THE FLOODED TAILINGS IMPOUNDMENT AT THE EQUITY SILVER MINE

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ABSTRACT

The Equity Silver Mine operated between 1980 and 1994, producing silver, gold, and copper from three open pits and a small underground operation. Mine components include a flooded tailings impoundment constructed from till, and waste and quarried rock. This paper describes the initial design and subsequent performance of the flooded tailings impoundment. Materials disposed in the tailings impoundment include tailings, lime treatment sludge, cyanide and acidic drainage.

Key Words: underwater disposal, cyanide, drainage chemistry, mine closure

INTRODUCTION

The Equity Silver mine, now owned by Goldcorp Canada Ltd., is located in central British Columbia, 35 km southeast of the town of Houston, at latitude 54 degrees 11 north and longitude of 126 degrees 15 east. The mine operated from 1980 to 1994, producing primarily silver with some additional gold and copper from three open pits and a small underground operation. The primary economic minerals were tetrahedrite and chalcopyrite. Site components include a contiguous series of waste rock dumps, a plant site, a flooded tailings impoundment, and systems for clean water diversion and collection, and lime treatment of contaminated drainage.

The property is located in the rolling west central portion of the Nechako Plateau at an elevation of 1200 m. The climate is continental with less than 60 frost-free days. Snow typically remains on the ground from October to April and in an average year accounts for approximately 50 % of the precipitation. The mine discharges treated water into fish bearing creeks and the closest residents live approximately 20 kilometers below the mine.

Equity Silver is a source of information on a wide variety of aspects of prediction, treatment, and mitigation of acidic drainage from sulphidic geologic materials (Aziz and Meints 2011, Morin and Hutt 2010, Price 2007 and Price et al. 2011). This paper describes the initial design and subsequent performance of the tailings impoundment.

IMPOUNDMENT DESIGN

The tailings impoundment has dams on the north, west and south sides (#1, Diversion, and #2 dams respectively), and is constrained by a natural slope on the eastern side (Figure 1). The impoundment has a surface area of 120 ha with very little additional catchment if the diversion ditches are operational. An emergency spillway capable of passing the probable maximum flood (PMF) is located on natural rock at northeast corner at 1292.5m elevation. The spillway reports to the Berzelius Diversion, which limits drainage input into the impoundment from the higher natural ground on east side above the impoundment. The Berzelius Diversion flows into Foxy Creek at the north end of the property.

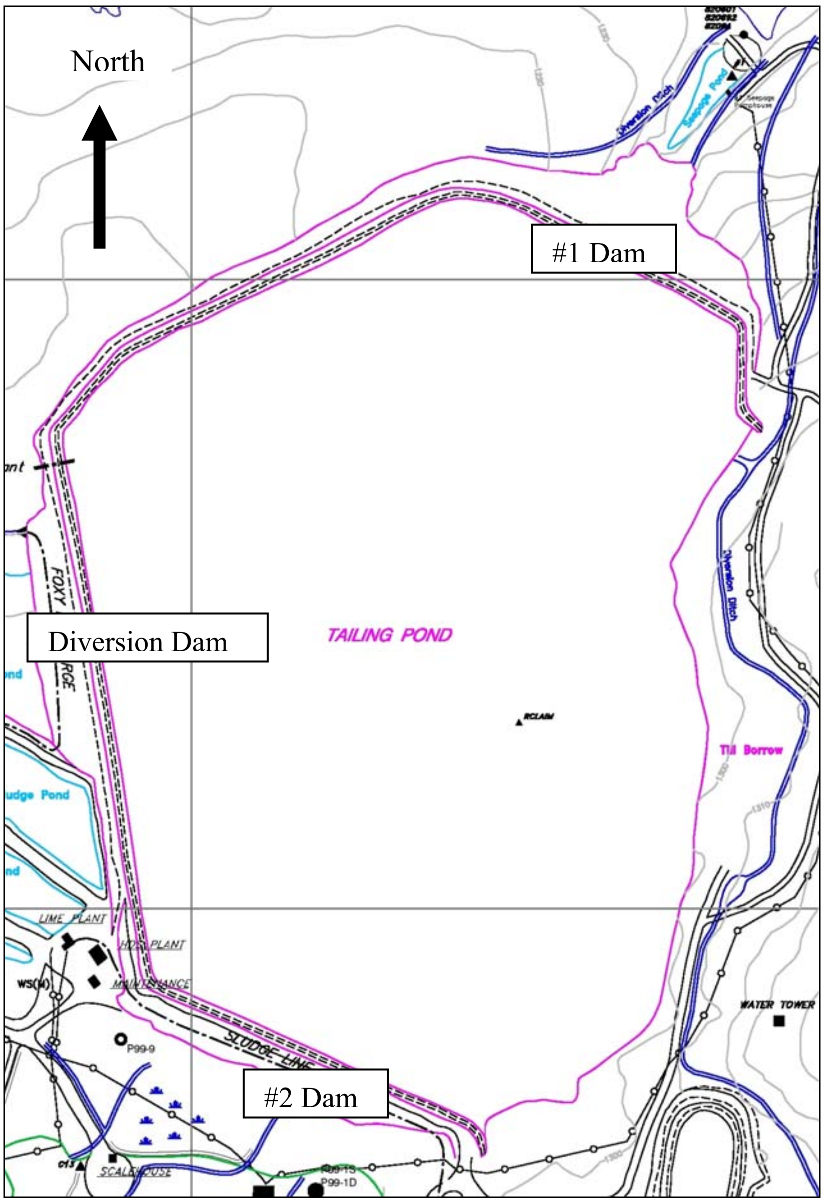

Figure 1. Map of Tailings Impoundment

The tailings dams were designed for water retention and constructed of compacted rockfill with an impervious glacial till membrane on the upstream slope. A transition zone was included between the till and downstream rockfill shell. Potentially acidic waste rock was used to construct initial lower lifts of the downstream portion of Dam #1. Subsequent to 1983, dams were built with not potentially acidic (NPAG) monzonite and gabbro rock, primarily from the pits and supplemented with rock from a quarry. The water cover abuts the dams and rip-rap protects the till dam above the tailings from erosion by wave action.

As required by the BC Ministry of Mines, the tailings impoundment and other areas of the site have an Operations, Maintenance and Surveillance (OMS) Manual and Emergency Preparedness Plan. The tailings impoundment dams are classified as very high consequence of failure according to the Canadian Dam Association 2007 Dam Safety Guidelines (AMEC 2012). The spillway design flow required for a very high consequence of failure is 2/3 between the 1:000 and probable maximum flood (PMF).

Annual monitoring and maintenance of dams includes:

- putting additional rip rap protection along the tailing dams and repair of erosion as required,
- routine inspection of the dams and the spillway,
- removal of woody vegetation and.
- annual geotechnical review of dam stability by a qualified person.

WATER BALANCE AND DEPTH OF THE WATER COVER

Flooding of the stored wastes results from the underlying till, till layer on the dams and positive water balance. Average annual drainage inputs of 869,860 m^3/yr of direct precipitation and 66,000 m^3/yr of runoff and drainage losses of 610,000 m^3/yr by evaporation and 68,076 m^3/yr by seepage result in a net surplus of 257,784 m^3/yr, increasing the pond elevation by 0.21 m/yr (AMEC 2012). Each year the pond level is lowered to approximately 1292.00 m to accommodate storage of large spring runoff and other flood events. A 100-year annual precipitation plus a 1000-year 96-hour storm would result in a 0.90 m increase in pond level.

To date, excess drainage has been either decanted into the lime treatment discharge pond (Diversion Pond) or pumped to the Main Zone pit lake and diluted prior to discharge. No discharge has occurred to date through the spillway. Pond levels above the height of the spillway can be handled by either drainage removal or raising the height of the spillway temporarily with sandbags or till until the water level can be lowered through pumping.

The depth of the water cover over the wastes in the impoundment needs to be deep enough to ensure the wastes remain flooded during a long drought and prevent waste movement by ice or waves. The impoundment is wide and wind-swept and large waves are commonly observed.

Ripples on the surface of flooded tailings were used as evidence of the maximum depth of wave-induced tailings movement (Hay and Company 1996). No bed movement was observed beneath a depth of 1.4m. The depth of the water cover over the wastes now ranges from 1.7 to 7.5 m deep.

SEEPAGE THROUGH #1 DAM

Seepage through the #1 Dam contacts acidic waste rock in the toe of the dam, becomes acidic, and is collected in a seepage pond named #1 Dam Seepage (Figure 2). During mining, ARD from #1 Dam Seepage was pumped into the tailings impoundment to increase cyanide degradation and lower the pH of the water sufficiently for re-use in the mill. Since mine closure, drainage from #1 Dam Seepage has been pumped to a holding pond and treated using lime along with drainage from the waste rock dumps and plantsite. Other smaller seepages from the tailings impoundment occur through the Diversion Dam into the Diversion Pond and through #2 Dam into the ARD collection system. These smaller seepages are much lower in volume and are not acidic since the rockfill for those dams was NPAG.

Acidity from the #1 Dam Seepage Pond increased rapidly from 1981 to 1982 and exceeded 10,000 mg $CaCO_3$eq /L from 1983 to 1989. Since 1989, acidity has steadily decreased and is now less than 1500 mg $CaCO_3$eq /L. It is theorized that the decrease in acidity is due to the depletion of finer, more reactive sulphides and a higher ratio of drainage to exposed rock than large waste rock dumps. The average volume of seepage from the #1 Dam is 68,076 m^3/yr, approximately 20% of the volume, but only 4% of the acidity load that the site needs to treat. Improvements to the collection of acid water below the #1 Dam have included diversion ditches to reduce the volume of uncontaminated drainage that is collected and purchase of a diesel generator to provide power for the pumps in the event of a power failure.

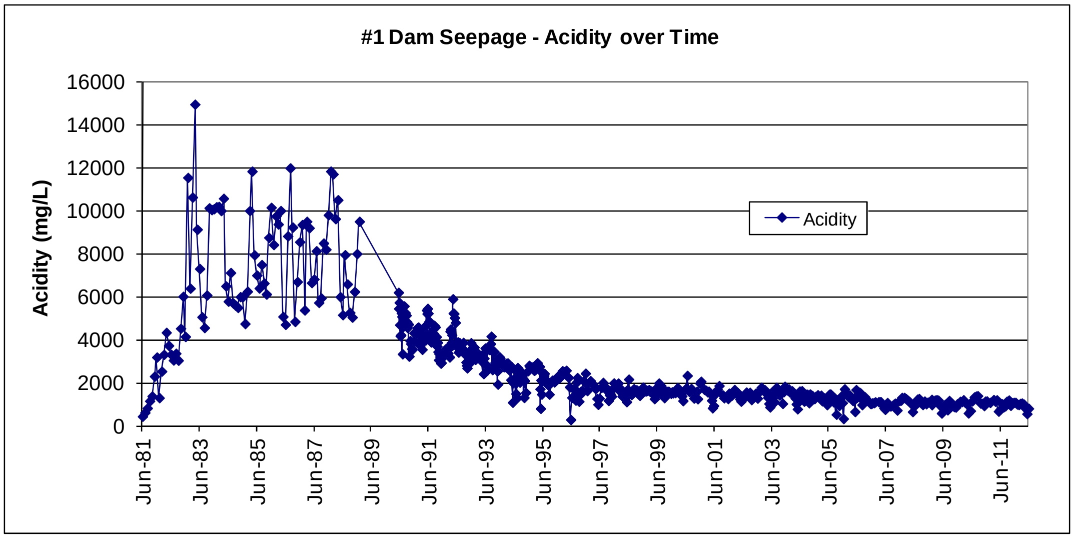

Figure 2. Concentration of acidity in drainage from #1 Dam

MATERIALS DISPOSED IN TAILINGS IMPOUNDMENT

Materials disposed in the tailings impoundment include:

- Tailings 33.7 Mt
- Lime treatment sludge (95% moisture) 974,385 m^3
- Bulk sulphide 30,000 t
- Pit waste rock (dam construction) 4.6 Mt
- Sodium sulphate landfill 2,500 t

During mining, concentrate was produced from the ore using conventional crushing, grinding, flotation and dewatering circuits. In 1984, a cyanide scavenger circuit (carbon in leach) was constructed to extract additional gold and silver. Cyanide (CN) was reduced during milling using the Inco SO_2 process and natural degradation in the impoundment.

During the early phases of mining, the mill process was modified to include a plant to leach arsenic and antimony from the concentrate. The resulting As and Sb were shipped off site. A short time after start-up of the leach plant, penalties for high arsenic and antimony in the ore declined and in April 1984 the leach plant was closed. A portion of the leach plant was then retooled to convert molybdenum trioxide concentrate from the Endako Mine from technical to chemical and catalytic grade. The upgrade of the molybdenum concentrate started in January 1985. In September 1987, the market for this product declined and the circuit closed. There is no record of whether the molybdenum conversion produced any waste products and if so where they were disposed.

The mill processed approximately 9,000 tonnes of ore per day. Limited sampling in 1995 indicates tailings have 4.8 to 8.2% S and 6 to 26 kg $CaCO_3$eq/t NP. Tailings produced by the mill were deposited in a flooded impoundment. Flooding has prevented sulphide oxidation, minimizing metal release and preventing tailings from producing acidic drainage.

Average daily inputs into the impoundment in 1990: tailings 8,558 t/d; slurry 17,212 m^3/d; MIBC (methyl isobutyl carbinol, $C_6H_{14}O$) 334 kg/d; lime 8,053 kg/d; sodium cyanide 3,732 kg/d; sulphur dioxide 4,110 kg/d; caustic (NaOH) 290 kg/d; nitric acid 878 kg/d; xanthate 116 kg/d and copper sulphate 738 kg/d. Average daily output from the impoundment in 1990: recycled water 14,218 m^3/d.

POST-CLOSURE CHANGES

After the mill closed, CN continued to be reduced by natural degradation. By 2003, natural degradation had decreased CN levels from 4.5 mg/L to 0.007 mg/L and thiocyanate was below detection (0.5 mg/L). Total cyanide levels in 2009 were below the detection limit (< 0.005 mg/L). CN decomposition produced ammonium (NH_4^+) levels which reached values as high as 90 mg/L in 1996 (Figure 3). Phosphorous fertilization was considered as a means to accelerate NH_4^+ decomposition but rejected due to concerns about remobilization of treatment sludge and other secondary wastes. Since 1997, NH_4^+ has steadily decreased and since 2009 has averaged less than 0.3 mg/L.

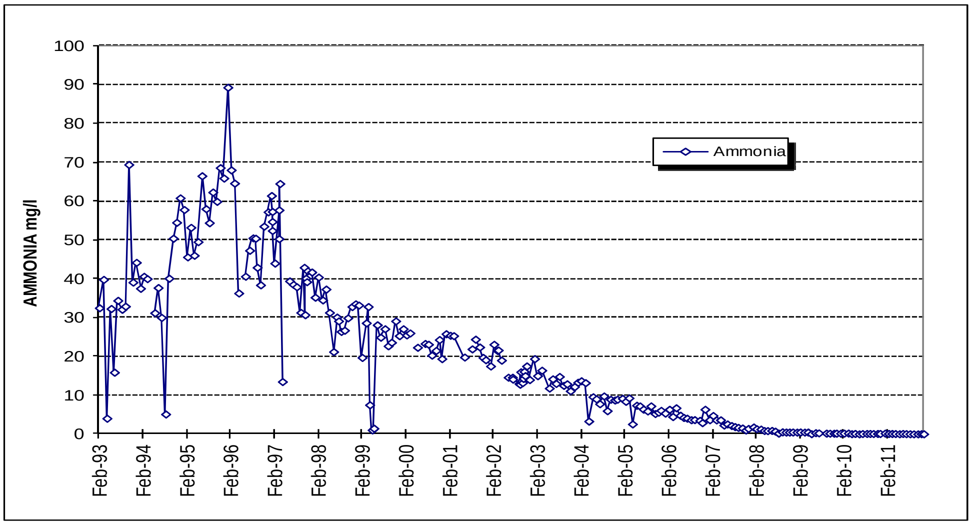

Figure 3. Concentration of ammonium in tailings pond (Aziz and Meints, 2012)

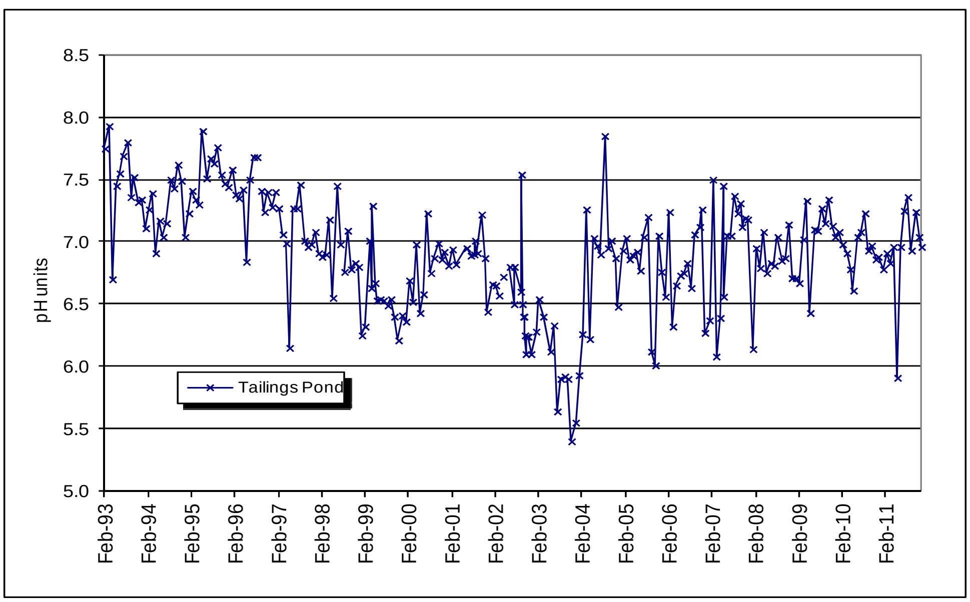

Figure 4. pH of tailings pond (Aziz and Meints, 2012)

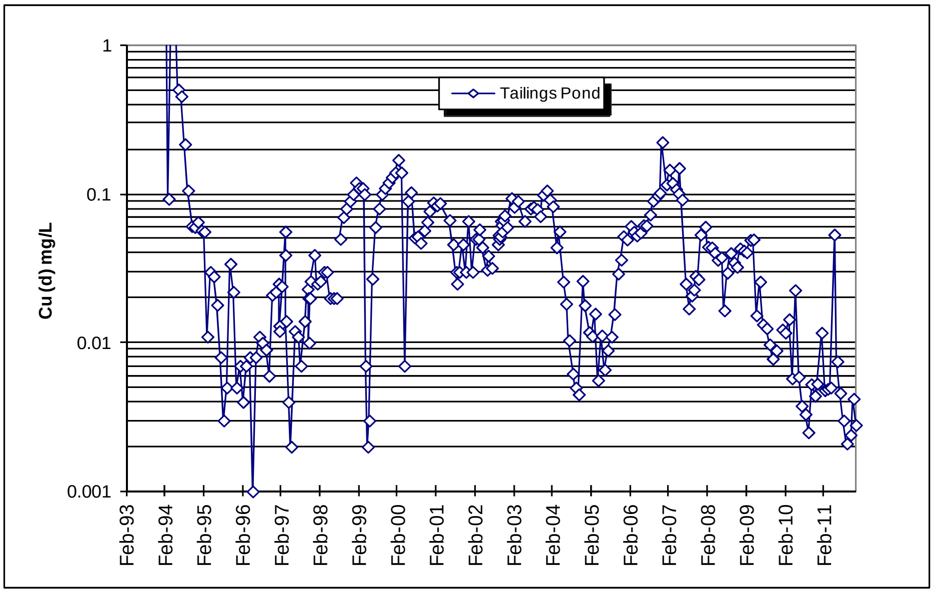

Figure 5. Concentration of copper in tailings pond (Aziz and Meints, 2012)

Sampling of the water cover is done around the sides of the impoundment or from the discharge during decant/pumping periods. Anomalously low Cu and pH values (Figures 4 and 5) often occur in the spring (e.g., in 1997, 1999 and 2000) when the ice is melting and the water cover is stratified with cold melt water on surface. Low Cu and pH values at these times reflect the chemistry of on land runoff and snow melt rather than changes to the chemistry of water cover.

At the time the mine closed (1994), the pH of the water cover was 7 to 8 (Figure 4) and there was a large, more than two orders of magnitude decrease in dissolved Cu (Figure 5). In 1997, dissolved Cu was less than 0.01 mg/L.

In 1997, the pH of the impoundment started to decrease (Figure 4) and dissolved Cu and Zn started to rise (Figure 5). By 2000, the pH had decreased to less than 6.5 and Cu(d) and Zn(d) had increased to 0.2 mg/L. The decline in pH was attributed to depletion of lime added with process water and treatment sludge when the mine was operating and acidity inputs from 866,000 m^3/yr of pH 5.5 incident precipitation.

Three peepers were inserted in tailings to locate the source of increasing Cu. The peeper in the southern corner, the location of sludge inputs, fell over ("became dislodged and was not processed for fear of compromised sample integrity"). Based on results from the peeper near to the #1 Dam, it was postulated that the source of Cu and Zn was remobilization of pH sensitive hydroxides ($Cu(OH)_2$ and $Zn(OH)_2$) created (precipitated) when ARD from #1 Dam was pumped into and neutralized in the impoundment (Lorax, 1999). Other potential Cu sources were lime treatment sludge and 738 kg/d of $CuSO_4$ added in the process water.

Approximately 51 and 23 tonnes of lime slurry were added to the impoundment from tanker trucks during the second and third quarters in 2000 and 2001 to raise the pH (Table 1). The pH was monitored and lime was added incrementally in small doses to ensure the pH did not get too high and dissolve other contaminants. The amount of lime added was calculated to neutralize acidity added from 5 years of rain and snow. The addition of lime caused the pH to increase from an average of 6.2 in 1999 to above 6.8 in 2001 . Copper values decreased from a high of 0.2 mg/L to a less than 0.06 mg/L.

Starting in 2002, the pond pH again decreased reaching a low of pH 5.4 and Cu concnetrations increased. Based on advise from a helpful regulator that some consider a lucky guess confirmed by rigorous limnocorral results, it was concluded that the primary cause of the decline in pH was acid produced by nitrification of ammonium produced from the degradation of CN rather than the original hypothesis that the main acid source was incident precipitation (Equation 1).

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O \qquad (1)$$

A modeling exercise was used to predict how much lime was required to neutralize acid from oxidation of NH_4^+ (Lorax, 2003) Again using a cautious, incremental additions approach to ensure the pH was not raised too high, 88 and 35 tonnes of slaked lime slurry were added to the tailings pond in 2003 and 2004. The addition of lime caused the pH to increase from an average of 6.0 in 2003 to an average 6.8 in 2004 . Copper values in 2004 decreased from a high of 0.092 mg/L in January to lows of 0.005 mg/L in September and October.

In 2005/2006, the pH again decreased to below 6.5 and Cu increased to above 0.1 mg/L. To counteract this, 7.92 tonnes of lime slurry was added in 2006 and 32.0 tonnes of lime slurry was added during the summer of 2007. Since the last lime addition in 2007, the pH has remained above 6.5, with an average pH between of 6.83 and 7.02 for the years 2007 to 2011. Average dissolved Cu decreased from 0.038 mg/L in 2008 to 0.025 mg/L in 2009 and was below 0.010 mg/L for 2010 and 2011. Average dissolved zinc decreased to 0.128 mg/L in 2008, 0.109 mg/L in 2009 and was less than 0.08 mg/L for 2010 and 2011.

Table 1. Tonnes of lime added to tailings pond (Aziz and Meints, 2012)

Year	Tonnes of Lime
2000	50.6
2001	23.0
2003	87.8
2004	34.6
2006	7.9
2007	32.0
Total	235.9

The stable pH since 2007 is correlated with the depletion of NH_4^+ and supports the hypothesis that the main source of acid was ammonium oxidation rather than incident precipitation (Figure 6). The low ammonium concentration indicates relatively little acidity will be generated in the future by the nitrification of ammonium. Future lime slurry additions are only planned if the pH needs to be raised to suppress Cu solubility. The steady decline in dissolved Cu since 2007 (Figure 5) suggests that the soluble Cu precipitates near the surface of the flooded tailings have been depleted.

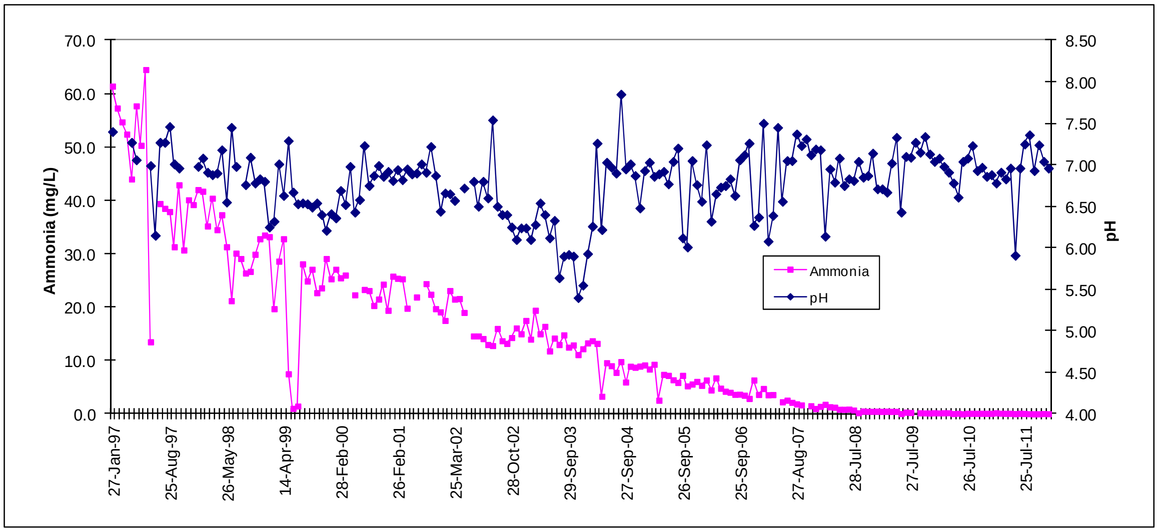

Figure 6. Changes in ammonia and pH over time

Until recently dilution of the annual discharge from the tailings impoundment has been required to lower Cu and NH_4^+ concentrations sufficiently to meet discharge limits. Dilution of excess tailings water was achieved by pumping tailings pond water to the Main Zone Pit or the Diversion Pond. Currently the discharge permit only allows discharge from the site from either the Main Zone Pit or the Diversion Pond.

FUTURE CONSIDERATIONS

An important component of a successful program to prevent impacts from sulfidic materials is the requirement to handle changing conditions. Properties of the tailings impoundment, such as drainage inputs, water quality and biological activity are continually changing, and may change future drainage chemistry (e.g., metal concentrations).

Presently the shallow tailings pond contains relatively little aquatic vegetation. Eventually there is likely to be more extensive plant invasion increasing the organic content of the upper layer over the mine wastes (Figure 7). A question regarding the long-term performance of the impoundment is whether accumulation of organics and more reducing conditions in the flooded mine wastes will release trace elements such as arsenic and antimony co-precipitated within lime treatment sludge. Released elements may re-precipitate in situ as sulphides or be released into the water cover. The arsenic concentration in the pond of approximately 3 ug/L between 2009 and 2011 was low and within historical levels. If treatment is required in the future, the water would be routed from the tailings pond to the HDS plant.

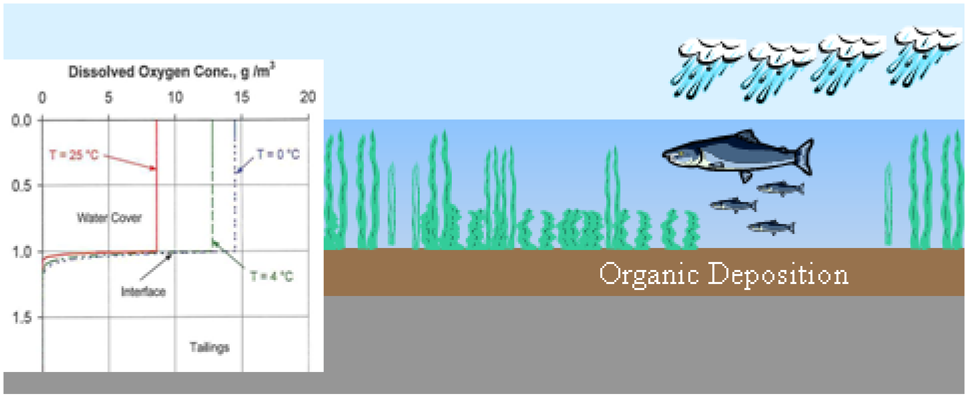

Figure 7. Schematic depiction of the impact of increasing biological activity in the tailings impoundment

One management option for the tailings impoundment that has been considered, but that has not been feasible so far, has been reprocessing the tailings to recover the large amount of silver and gold. Hopefully this would also remove sufficient sulphides to make the tailings NPAG, and removing the need for a flooded impoundment. Tailings reprocessing will raise a number of environmental issues. These include the fate of the lime treatment sludge and other potentially soluble components presently intermingled with tailings, and their impact on water quality.

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