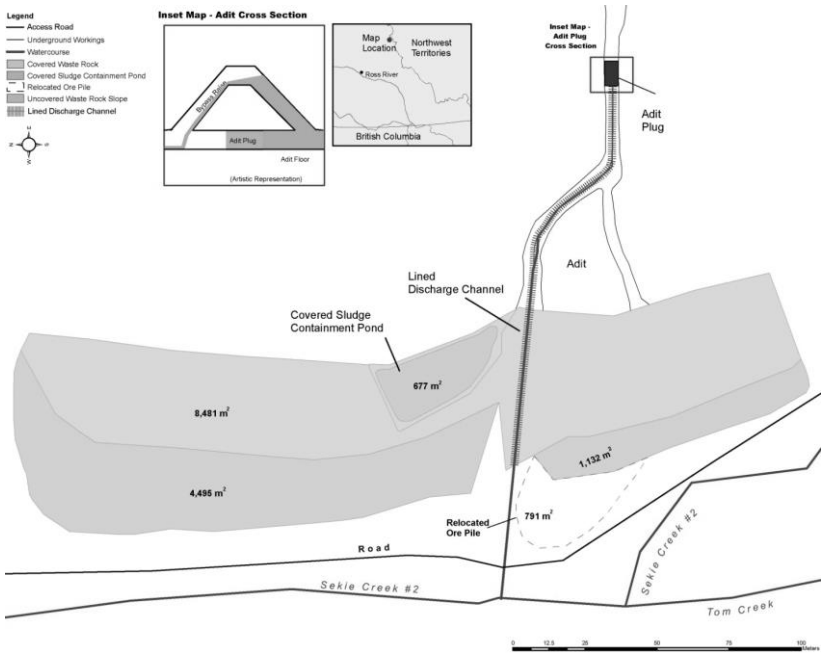

Figure 5 Waste rock cover and lined discharge channel plan view

5 Tom property adaptive management plan

As part of the YESAB Decision Document an AMP was required to assess the performance of the adit plug and associated workings at the Tom property. On 28 May 2009 and 29 November 2010 the Tom Valley Conceptual AMP and the Tom Valley Final AMP were submitted to the Yukon Water Board, respectively.

Ten AMP "components" were identified through the YESAB and Water Licence amendment processes. One component, sludge stability, from the conceptual AMP (AECOM Canada Ltd., 2009) has been removed as the sludge pond has been covered with a HDPE liner and 0.5 m of local material as a protective barrier. The effectiveness of the sludge pond cover will be monitored and reviewed as part of component 7, waste rock cover physical effectiveness. These nine components represent possible future environmental conditions that would require a management response, if they were to respond negatively to the remediation plan (AECOM Canada Ltd. et al., 2010). The nine remaining AMP components are: adit water quality, receiving environment water quality, seepage from the base of waste rock dump and slopes influenced by flooding of the workings, seepage from exploration boreholes, hydrostatic pressure behind adit plug, change in water levels in groundwater wells, waste rock cover physical effectiveness, physical site stability, and adit plug integrity.

6 Initial post plug adit water quality

Following the completion of the adit plug installation on 28 August 2011, flooding of the underground workings took 16 days and flow out of the adit resumed on 13 September 2010 at ~1300 hrs. The initial adit water quality (W5) results from six sampling events from 13 September 2010 to 24 March 2011 are presented in Table 3. The sample collected on 13 September was collected within the first 30 minutes of the adit resuming flow and contained elevated total suspended solids from the flushing of the underground wall rock. This is observed in the elevated total copper concentration of 1.86 mg/L in comparison to the dissolved copper concentration of 0.951 mg/L for this date and subsequent significantly lower total copper concentrations observed. The post adit plug water quality shows both improvements and degradation in comparison to the adits median concentrations from the reference period of 2000 to 25 August 2010. The minimum sample set for reference period is 35 samples depending on the parameter. The pH of the adit has increased from the median pre-plug pH of 3.3 to a pH ranging from 4.0 to 4.9. The initial pH of 4.9 is believed to be attributed to the alkalisation of the adit water from the shotcreted downstream bypass raise. Visual observations of the bypass raise has identified that the majority of the shotcrete has been now covered by iron precipitation and the more alkaline pH is a by-product of the flooded underground workings and the reduction in oxidation of the acid generating adit wall rock. Elevated concentrations of total lead and dissolved arsenic are observed in the post plug adit water quality when compared to the pre-plug median concentrations. Background station T5, which is located on a tributary of Sekie Creek #2, has also shown a strong increasing trend in many metals including total zinc with a maximum concentration of 47.4 mg/L during the 2010–2011 fall-winter sampling period.

Due to the remoteness of the site and the nature of the water licence monitoring, water quality sampling of the adit and background stations were not completed during the late fall and winter periods. It is not possible to confirm if the initial above mentioned trends in adit water quality are a result of the installation of the adit plug or seasonal trends not previously observed during the low flow period. A preliminary assessment of the performance of the adit plug to improve the adit's water quality should be completed by mid September 2011 following the monitoring of the adit water quality during the open water season.

6.1 Ongoing monitoring, inspection and reporting

Environmental monitoring and geotechnical inspections at the Tom Property will continue to be done up to 2013 to assess the performance of the adit plug on the change in adit water quality and the other components of the reclamation plan. The ongoing monitoring, inspection and reporting for the Tom Property includes; monthly monitoring between June and September, annual geotechnical inspections, and annual reporting.

Table 3 Tom adit (W5) water quality summary post plug adit installation

Parameter	13-Sep-10	20-Sep-10	7-Oct-10	1-Nov-10	28-Jan-11	24-Mar-11	Median: 2000 to 25-Aug-10
Flow (L/s)	1.3	10.3	12.2	11.5	6.1	8.7	10.0
pH (pH)	4.9	4.8	4.3	4.2	4.0	4.1	3.3
Diss. arsenic	0.0009	0.0167	0.0206	0.027	0.0626	0.0701	0.0242
Total copper	1.86	0.153	0.232	0.141	0.0611	0.0446	0.045
Total lead	0.0637	0.0955	0.140	0.173	0.192	0.172	0.108
Total nickel	0.848	1.03	1.40	1.69	1.92	1.72	1.37
Total zinc	16.7	18.5	23.7	25.6	22.0	19.5	24.1

All units in mg/L unless otherwise specified.

7 Conclusion

This paper outlines the various components of the reclamation and remediation of the Tom Property including alternative assessment, environmental assessment and permitting, reclamation plan, AMP, and initial results. A preliminary assessment of the performance of the reclamation plan should be available by 15 September 2011.

Acknowledgements

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