Long Term Effectiveness of an Adit Plug – Passive Treatment for Adit Discharge in a Northern Climate

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Abstract

Low-cost, long-term passive treatment to improve water quality from flowing adits is desirable, particularly in remote, cold-climate locations where active treatment is not practicable. This paper assesses the effectiveness of the installation an adit plug and other reclamation work at the Tom lead-zinc-silver exploration site located in remote eastern Yukon, Canada.

The Tom adit plug is a good example of a low maintenance, and cost-effective closure strategy particularly in northern Canada that has been able to stabilize acid rock drainage and metal leaching from a flowing adit, which is meeting its closure objectives and licenced discharge standards.

Keywords: adit plug, water quality prediction, acid rock drainage, passive treatment

Introduction

The Tom Property is located in the remote Macmillan Pass area, near the Yukon-Northwest Territories border, Canada. Between 1970 and 1982, 3,523 m of underground development was 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. When the underground workings were extended, significant inflows of water eventually resulted in a shut-down in 1982. Exploration activities ended at the Tom property in the early 1990s and, between 1992 and 1994, the Tom adit was covered with granular fill and drainage pipes were installed to permit the water from the underground workings to drain to surface. In 1994, a notification from the federal government that the property had been reclaimed to satisfactory conditions was received.

In the spring of 1999, a routine inspection by government inspectors found that the adit backfill had been breached by water from the adit. It was hypothesized that the drainage pipe through the backfill in the adit had frozen and the hydraulic head that had developed behind the frozen face eventually overcame the resistance of the backfill and washed it out. At the time, the adit discharge was noted to have degraded since the adit breach and did not meet regulatory standards at that time.

In order to address these issues, and in consultation with regulators, a surface and underground reclamation program was developed and implemented between 2000 and 2010. As part of comprehensive reclamation measures, an adit plug was installed as a long-term passive treatment solution to improve the adit discharge quality by reducing the oxidation of sulphide minerals, resulting in decreased acidity, zinc and other metal concentrations. This type of passive treatment was selected as the preferred option in consultation with local regulators and in consideration of several factors, including the remote northern location of the site, seasonal access, and lack of power source.

This paper presents the results from the first seven years of the adit plug's performance. Water quality predictions are compared with the post-adit results for the flushing, short and long term phases. Implications for ongoing closure and reclamation planning are discussed.

Site Conditions

The Tom deposit is a Sedex type lead-zinc-silver deposit that is hosted within the Lower Earn Group (Devonian). The Group contains the Itsi Member (sandstone, siltstone and shale), Tom Sequence (shale and chert), and Macmillan Pass Member (chert pebble conglomerate) (Abbot, 1983). Static geochemical testing on approximately 39 samples indicate that all the units tested in the region have the potential for acid generation and metal leaching. The sedimentary rocks contain sulphide minerals including pyrite, sphalerite and galena.

Naturally-elevated metals in the undeveloped surrounding area's surface waters have been well-documented in studies completed during the past 40 years. This includes over seventeen years of monitoring and studies for the purposes of characterizing anthropogenic and natural metal loading observed in the Upper South Macmillan River watershed, including Sekie Creek #2 (Figure 1). Background water quality in Sekie Creek #2 is influenced by natural acid rock drainage (ARD) and metal leaching, with the loadings contributing the majority of zinc to the receiving environment, the South Macmillan River. Investigations and studies show the Tom adit's contribution to metal loading at downstream locations is insignificant, including those with known fisheries presence (Garter Lee, 2008).

Tom Property Reclamation Plan

From 2000-2009, baseline data collection, reclamation planning, and the necessary regulatory project support and approvals to implement the reclamation plan were completed. Figure 1 shows the main reclamation program features. The reclamation plan was implemented in 2009 and completed in 2010, including:

- Installing the Tom adit plug;
- Constructing a bypass raise including shotcreting the downstream raise;
- Installing covers for the waste rock pile and the sludge pond; and
- Installing a lined discharge channel.

The adit plug construction was completed on August 28, 2010. Between August 28 and September 13, 2010 (16 days), controlled re-flooding of the underground workings (≈18,000 m^3) was conducted, with discharge resuming from the adit once the water level reached 24 m above the adit floor (September 13, 2010). During the previous 16-day construction period, flow from the adit had ceased and weekly monitoring was conducted in Sekie Creek2, showed that the adit water discharge was not a significant loading source to the receiving environment. Since construction, the hydrostatic pressure (water level) behind the plug has been continuously monitored by a vibrating wire piezometer and has remained stable at approximately 24 m above the adit floor. Upon completion of this work, the adit discharge was effectively isolated from the waste rock and directed along a high density polyethylene (HDPE) lined channel.

Post-Adit Plug Water Quality Predictions

As part of the environmental assessment and regulatory applications to support the reclamation work, post-adit plug water quality was predicted for three different post-adit plug phases: flushing, short term and long term (Table 1). Due to a number of environmental variables, the different phases were not initially defined with fixed time periods, but were determined through monitoring of the adit discharge. The flushing phase was anticipated to last approximately one year, the short term phase was anticipated to last 1-5 years, and the long term phase was expected to start thereafter. These three phases were developed to replicate the expected adit discharge transition from oxygen-rich to oxygen-reduced conditions and their anticipated metal concentrations. The adit water quality predictions for the three different phases were conducted using three different data sets (static geochemical testing, historical adit water quality, and background water quality).

Table 1 summarizes the results of static geochemical testing for seven rock samples collected in 2007 from the adit wall for parameters that have effluent quality standards in the adit discharge. These samples are characterized by total sulphur ranging from 1.08 to 4.63% and all with a neutralization potential ratio (NPR) of less than one. Shake flask tests were conducted on the seven rock samples using adit water to predict the wa-

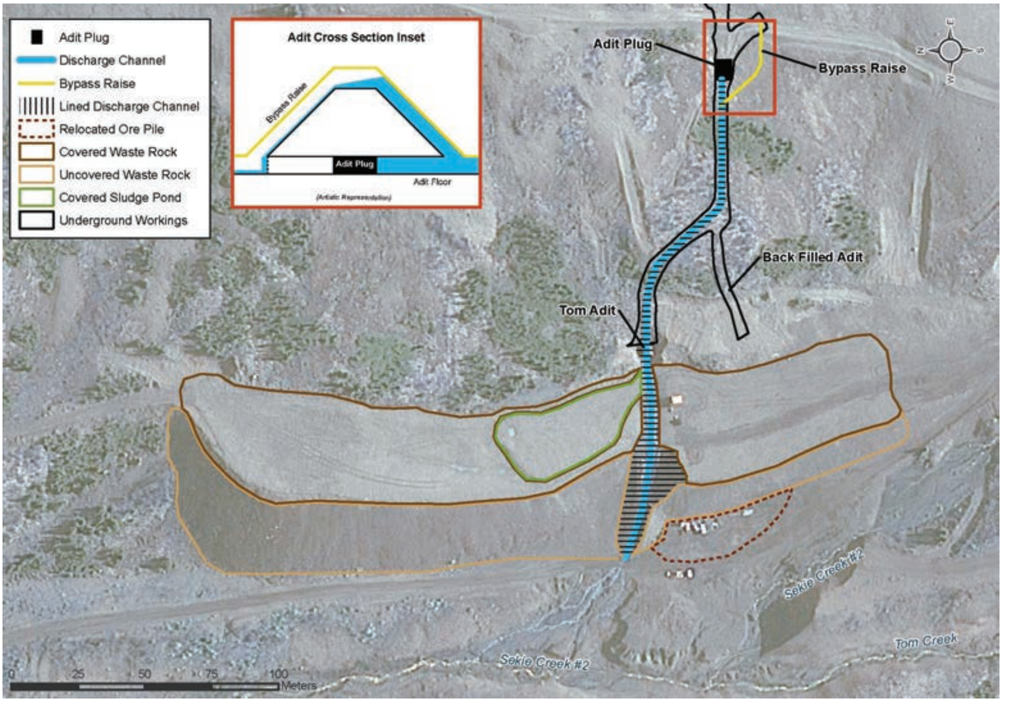

Figure 1 *Tom property reclamation plan features layout*

ter quality during the flushing phase. Table 1 presents the maximum concentrations observed from the shake flask tests that were incorporated into the flushing phase water quality predictions.

The short-term adit water quality was predicted using the 75th percentile from the pre-adit plug discharge covering a 10 year data set consisting of 40 sampling events. The long-term phase was predicted using the 95th percentile of the 11 background stations that are upstream of the Tom adit and workings or in adjacent undeveloped watersheds from 2000 to 2017 (67 events).

Additionally, several underground investigations were undertaken to better understand the mass balance of the adit discharge from the east zone, west zone and flooded decline. The east and west zone were characterized by pH 3 water with elevated metals, including total zinc greater than 30 mg/L, whereas the flooded decline water quality had a pH of 6.25 and total zinc concentration of 15 mg/L. A summary of the decline water quality is presented in Table 2.

Results

The Tom adit discharge water quality (W5) summary statistics for 45 sampling events from September 13, 2010 to September 6, 2017 are presented in Table 2. Overall, the post-adit plug discharge water quality has shown improvements in comparison to the pre-adit plug period of April 4, 2000 to August 25, 2010.

pH

The post-adit plug discharge pH improved, rising from the median pre-adit plug pH of 3.3 to a post-adit plug pH ranging from 3.9 to 4.9. The less acidic pH currently observed is likely a by-product of the flooded underground workings and the decrease in oxidation of the adit wall rock. The post-adit plug adit water pH results are stable between pH 4.0 and 4.5 and are less acidic than all the predicted phases, as well as the pH measured at all stations that are representative of naturally-occurring surface water in Sekie Creek #2.

Table 1. Summary of Tom adit water quality post-adit plug installation as predicted from tests on rock samples collected in 2007

Parameter	Unit	Flushing	Short Term	Long Term
Physical Parameters				
Field pH	pH	3.10	3.4	3.52
Specific Conductance (field)	µS/cm	5124	1825	2106
Acidity	mg/L $CaCO_3$	2800	893	1614
Sulphate	mg/L	3200	1100	1568
Metals				
Total Copper	mg/L	2.12	0.0995	1.78
Total Iron	mg/L	858	218	240
Total Lead	mg/L	0.0663	0.117	0.070
Total Nickel	mg/L	2.78	1.56	3.13
Total Zinc	mg/L	31.4	25.9	29.1
Dissolved Arsenic	mg/L	0.429	0.029	0.043

Table 2. Summary statistics for Tom adit (W5), flooded decline (DC) and background stations

	Field pH pH unit	Specific Conductance µs/cm	Sulphate mg/L	Total Iron mg/L	Total Lead mg/L	Total Nickel mg/L	Total Zinc mg/L	Dissolved Arsenic mg/L
W5 – Tom Discharge Pre-Adit Plug, April 4, 2000 to August 25, 2010								
number of observations	24	26	37	40	40	40	40	39
Minimum	2.80	1215	155	80.0	0.085	0.698	10.5	0.0114
Median	3.33	1586	1000	190	0.108	1.37	24.3	0.0246
Maximum	3.90	2004	1530	269	0.128	2.31	30.1	0.0360
95th Percentile	3.73	1920	1412	248	0.126	2.05	28.7	0.0331
W5 – Tom Discharge Post-Adit Plug, September 13, 2010 to September 6, 2017								
number of observations	42	43	45	45	45	45	45	45
Minimum	3.88	1325	730	109	0.064	0.85	16.7	0.001
Median	4.31	1622	1190	280	0.172	1.54	22	0.086
Maximum	4.89	2024	1440	331	0.295	2.05	29	0.135
95th Percentile	4.60	1900	1360	320	0.214	1.90	25.8	0.100
DC - Flooded Tom Decline Discharge Pre-Adit Plug, July 2008 to June 2010								
number of observations	7	7	7	7	7	7	7	7
Minimum	6.15	1036	585	107	0.0003	0.535	12.6	0.0056
Median	6.25	1211	640	132	0.00045	0.63	14.5	0.0127
Maximum	6.57	1270	662	140	0.00079	0.71	17.7	0.0171
95th Percentile	6.54	1259	658	139	0.00076	0.71	17.3	0.0167
Background Stations, 2000 to 2017								
number of observations	277	277	273	277	277	277	277	277
Minimum	2.60	55	11	0.09	0.00005	0.011	0.07	0.0001
Median	3.03	1110	569	56.5	0.02	1.01	5.74	0.0038
Maximum	4.43	3820	3970	542	0.10	6.27	61.3	0.0995
95th Percentile	3.52	2106	1568	240	0.070	3.13	29.1	0.0429

Copper

The post-adit plug copper concentrations are considered to be stable and are below the long-term prediction and Effluent Quality Standard. The first sample collected on September 13th, 2010, had an initial elevated total copper concentration of 1.86 mg/L, attributable to elevated suspended solids. The total copper concentrations during the post-adit plug period showed an initial increasing trend until June 2013, when a maximum of 0.414 mg/L was observed followed by a decreasing trend and has stabilised below 0.250 mg/L.

Lead

The total lead concentrations observed to date are all below the effluent quality standard of 0.4 mg/L, but greater than the long term prediction (0.07 mg/L). The post-adit plug total lead concentrations have ranged from 0.064 to 0.295 mg/L for the 45 monitoring events post-adit plug installation. Since the installation of the adit plug, total lead concentrations steadily declined to 0.15 mg/L until late summer 2017. Total lead concentrations approximately doubled in July 2017 from 0.152 mg/L to 0.289 mg/L in August and 0.295 mg/L in September 2017, which are the maximum concentrations observed to date.

Zinc

The total zinc concentrations in samples collected during the post-adit plug period have been less than predicted and are below the total zinc concentrations observed pre-adit plug installation. Total zinc concentrations in adit water samples collected during this post-plug period have ranged from 16.7 to 29.0 mg/L, with all of the 45 samples containing total zinc at concentrations below the long-term prediction (29.1 mg/L). There was an observable decreasing trend in the total zinc concentrations since 2010, with the lowest historical total zinc concentration measured in June 2017 (17.9 mg/L). All total zinc concentrations were below the effluent quality standard since it became in effect April 29, 2016.

Arsenic

Dissolved arsenic concentrations have been discussed rather than total as the regulatory standard is for dissolved arsenic. The dissolved arsenic concentrations (0.0009 to 0.135 mg/L) observed during all the post-adit plug monitoring events were well below the dissolved arsenic EQS of 1.0 mg/L. Concentrations have been below the flushing prediction of 0.443 mg/L, although slightly above the predicted short term and long term predictions. The dissolved arsenic concentrations show a stabilized trend.

Nickel

Post-adit plug total nickel concentrations in adit waters were below pre-adit plug nickel concentrations observed in 2009 and 2010 as well as the effluent quality standard of 2.1 mg/L, although there is more variation in the results. Total nickel concentrations (0.848 to 2.05 mg/L) for all post-adit plug monitoring events were below the flushing and long term predictions, while 21 of 45 samples were above the short term prediction. The most recent total nickel concentration of 1.59 mg/L is slightly above the short term prediction of 1.56 mg/L.

Flow Rates

The adit discharge pre-adit plug was characterized by a median flow of 9.9 L/s and the post-adit plug discharge was characterized by a median flow of 12.1 L/s. The slight increase in the median flow level during the post-plug period is attributed to the increased accuracy of flow measurements resulting from the development of the lined discharge channel.

Discussion

The predicted Tom adit discharge water quality recorded during the period following the adit plug installation, using static geochemical tests and background water quality, has been a reasonably effective approach in predicting the flushing phase and long term adit water quality for the first seven years. Utilizing the 75^{th} percentile for the pre-adit plug concentrations was concluded to not be an appropriate tool in determining the short term post-adit plug concentrations and a higher percentile or different method would be recommended for future projects.

The data resulting from the shake flask tests on adit water and adit wall rock for determination of flushing-phase water quality indicates that this was a generally effective method to establish conservative water quality predictions for the Tom adit discharge. Testing of the leachability of iron hydroxide sludge that coats the adit floor and discharge area with adit water was determined to be a supporting factor to assist in the development of the post-adit plug water quality predictions, but based on the concentrations observed to date, the approaches used are recommended in predicting the flushing phase concentrations for sites of similar nature.

Due to the naturally-elevated metal concentrations in regional background waters of Sekie Creek #2 and the South Macmillan River, resulting from local natural ARD and metal leaching, the data suggests that the most effective and most applicable long-term site specific water quality objectives for the Tom adit discharge would be best developed using statistical analysis from background water quality.

Although concentrations of total lead and dissolved arsenic are slightly higher in the post-adit plug water quality when compared to the pre-adit plug median concentrations, the concentrations show a stabilization of these parameters and are lower than the effluent quality standards. Total zinc post-adit plug discharge concentrations have shown a decreasing trend and are below the pre-adit plug zinc concentrations observed in 2009 and 2010. The adit plug has resulted in lower oxidation reduction potential from 450 mv to between 250 to 300 mv. If the change in oxidation reduction potential in the adit discharge further reduces, the long term adit discharge is anticipated to improve the water quality as shown in Table 2.

Conclusion

The first seven years of Tom adit discharge data have been within the predicted water quality for the flushing phase with the exception of total lead, which has stabilized at concentrations less than the applicable regulatory standard. Future water quality predictions for flushing phases from an adit plug built as a passive treatment system are recommended to incorporate static geochemical testing including shake flask tests using all adit wall rock units intercepted by the underground workings with adit water. The adit discharge has been generally within the long term phase water quality predictions with variations in the trend shown by total lead and dissolved arsenic. Utilising the background method to establish long term predictions is therefore concluded to be appropriate.

Additional monitoring will be completed in 2018 to 2020 to further assess the water quality trends identified from the first seven years of post-adit plug monitoring. The analytical results for work conducted to date will be used to develop, in association with regulatory guidance, the final closure plan for the Tom property. The adit plug at the Tom property has demonstrated its effectiveness and appropriateness as a long term passive treatment solution for a remote exploration site location, demonstrating clear improvements in pH and alkalinity, and the stabilization/decrease of regulated metal concentrations, including zinc, in the adit discharge.

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