

Samatosum - A Tale of Two Early Acid Drainage Prevention Approaches

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Abstract

Two acid drainage (AD) mitigation measures incorporated into the design of the Samatosum Mine Project have displayed diverse outcomes: the water covered tailings impoundment was very successful; the layered waste rock dump was not successful. The effectiveness of the AD mitigation measures has been monitored since they were implemented. Discharge from the waste dump became acid briefly during the 1995 freshet. Since 1995, the primary seep from the waste dump has become acid during every freshet, and a small seep is acid almost all of the time. A water collection and treatment system was commissioned before the 1997 freshet, and has been in operation since that time. An on-site sludge management program has been implemented to manage the residuals from the treatment process. Potentially acid generating (PAG) tailings were deposited in an impoundment designed to maintain a water cover over the tailings. There have been no indications of AD from the tailings facility to date. Water management and treatment facilities, and their post closure operation, are described in this paper. Monitoring results are also presented and discussed.

Key Words: acidic drainage, acid potential, neutralization potential ratio, layered waste dump, water cover.

Introduction

The Samatosum closed mine site is owned by Inmet Mining Corporation (Inmet), a Canadian-based global mining company that produces copper and zinc. Inmet is active in production, development and exploration — three key components to delivering sustainable growth and long-term value for shareholders. The Samatosum closed mine site is one of six closed mining properties in North America and is part of Inmet's Closed Properties Group.

The Samatosum Mine operated between May 1989 and September 1992. A total of 566,000 tonnes of ore and about 9.6 million tonnes of waste were mined from the open pit and small underground mine. Waste rock was placed in a dump adjacent to the open pit and tailings were placed in an impoundment adjacent to the process plant, located 1,200 metres northwest of the open pit. In the second half of 1996, a lime treatment plant was constructed below the toe of the waste dump to treat acid drainage (AD) from the waste dump and open pit. The plant was upgraded to a high density sludge (HDS) system in 1998.

A 320ha drainage basin above the tailings impoundment was diverted around the facility during operations and was re-established in late 1994 to create and maintain a water cover above the tailings during post closure. Discharge from the impoundment is released directly to the environment. An air photograph plan of the mine area is presented as Figure 1.

The open pit and waste dump lie within a common drainage area. All collected seepage and runoff that is directed to the treatment plant, and runoff and seepage that occur below the open pit and waste dump, are directed to the Mine Water Sedimentation Pond (MWSP) by a network of ditches (Figure 1). The total catchment area reporting to the MWSP is 74.7ha. The MWSP discharges to Johnson Creek, which ultimately drains to Adams Lake.

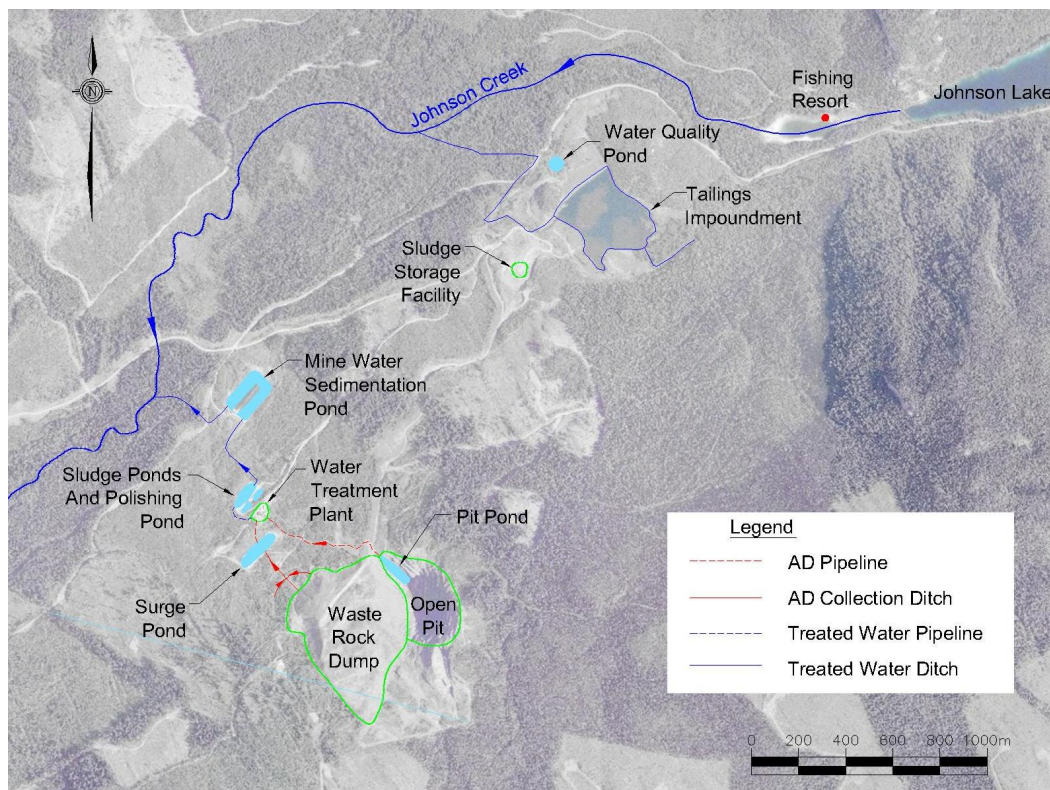


Figure 1. Airphoto site plan of Samatosum Mine

Chronology of Mine Construction and Operation

- 1986 A polymetallic Ag-Pb-Zn deposit was discovered at Samatosum.
- 1989 The Mine Reclamation Permit was secured.
The mine opened in May and was operated at 500 tonnes of ore per day; 566,000 tonnes of ore were mined; 23,864 tonnes of concentrate were produced.
- 1992 The mine closed in September; 422,462 cubic metres (542,000 tonnes) of tailings were deposited in the sub-aqueous tailings impoundment.
Tailings were re-distributed to an elevation of less than 1,134m above mean sea level for closure.
- 1993 Tailings supernatant was treated and discharged.
Waste rock slope stabilization and re-vegetation was initiated.
A permanent fishway was installed at the outlet of Johnson Lake.
- 1994 The diverted creek was rerouted into the tailings impoundment to create a permanent water cover.
- 1995 The water cover was successful and tailings impoundment supernatant overflow was compliant.
AD occurred from waste rock during the freshet, the counterpart to the above success.
Treatment was required, contrary to the closure plan.
- 1996 Control Order was received from BC Ministry of Environment (MOE).
A low density lime water treatment plant (WTP) was constructed to treat mine drainage.
- 1998 The WTP was upgraded to a high density sludge (HDS) system.
- 2003 MOE Discharge Permit was amended and the Control Order was rescinded.
A small instability developed at the toe of the waste rock dump.
- 2005 Waste Rock Dump Stability Review was conducted by Piteau Associates.
- 2006 Piteau Associates completed waste dump regrading design (review of ten remediation options).
- 2007 A waste rock dump regrading contract was awarded and construction started.
- 2008 Waste dump regrading was completed.
Samatosum Closure Project received the 2007 Jake McDonald Mine Reclamation Award.

Tailings Water Cover Performance

Tailings Impoundment Description

Tailings were deposited in a small valley behind a 30m high earthfill dam. A low embankment was constructed across a topographic saddle to the southwest of the main dam, and the permanent spillway was constructed through the saddle dam (Photo 1). The main earthfill dam and saddle dam were constructed of compacted low hydraulic conductivity glacial moraine, on a dense glacial moraine foundation. Seepage from the dam was estimated to be about 1.2 L/s (Piteau, 1988).

A total of 542,000 tonnes of tailings were deposited in the impoundment between May 1989 and September 1992. A small creek that was diverted around the tailings impoundment during operations was rerouted through the facility in late 1994, to maintain a water cover over the tailings (Photo 1). Tailings deposition near the end of the mine life and in the closure works were designed to provide a final surface over which a minimum 1m water cover could be maintained. The minimum 1m depth was predicted to be sufficient to maintain a water cover during an extended drought (Minnova, 1988). At closure, the depth of water cover varies between 8m and 1.5m, with the exception of some small areas around the margins of the pond where the water cover depth is slightly less than 1m.



Photo 1. Aerial view of the tailings impoundment

Water quality monitoring of tailings discharge was performed five times per year until 2005, and has been performed a minimum of twice per year since 2005. Influent water quality is periodically checked as part of site background water quality monitoring. Two monitoring wells and a seepage collection pond (Water Quality Pond) below the toe of the tailings dam are also sampled annually (as a minimum).

Tailings Characteristics

Composite samples were collected on a quarterly schedule from the tailings stream during operations. Results of the sampling indicated an average sulphur content of 3.96% and an overall net neutralizing potential (NNP) of -33.03 kg/t CaCO_3 equivalent (Table 1). The average acid potential to neutralization potential (AP/NP) ratio is 1.46, with quarterly samples ranging from 0.96 to 2.14. The potentially acid-generating (PAG) nature of the sampled tailings was consistent with their original characterization. The original impoundment design included a water cover over the tailings at closure, to mitigate the risk of AD (Minnova, 1988).

Table 1. Samatosum tailings – Acid Base Accounting (ABA) quarterly composite sampling data

<u>Sample</u>	<u>Sulphur</u> %	<u>Paste pH</u>	<u>AP</u> kg/t	<u>NP</u> kg/t	<u>NNP</u> kg/t	<u>AP/NP</u> kg/t
Q2 1989	3.35	8.6	102.5	50	-52.5	2.05
Q3 1989	3.07	8.2	93.9	40.7	-53.2	2.31
Q3 1989	3.97	8.4	121.5	61.7	-59.8	1.97
Q4 1989	3.58	8.9	109.5	81.8	-27.7	1.34
Q1 1990	3.24	8.7	99.1	103.1	4	0.96
Q2 1990	3.39	8	103.7	100	-3.7	1.04
Q3 1990	4.01	8.5	122.7	86.7	-36	1.42
Q4 1990	4.07	8.6	124.5	110	-14.5	1.13
Q1 1991	4.57	9.7	139.8	92.6	-47.2	1.51
Q2 1991	4.78	9.3	146.3	76.4	-69.9	1.91
Q3 1991	4.44	8.9	135.9	93.8	-42.1	1.45
Q4 1991	4.56	9.2	139.5	122.3	-17.2	1.14
Avg	3.92	8.75	119.91	84.93	-34.98	1.52

Water Cover Chemical Characteristics

A series of water quality samples were taken from the water cover in the late summer of 2011. Seven samples were collected from 30cm above the top of the tailings, at sites where the water cover was near or less than 2m depth. Samples were taken from the creek inflow and tailings decant spillway at the same time. While decant samples generally showed higher metal values than inflow samples, all dissolved metal concentrations (Table 2) were below their respective freshwater aquatic life criteria (FWAL). Total arsenic concentrations in the tailings decant have averaged 2.3 µg/L since 1998, and have not exceeded 4.79 µg/L. Dissolved oxygen concentrations ranged from 5.8 mg/L to 9.7 mg/L and averaged 7.9 mg/L. There is no indication of metals leaching in the data

Table 2. Summary of water cover samples from October 2011

Parameter	Units	Minimum	Maximum	Inflow	Decant	FWAL
As	µg/L	0.18	3.67	0.18	3.53	5
Cd	µg/L	ND	0.007	ND	ND	0.04
Cr	µg/L	ND	ND	0.10	ND	1
Cu	µg/L	0.44	1.54	0.44	1.17	5
Fe	µg/L	3	17	3	8	350
Pb	µg/L	0.01	0.124	0.005	0.097	7.3
Mn	µg/L	0.27	0.49	0.47	0.37	1100
Zn	µg/L	0.20	0.9	0.2	0.4	33
DO	mg/L	5.80	9.74	8.71		

ND = not detected FWAL = freshwater aquatic life criterion

Water Quality Monitoring Review

Sulphate concentrations in samples from the tailings impoundment decant and the water quality pond (WQP) at the toe of the main tailings dam are plotted on Figure 2. Prior to late 1994, water was retained in the tailings impoundment and was only discharged after treatment. Once the water quality approached discharge criteria, the diversion was rerouted through the tailings impoundment. Sulphate monitoring data since 1995 indicate decant water from the tailings impoundment is dominantly meteoric water with no

indication of significant effects from the tailings. Sulphate monitoring data for the WQP are significantly higher. During operations, the WQP chemistry was affected by elevated rates of seepage from the tailings impoundment, associated with the high level maintained in the supernatant pond. The level was high as discharges from the pond were constrained by problems with the treatment system. Since 1995, sulphate concentrations have fluctuated between 100 and 200 mg/L. This range is attributed to mixing of locally recharged groundwater on the downstream side of the dam, with pore water seeping from the tailings. A steady-state trend is evident, indicating time-dependent oxidation processes are not occurring.

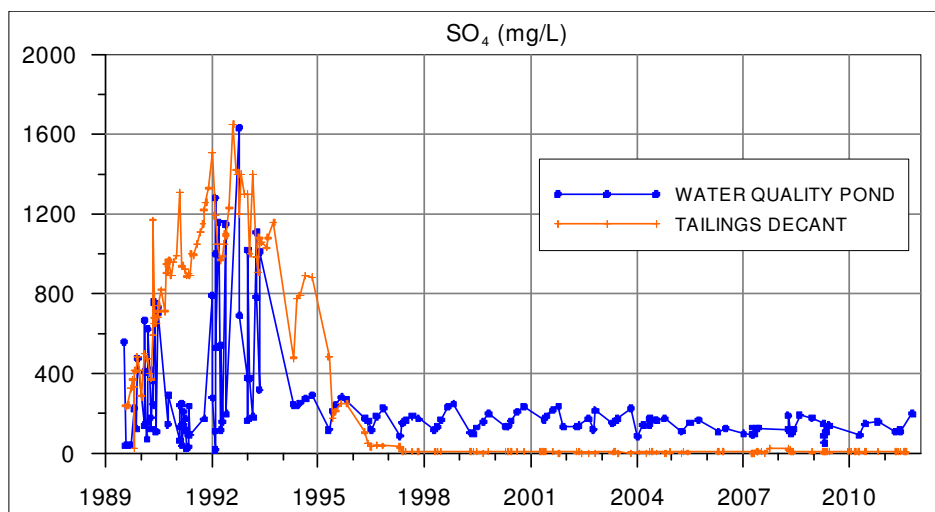


Figure2. Sulphate monitoring data for tailings decant and the WQP

Sulphate monitoring data for two groundwater monitoring wells (labelled Wells on Photo1) exhibit a similar trend to the WQP (Figure3). Sulphate concentrations measured in samples from both monitoring wells installed at Site 9 - 89-01 are very low, indicative of locally recharged groundwater that is not affected by the tailings. The chemistry of water at Site 9 - 89-02 exhibited a rising trend during mine operations, but has fluctuated between 10 and 270 mg/L over the past 17 years. The chemical composition of this groundwater is similar to that sampled from the WQP, and is interpreted to be a mixture of pore water seeping from the tailings, and locally recharged groundwater.

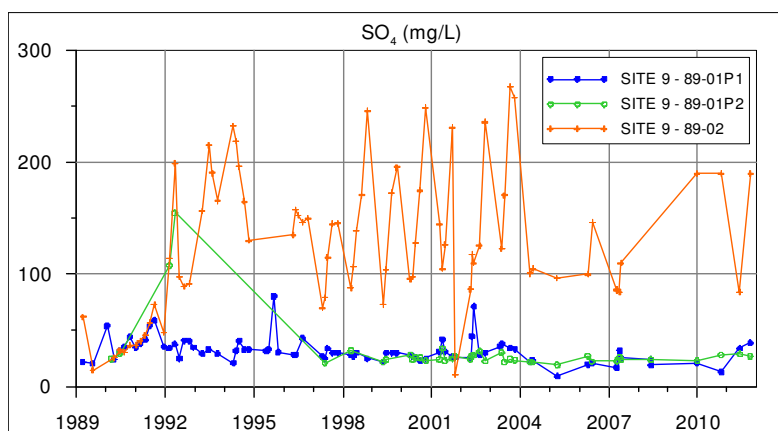


Figure 3. Sulphate monitoring data for groundwater monitoring wells

Copper monitoring data for the tailings pond and WQP are plotted on Figure 4. Copper concentrations were elevated in the tailings impoundment during operations, and the high supernatant pond operating

levels resulted in effects to seepage downstream of the tailings impoundment. Since 1993, copper concentrations in the WQP have been at background levels, and do not exhibit any apparent effects from the tailings. This indicates that, as expected, copper is not as mobile as sulphate in the groundwater flow regime through the glacial moraine. The other metals monitored as part of the regulatory program exhibit similar trends to copper, with all concentrations below FWAL criteria.

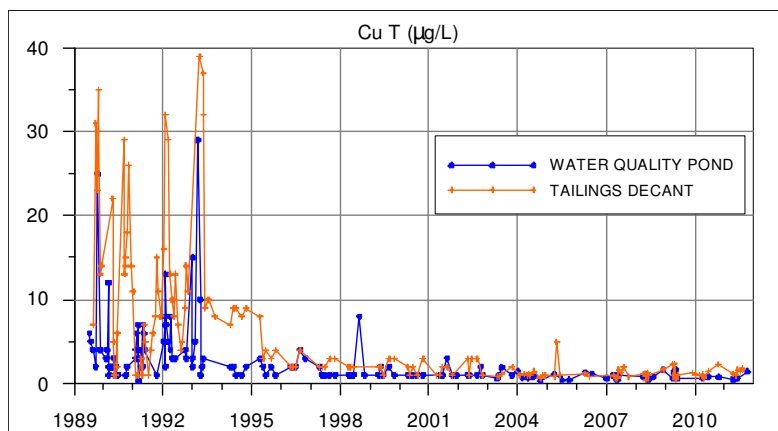


Figure 4. Copper monitoring data for tailings decant and the WQP

The monitoring data indicate that the water cover has been very effective for limiting oxidation of the tailings. Residual downstream effects to groundwater are attributed to the chemistry of the pore water that is slowly being flushed from the deposited tailings. Based on a pore volume of 170,000m³ (estimated to be 0.4 times tailings volume), and the estimated seepage rate of 1.2 L/s, one pore volume of water will flush through the tailings in approximately five years. The slight decline in sulphate concentrations in the WQP samples between 1995 and 2007 (Figure 2) suggests that the actual one pore volume flushing period is about 12 years.

Waste Rock Dump Design and Closure Management

Design and Management

The waste rock dump was constructed in 6m lifts. PAG waste was placed in two nominal 6m thick layers within the dump, and was placed on and covered by Non-PAG mafic pyroclastic waste (MAF).

The PAG waste was a blend of muddy tuffs, sericitic tuffs, argillite, chert and quartzite. A total of 3.9 million tonnes of PAG waste, with an average NNP of -43 kg CaCO₃ equivalent per tonne, were placed in the waste dump (Denholm and Hallam, 1991). MAF waste, with an NNP of approximately 305kg CaCO₃ equivalent per tonne totalled 5.7 million tonnes. The overall average NNP for the entire dump was 164kg CaCO₃ equivalent per tonne. Average sulphur contents in the PAG and MAF were 3% and 2.3%, respectively, indicating a total sulphur mass of 249,000 tonnes is contained in the waste rock dump. Approximately 20% of the MAF is dolomite (Hallam Knight Piesold Ltd., 1992), resulting in an estimated dolomite mass of 1.1 million tonnes.

The waste dump was covered with a 0.5 to 1m thick till cap which provides a growing medium but does not limit infiltration. Snowmelt, which is the principal source of recharge to the dump, typically seeps through the till, with little runoff noted (Ghomshei et al., 1997). Infiltration into the waste dump, and seepage beneath the waste rock, discharges at two springs at the toe of the waste dump, referred to as MOE6A and 6B (Figure 5). The primary seepage discharge occurs at MOE6A. Discharge from MOE6B accounts for less than 10% of the waste dump discharge, and is essentially stagnant for many months of the year. Seepage from these springs, and all surface flow originating in the open pit and waste dump

area, is collected in ditches and directed to a 12,000m³ surge pond, which drains via a gravity pipeline to an HDS treatment plant (Figure 5).

The surge pond has sufficient capacity to store waste dump seepage for a period of up to three months during the coldest months of the year. If warm weather results in increased seepage or snowmelt during the winter months, the WTP can be operated to maintain adequate freeboard in the surge pond.

Underflow from the WTP is discharged to one of two sludge settling ponds constructed below the WTP. Clarified water from the WTP overflow discharges to a polishing pond. Decant from both the sludge ponds and the polishing pond is conveyed via ditches to the mine water sedimentation pond (MWSP) at the bottom of the slope (Figure 5). The MWSP receives both WTP discharge and site background waters, and decants into Johnson Creek.

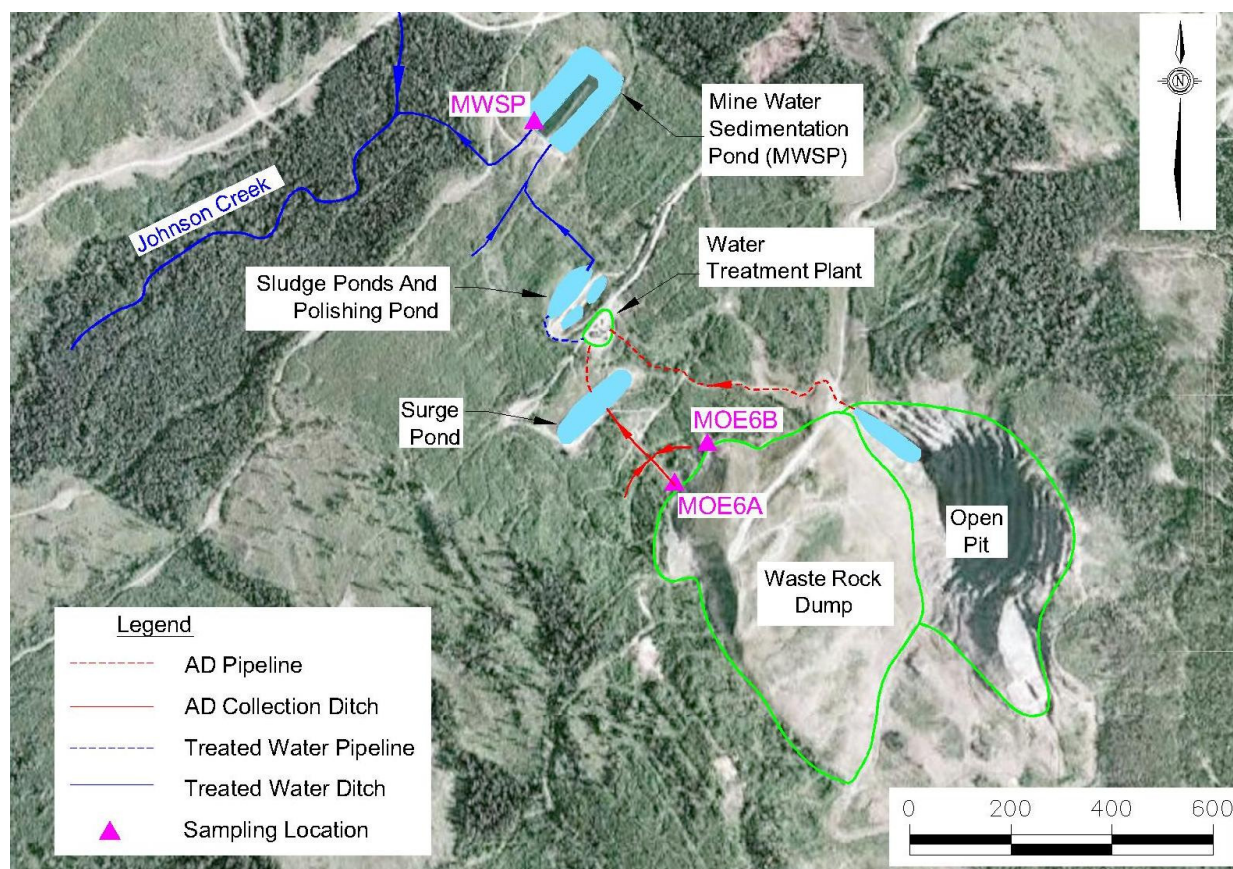


Figure 5. Airphoto plan of the waste dump and water treatment plant area

ARD Onset Description

Water in the open pit became acidic in the spring of 1992. Between 1993 and 1996, in-situ treatment with lime and/or sodium hydroxide was performed in the pit pond on a batch basis prior to release of water to the environment. During this period, the quality of seepage from the waste dump degraded progressively, to the degree where compliance was compromised at the point where water entered the local receiving environment in Johnson Creek. The waste dump became acid for the first time in the freshet of 1995.

Water Management and Water Treatment Mitigation Measures

In 1996, a WTP and a network of collection and diversion ditches were constructed to collect and treat seepage from the waste dump and open pit. The WTP used lime, flocculation and settlement to remove

metals from mine water. Although the plant was successfully operated in 1997 and 1998, it was upgraded in 1998 to an HDS facility to increase operating efficiency and confidence in process control. The upgraded plant was commissioned and successfully operated by the end of 1998.

The HDS WTP consumes an average of 100 tonnes of lime annually. It has proven to be effective in removing metals from the influent (Table 3) and creating a stable sludge. The optimal WTP target pH for treatment is 9.6, based on the solubility curves of influent metals, primarily zinc.

Table 3. WTP influent and effluent dissolved metals concentrations

µg/L	2009	2010	2011
Average Cu Inflow	1796	2781	914
Average Cu Outflow	1.9	2.2	1.8
Cu Inflow High	3880	4440	1820
Cu Inflow Low	9	24	7
Average Mn Inflow	6726	7293	3464
Average Mn Outflow	48	48	55
Mn Inflow High	11400	12500	9140
Mn Inflow Low	640	1790	305
Average Zn Inflow	34065	36427	12559
Average Zn Outflow	2.9	3.7	8
Zn Inflow High	64100	62300	35800
Zn Inflow Low	855	3080	518

Water Quality and Mass Balance Review

Waste dump seepage first exhibited low pH (3.8) in the freshet of 1993, from the small seep at MOE 6B (Figure 6). The primary seepage from the waste dump (MOE 6A) first exhibited low pH in the freshet of 1995. Acidic conditions have characterized waste dump discharge since 1995. Seepage from MOE 6A is only acidic during brief flushing periods each spring, following snowmelt. Seepage from MOE 6B is chronically acidic.

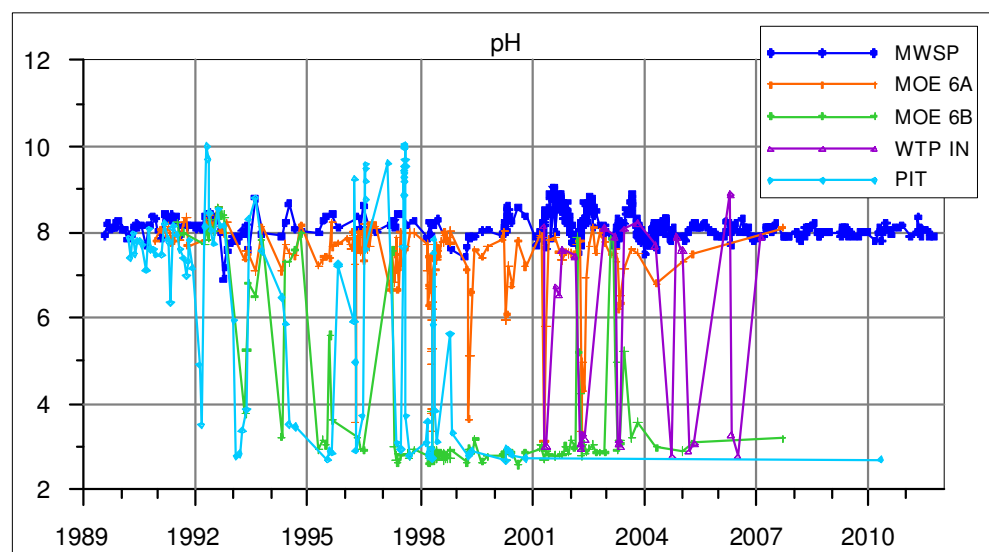


Figure 6. Time base plot of pH in waste dump, open pit and MWSP discharge

The open pit water quality first became acidic in late 1992, and was the cause of the reduced pH in the MWSP (Figure 6). Storage and batch treatment of open pit water, initiated in 1992, resulted in the elevated pH values in the monitoring record. Batch treatment was terminated after a pipeline was constructed to convey water to the WTP in 1997. Since then, the pH of water in the open pit has remained fairly stable at about 3 (Figure 6).

Previous assessment of monitoring data indicated a positive linear correlation of sulphate with calcium and magnesium (Ghomshei et al., 1997). This suggested that the buffering capacity was active and responded to acid generation. Mineralogical studies have indicated that pyrite is the primary source of sulphur, and dolomite is the most significant source of neutralization potential in the hanging wall rocks, which comprise the majority of the waste rock (Hallam Knight Piesold, 1992). Calcium and magnesium concentrations in the waste dump seepage discharge increased between 1992 and 1996, indicating dissolution of dolomite is occurring in response to AD. The concentrations have remained relatively constant over the last decade (Figure 7). The Ca/Mg ratio in the dump discharge declined from greater than 2 in 1992, to less than 0.4 in 1998. It has since increased slowly and has ranged between 0.4 and 0.8 since 2006 (Figure 7). The Ca/Mg ratios since 1993 are significantly less than the theoretical 1.65 ratio for dolomite. The low ratio and the decline in the ratio that occurred as the sulphate concentration increased suggest that calcium is precipitating within the waste dump, likely as gypsum or epsomite.

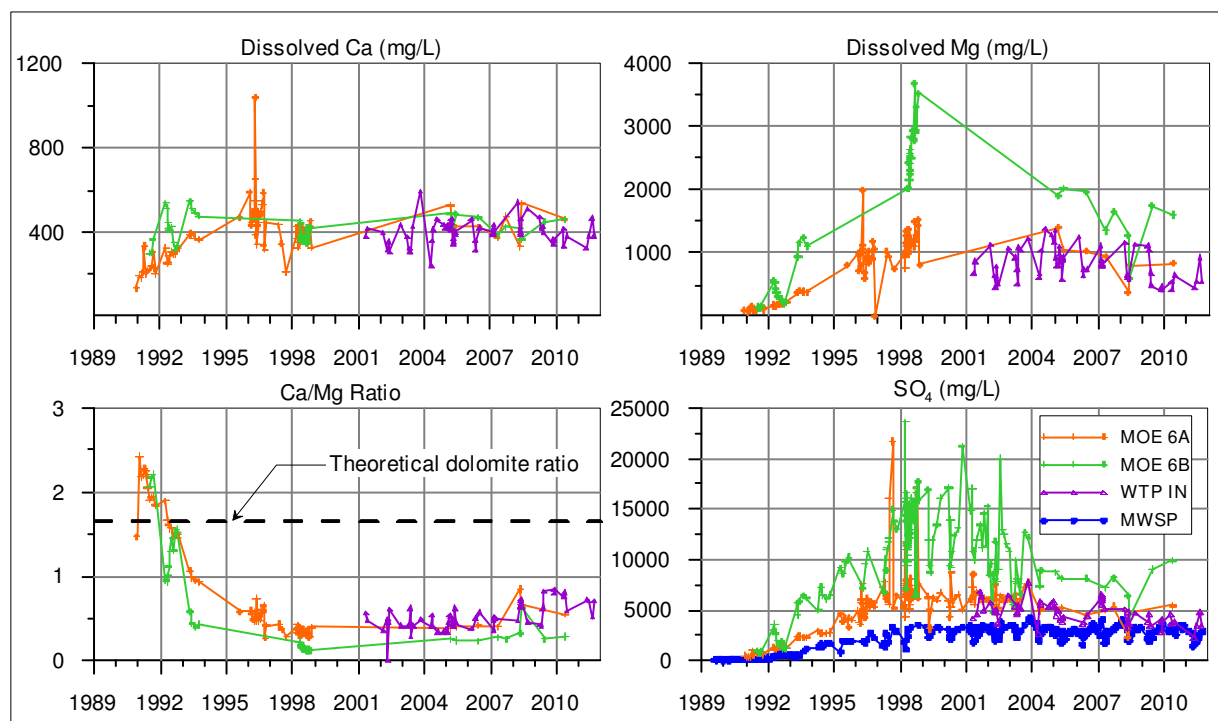


Figure 7. Time base plot of Ca and Mg concentrations, Ca/Mg ratio, and sulphate concentrations in waste dump discharge

Sulphate concentrations in waste dump discharge exhibited an increasing trend from 1992 until 1997/1998, when peak concentrations reached >20,000 mg/L (Figure 7). They have since declined, and now range between 5,000 and 10,000 mg/L, with the highest concentrations measured in the small seep at MOE6B. The peak sulphate concentrations in 1998/1999 were likely associated with the initial onset of AD, and the wet weather experienced from 1996 to 1998, which will have added moisture to the waste rock. Recent sulphate concentrations have been lower, likely due to some blinding off of pyrite surfaces

to oxidation. Sulphate monitoring data for the MWSP indicate that sulphate concentrations have been stable since about 1998, but this will have been largely dependent on the treatment provided by the WTP, and the solubility of sulphate. The average MWSP sulphate concentration of about 2800 mg/L suggests that magnesium sulphate is the predominant dissolved species.

Sulphate loading discharged from the waste dump increased rapidly after 1992, and peaked at about 1660 tonnes/year in 1999 (Figure 8). Sulphate loading released from the waste dump has fluctuated between about 500 and 1000 tonnes/year over the past ten years, and now appears to be relatively steady at this rate. The sulphate loading discharged from the MWSP has typically been slightly lower than from the waste dump, likely due to precipitation of some of the sulphate in the sludge.

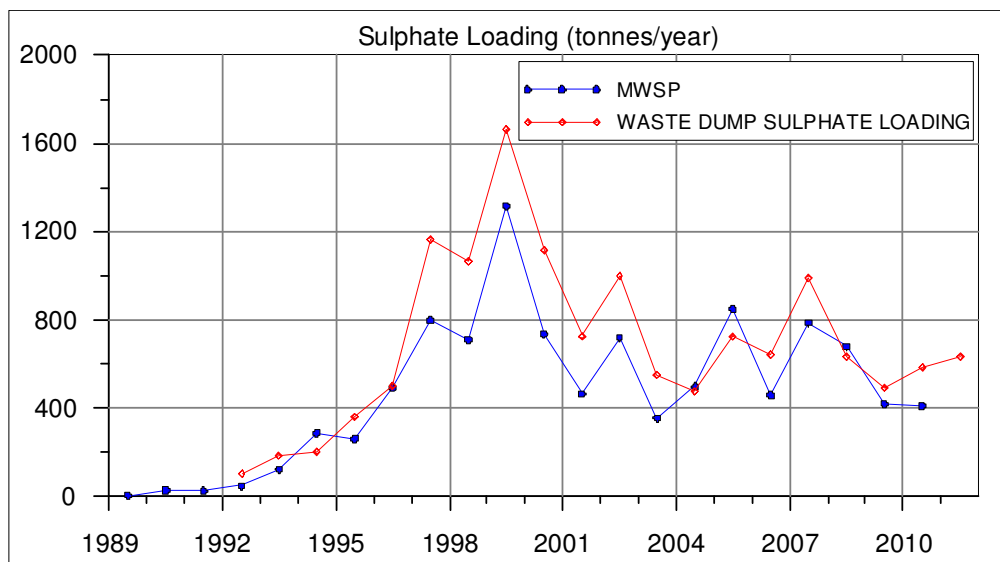


Figure 8. Annual sulphate loading from waste dump and MWSP

Estimates of the total masses of sulphur and dolomite originally placed in the waste dump are summarized on Table 4 (from Ghomshei et al, 1997). Estimates of the mass flux of sulphate, calcium and magnesium have been derived from the WTP monitoring data and from prior monitoring data. Mass balance calculations indicate that as of the end of 2010, 1.75% of the potential sulphate production within the waste dump has been discharged, and that 1.51% of the magnesium (and hence buffering capacity provided by dolomite) has been consumed. Additional sulphate has likely precipitated within the waste dump as gypsum, based on the low calcium/magnesium ratio of the discharge. The mass balance indicates that there is sufficient buffering capacity available in the waste dump to neutralize potential acid generation over the long term, subject to the availability of the carbonate in the waste rock, and variations to the flow channelling that occurs through the waste dump. However, the metals loading in the waste dump flow, the seasonal acidity in the major discharge from the waste dump at MOE 6A, and the chronic acidity exhibited by the small seep at MOE 6B, demonstrate that the available alkaline buffering capacity is insufficient to mitigate AD from the waste dump.

Table 4. Chemical Mass Balance and Summary of Waste Dump Discharge

Total Sulphur in Waste Dump	250,000	tonnes						
Total Sulphate Equivalent	749,000	tonnes						
Total Dolomite in Waste Dump	1,100,000	tonnes						
Total Magnesium Equivalent	144,100	tonnes						
Year	Mass Flux From Dump			Ca/Mg Ratio ¹	Flux From Waste Dump as % of Initial Content			
	(tonnes/year)				Sulphate		Magnesium	
	SO ₄	Ca	Mg		Annual	Cumulative	Annual	Cumulative
1992	100	21	16	1.31	0.01%	0.01%	0.01%	0.01%
1993	180	28	29	0.97	0.02%	0.04%	0.02%	0.03%
1994	200	27	31	0.87	0.03%	0.06%	0.02%	0.05%
1995	360	39	54	0.72	0.05%	0.11%	0.04%	0.09%
1996	500	84	137	0.61	0.07%	0.18%	0.10%	0.19%
1997	1162	48	125	0.38	0.16%	0.33%	0.09%	0.27%
1998-2000	1281	57	192	0.30	0.17%	0.85%	0.13%	0.67%
2001 to 2005	693	44	126	0.35	0.09%	1.31%	0.09%	1.11%
2006 to 2010	666	55	116	0.47	0.09%	1.75%	0.08%	1.51%

1. Stoichiometry Ca/Mg ratio for dolomite (on molecular wt. basis) is 1.645. A value below this may indicate significant precipitation of calcium and sulphate as gypsum.

Sludge Management

WTP sludge generated (in excess of HDS sludge recycle needs) is discharged from the treatment plant clarifier via 50 mm pipelines to holding/drying sludge ponds located immediately below the WTP (Figure 5). Most of the sludge is produced during the freshet period and the annual pre-winter pit pond drawdown.

Every four to six years the sludge ponds are emptied using an excavator and truck (Photo 2). The consolidated sludge is then transported to the sludge storage facility located at the old millsite near the tailings dam (Figure 1 and Photo 3).



Photo 2. Excavation and haulage from ponds below WTP



Photo3. Sludge storage facility. Recent load sludge from truck on right, 2005 pile on left.

The storage facility will eventually require capping and vegetation. Inmet is conducting vegetation and capping tests using a variety of trees, shrubs and reclamation grass mix (designed and periodically reviewed by Stantec (CEJones)).

Quarterly WTP sludge samples are tested for pH, metals, and leachability. In-situ sludge piles at the storage facility are also shake flask tested as an aid in determining the 'leachability' or potential for remobilization of metals contained within treatment plant sludge. In addition to the above sludge testing, long-term water quality testing at a runoff collection pond downstream of the sludge storage facility has been ongoing and will continue for the foreseeable future.

Samples of Samatsum sludge have been included in the MEND sludge characterization project being conducted by Lorax Environmental Services Ltd. The objectives of this program are to use high-resolution microscopy methods to identify the primary metal-bearing phases in the sludge materials, and to link sludge composition with AD influent chemistry.

Summary

Monitoring data compiled to date demonstrate that the water cover over the Samatsum tailings is an effective AD mitigation measure. Layering of PAG waste within the potentially acid consuming MAF waste in the waste rock dump has not been effective. A lime treatment system was necessary six years into the closure period. The HDS treatment system has proven to be an effective method to treat drainage from the waste dump and open pit.

A mass balance calculated from available monitoring data indicates that about 1.75% of the pyrite contained in waste dump was oxidized by 2010, and that a slightly smaller percentage of the dolomite has been consumed.

Onsite HDS sludge management is achieved with two sludge ponds located below the WTP. The sludge is allowed to dry and consolidate in the ponds for between 2 and 4 years, and is then moved to an on-site storage area for further drying and stockpiling. Evaluations for long term sludge management are ongoing.

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