The Flooded Tailings Impoundment at the Equity Silver Mine

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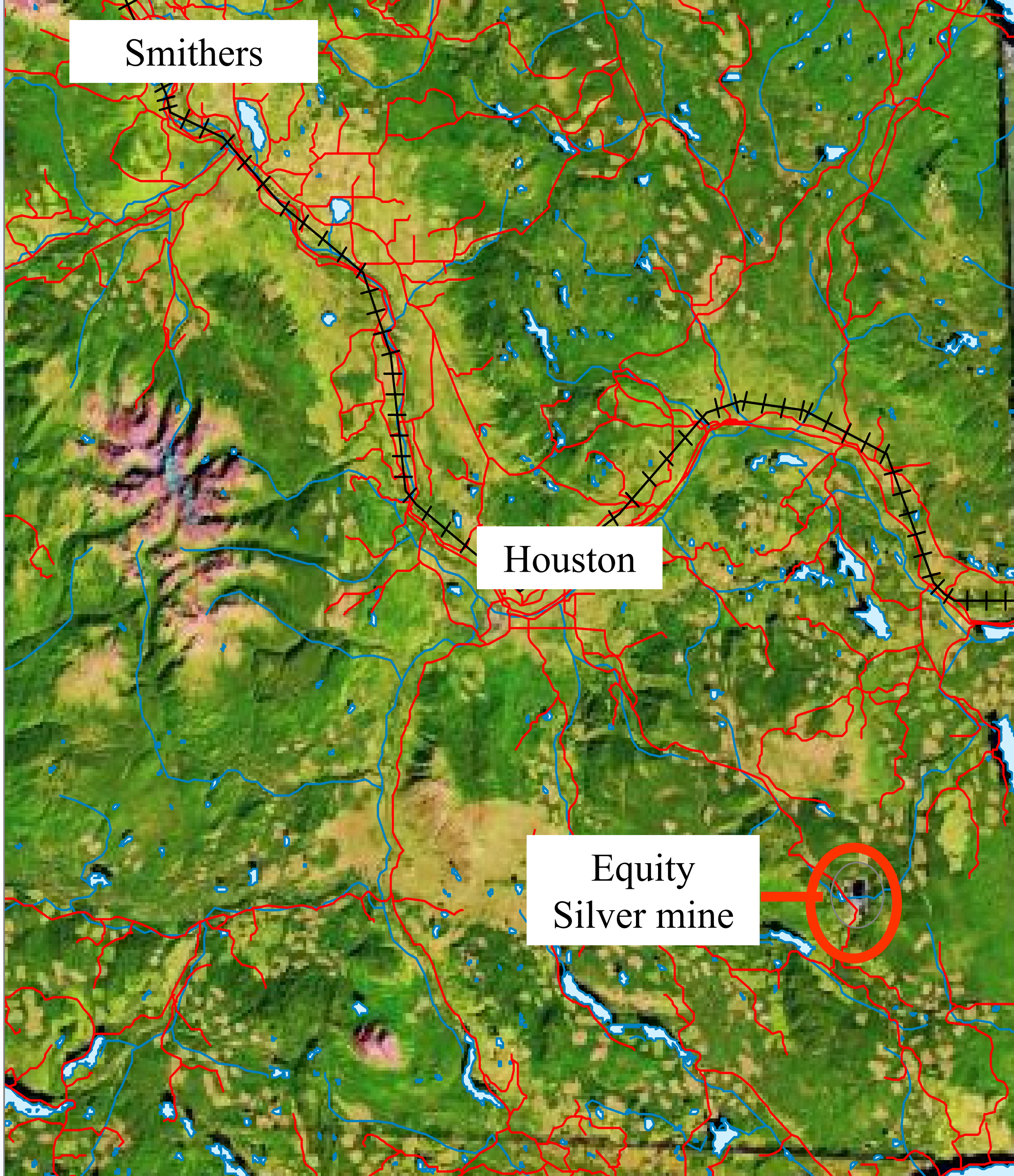
Mike Aziz and flooded TMF

Equity Silver is in central British Columbia.

The mine operated between 1980 and 1994, producing silver with lesser amounts of gold and copper.



Site components include three open pits, a small underground, a plant site, a contiguous series of waste rock dumps, and a flooded tailings impoundment.

The deposit is subvolcanic with pyrite the most abundant sulphide. Pyrrhotite is also present and ore minerals include tetrahedrite and chalcopyrite, galena and sphalerite.

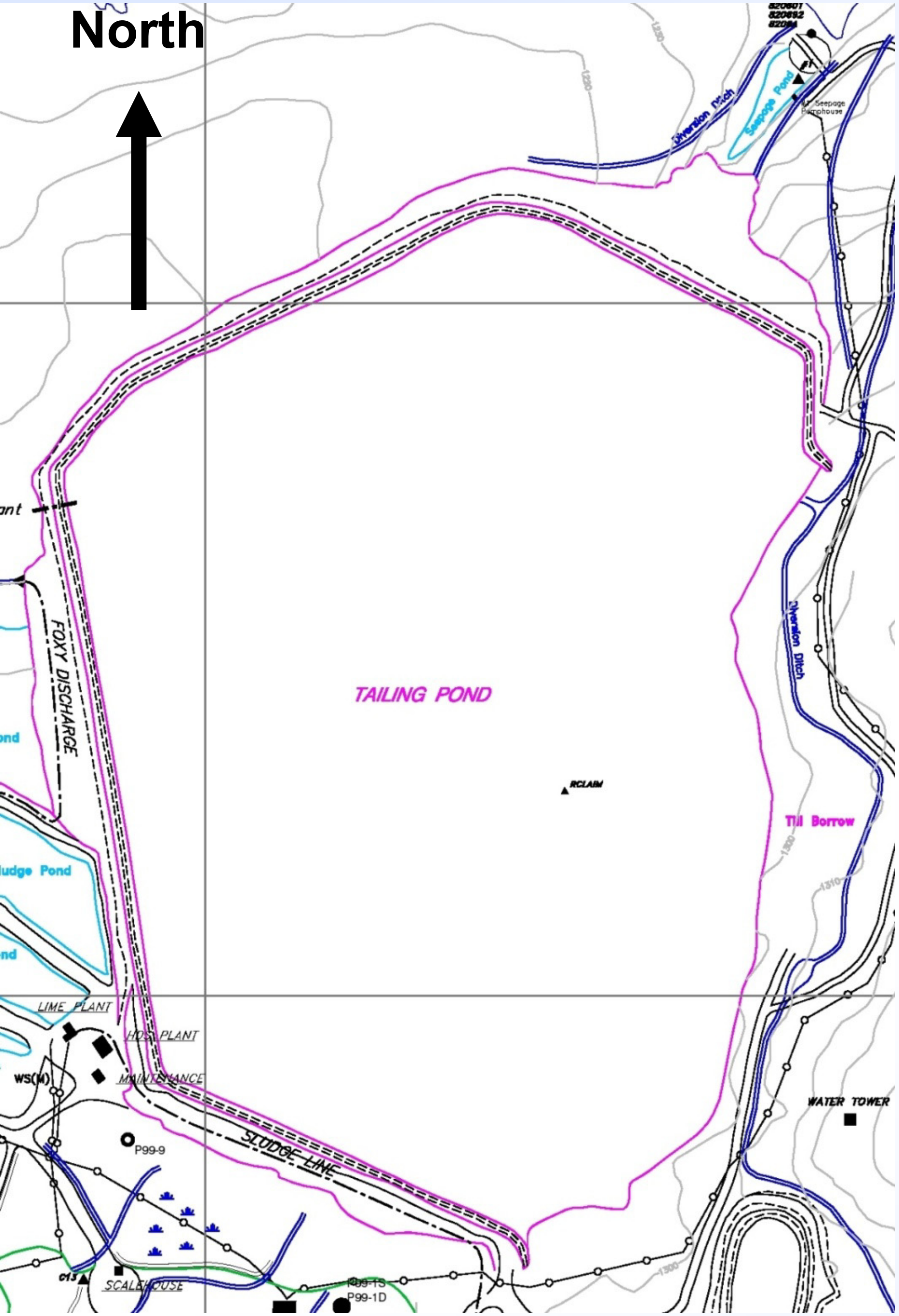
Most papers about Equity focus on the ARD generating dumps.

This paper describes the performance of the flooded tailings impoundment.

The impoundment has dams on north, west and south sides, and a natural slope on eastern side.

Surface area is 120 ha with very little additional catchment.

Spillway in northeast corner is capable of passing the probable maximum flood (PMF).



Water Balance

<u>Drainage inputs:</u>

869,860 m^3/yr precipitation

66,000 m^3/yr runoff (very little additional catchment)

<u>Drainage losses:</u>

610,000 m^3/yr evaporation

68,076 m^3/yr seepage

<u>Net surplus:</u>

257,784 m3/yr, decanted into treated effluent Pond or pumped to Main Zone pit.

To date, no discharge through spillway.

Dams were constructed of compacted rock fill with an impervious till membrane on the upstream slope for water retention.

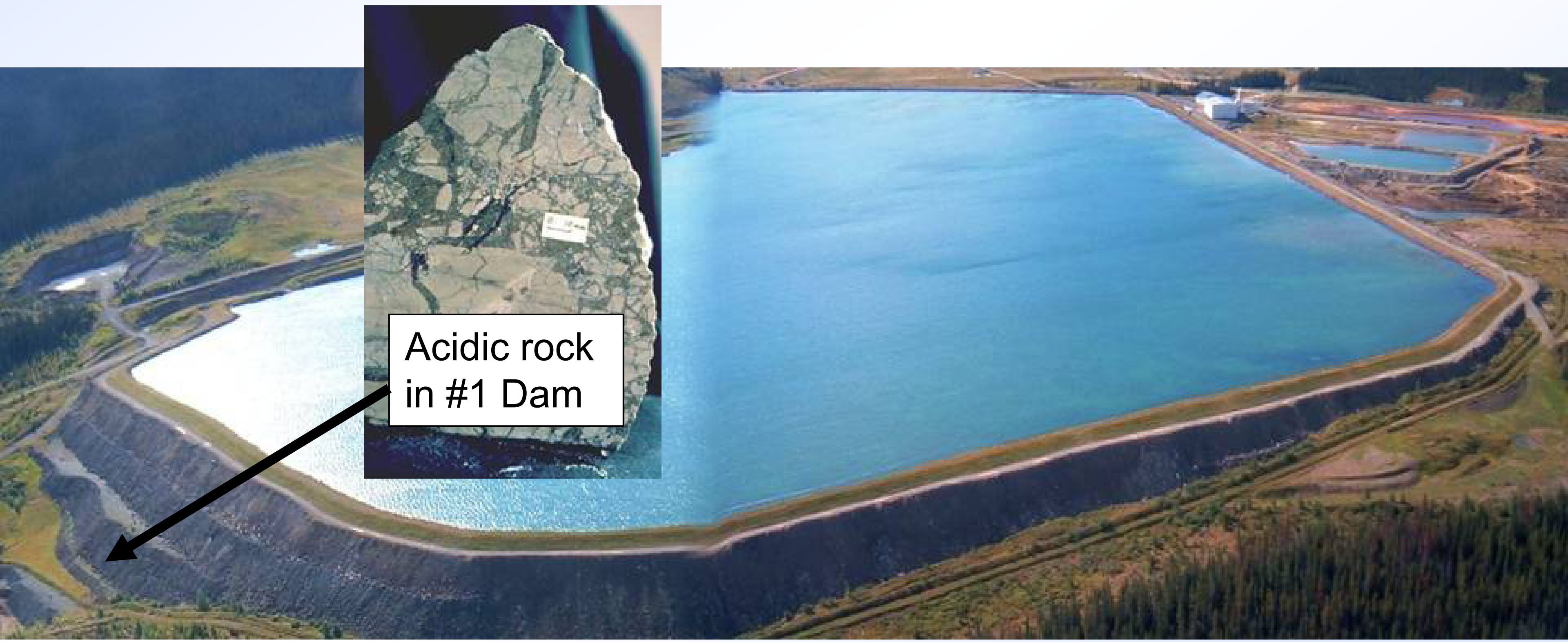
Annual dam monitoring and maintenance includes:

- routine inspection of dams and spillway,
- adding rip-rap and repairing erosion as required,
- removal of woody vegetation and
- geotechnical review of dam stability.

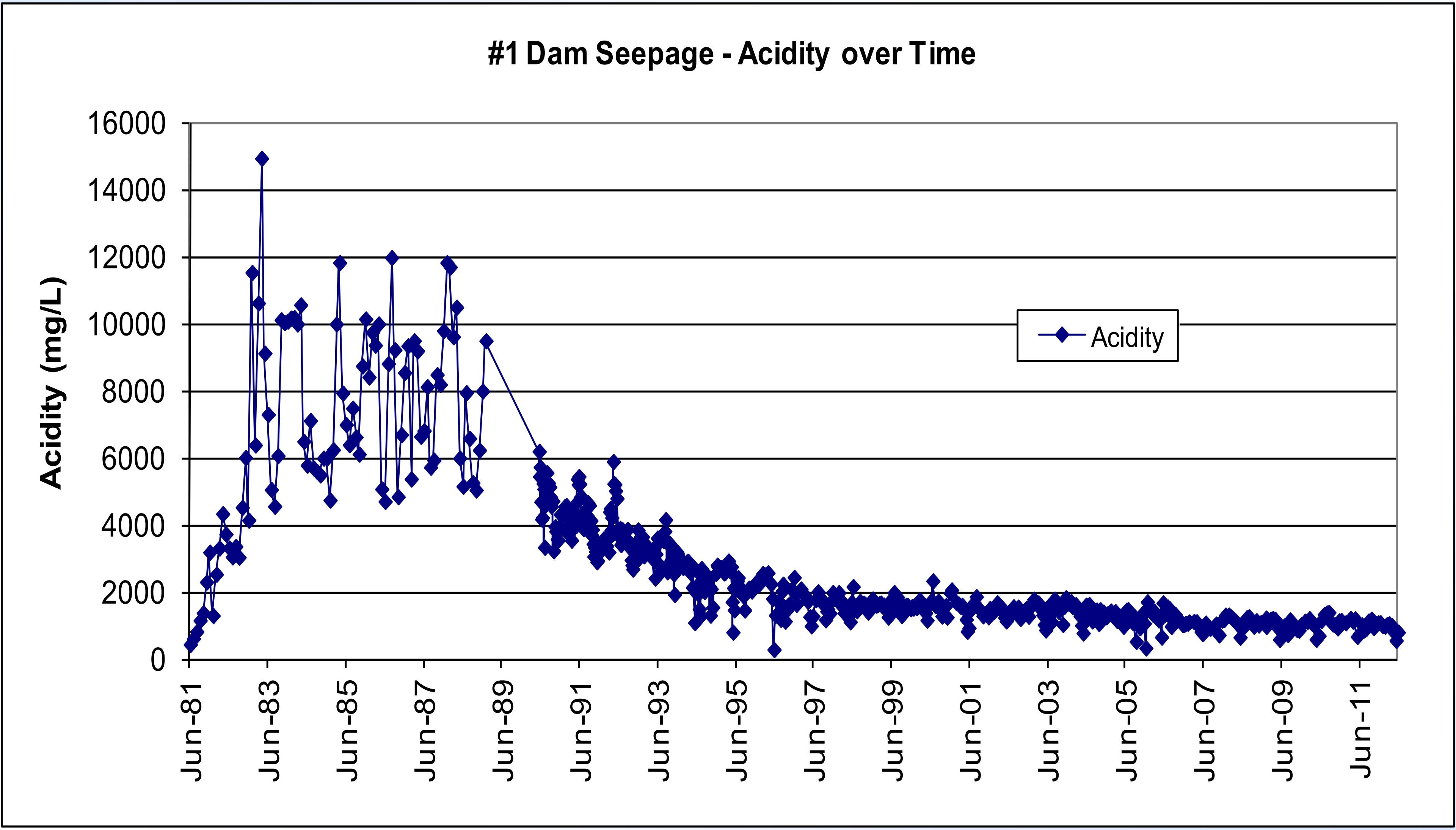
The mine initially did not recognize ARD potential and used potentially acidic rock (PAG) to construct lower lifts of Dam #1.

Subsequently dams were built with non-PAG rock.

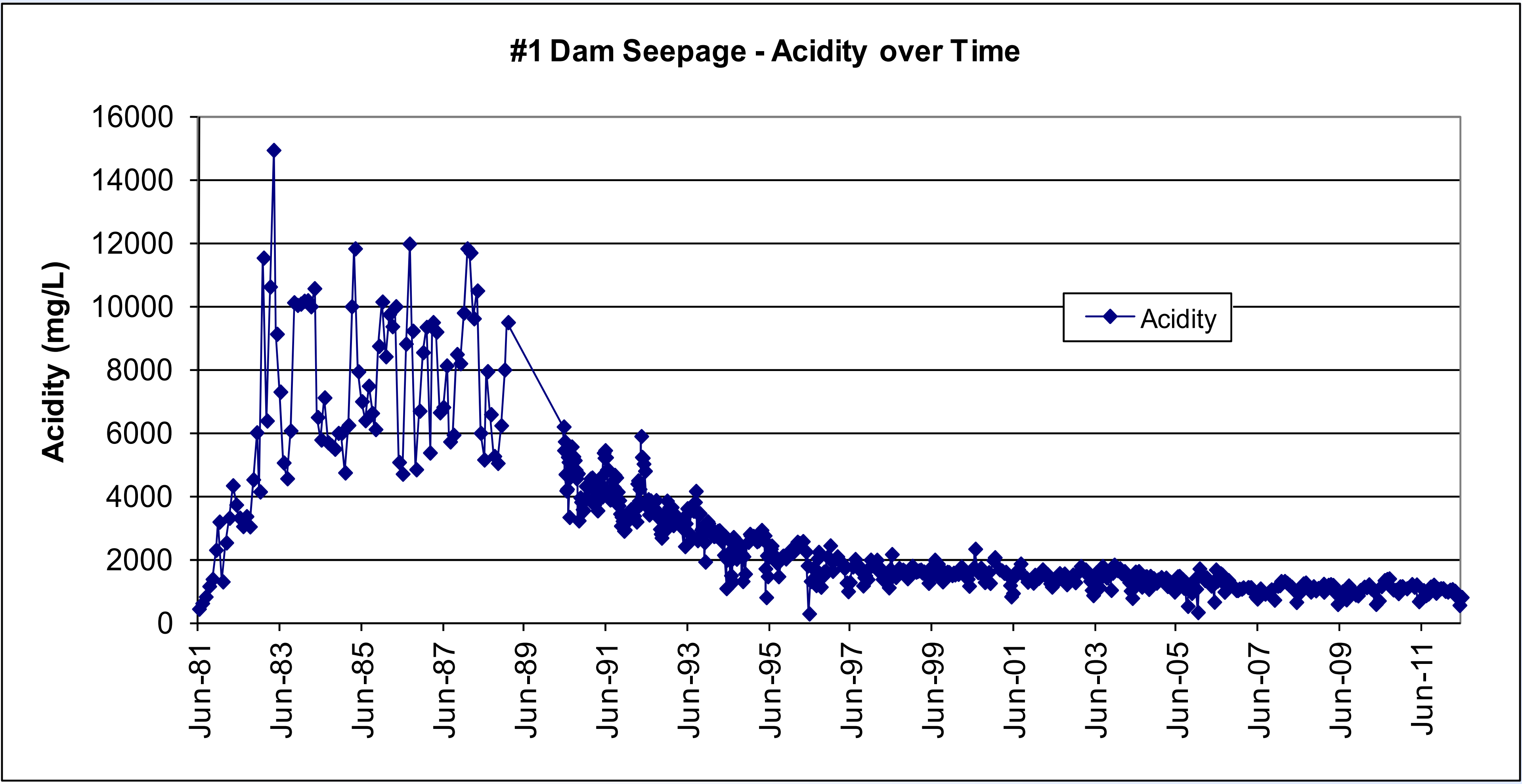
Seepage through #1 Dam contacts acidic waste rock and becomes acidic.



Acidity in seepage from #1 Dam increased rapidly and has exceeded 10,000 mg $CaCO_3$eq /L. Since 1989, acidity has steadily decreased and is now less than 1,500 mg $CaCO_3$eq /L.



A decrease in drainage acidity is not observed in drainage from the waste rock dumps. Explanations for the decrease in #1 Dam acidity are the much smaller mass of rock and higher ratio of drainage to exposed rock than the waste rock dumps.



During mining, ARD from #1 Dam was pumped into the tailings impoundment to increase cyanide degradation and lower pH of water re-used in the mill.

Since the mine closed, #1 Dam ARD has been pumped to the lime treatment plant.

Improvements to #1 Dam collection system have included diversion ditches to reduce the volume of drainage and purchase of a diesel generator to provide power for the pumps in the event of an ice storm or cause of a power failure.

Tailings in Impoundment:

- Tailings 33.7 x 10^6 tonnes
- Bulk Sulphide 30,000 tonnes

Tailings were produced using conventional crushing, grinding and flotation.

From 1985 to 1987, the mine upgraded molybdenum concentrate from another mine. There is no record of whether this process produced any waste products and if so where they were disposed.

Sampling indicates the tailings are strongly PAG with an AP of 155 to 275 and an NP of 6 to 26 kg $CaCO_3$eq/t. The water cover has impeded oxidation and subsequent acid generation and metal release.

To prevent oxidation, the water cover needs to be deep enough to ensure the tailings remain flooded during a long drought and prevent 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.

The maximum depth of ripples was 1.4m.

The depth of the water cover is maintained at 1.7 to 7.5 m.

Inputs (1990):

Tailings Solids	8,558 t/d
Slurry	17,212 m^3/d
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
Copper sulphate	738 kg/d
Lime treatment sludge	

974,385 m^3 of sludge (95% H_2O) from low density lime treatment was deposited in the impoundment when the mine was operating.

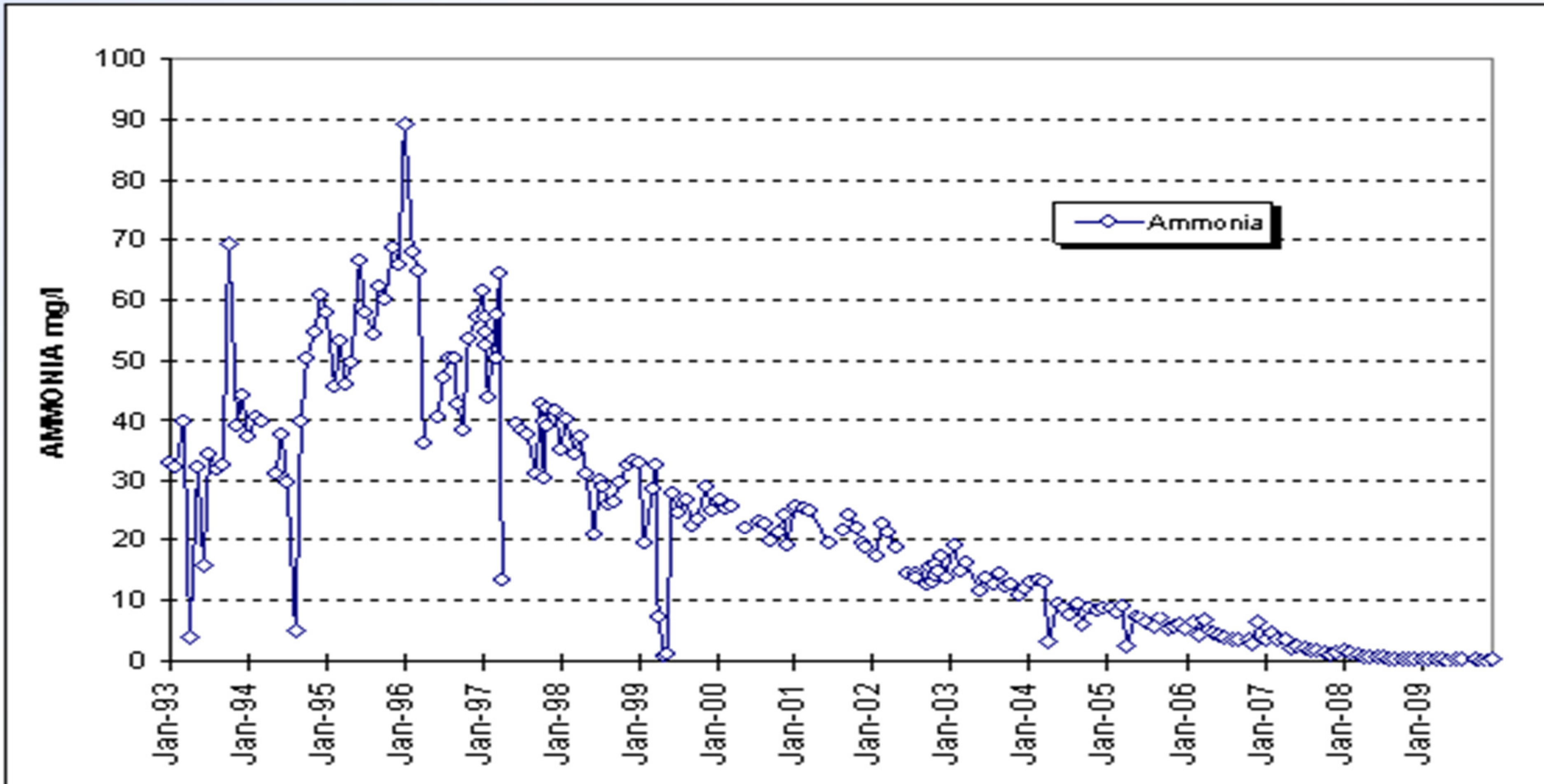
Cyanide (CN) and Its Degradation Products

In 1984, a carbon-in-leach cyanide scavenger circuit was constructed to extract additional gold and silver.

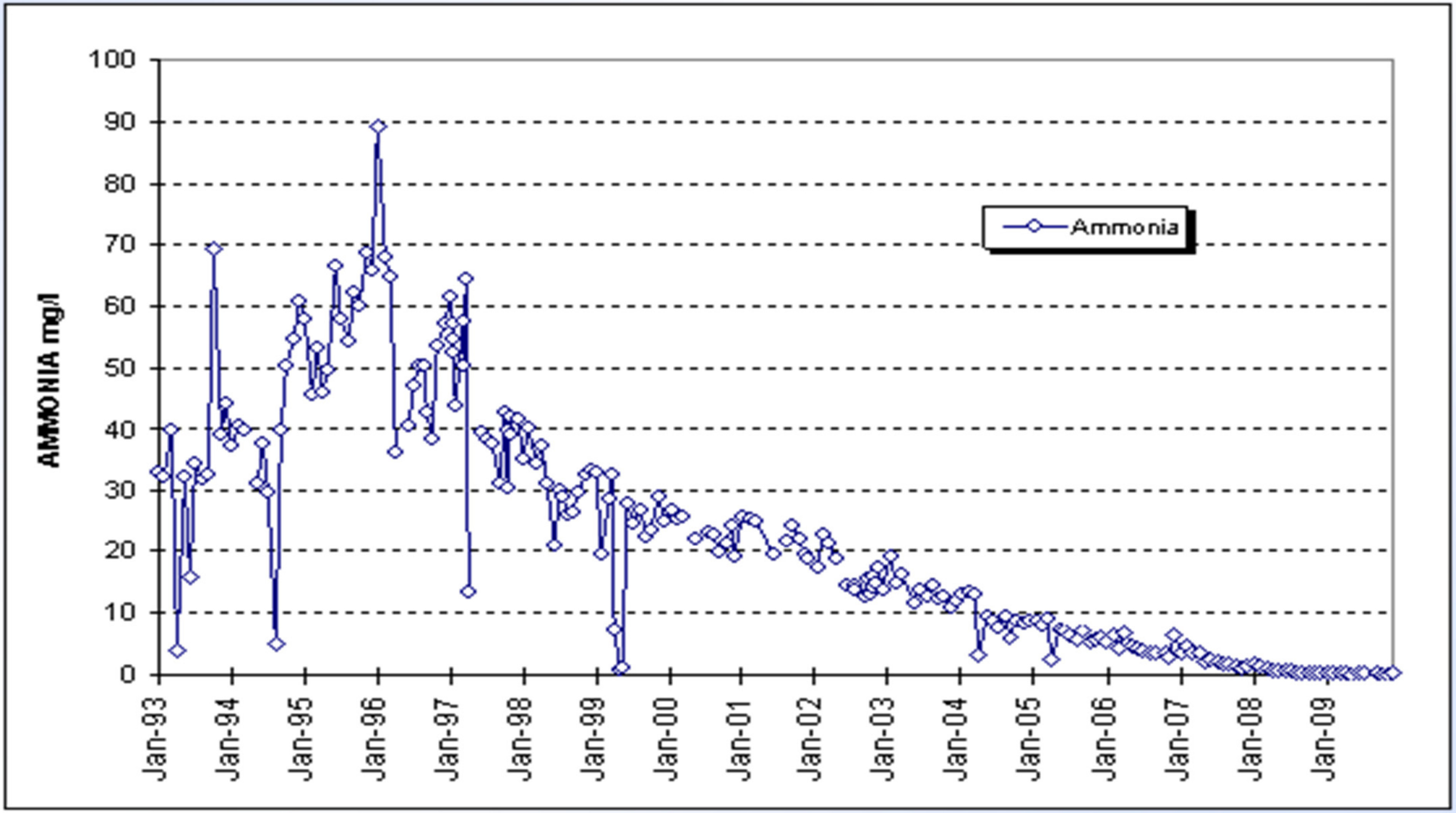
CN levels were reduced during milling using the Inco SO_2 process and after mine closure in 1994 by natural degradation.

Ten years after closure (2003), natural degradation decreased CN from 4.5 mg/L to 0.007 mg/L and thiocyanate to below 0.5 mg/L.

Sampling of the water cover is done through the year. Anomalously low solute concentrations may occur in the spring when the water cover is stratified with cold melt water on surface. Low values at these times reflect the chemistry of on-land runoff and snow melt rather than changes to the chemistry of water cover.



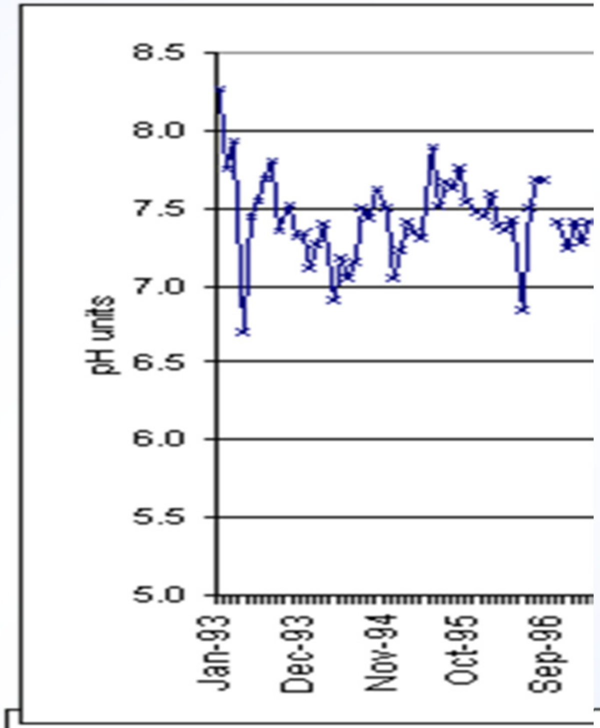
CN decomposition increased ammonium (NH_4^+) concentrations to 90 mg/L in 1996. Since 1997, NH_4^+ has steadily decreased and since 2009 has averaged < 0.3 mg/L.

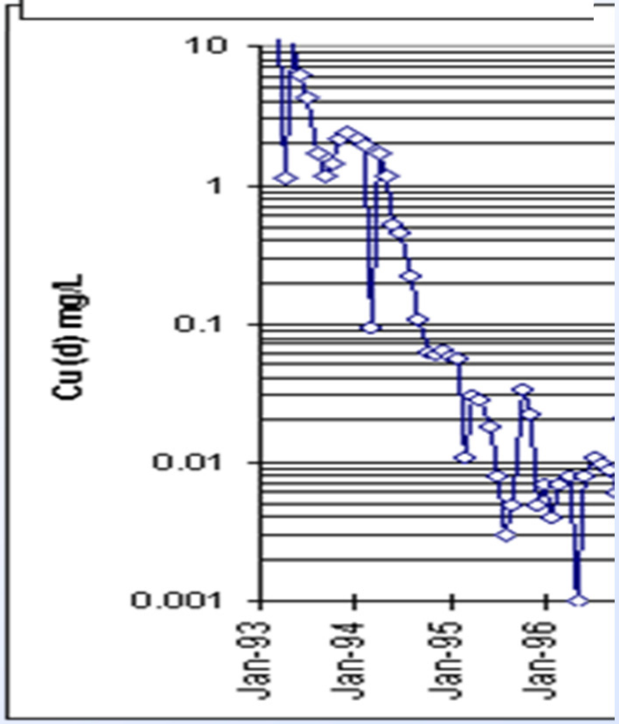


pH and Cu soon after Closure

- water cover pH was 7 to 8
- there was a more than two orders of magnitude decrease in dissolved Cu.

Dissolved Cu two years after the mine closed was less than 0.01 mg/L.



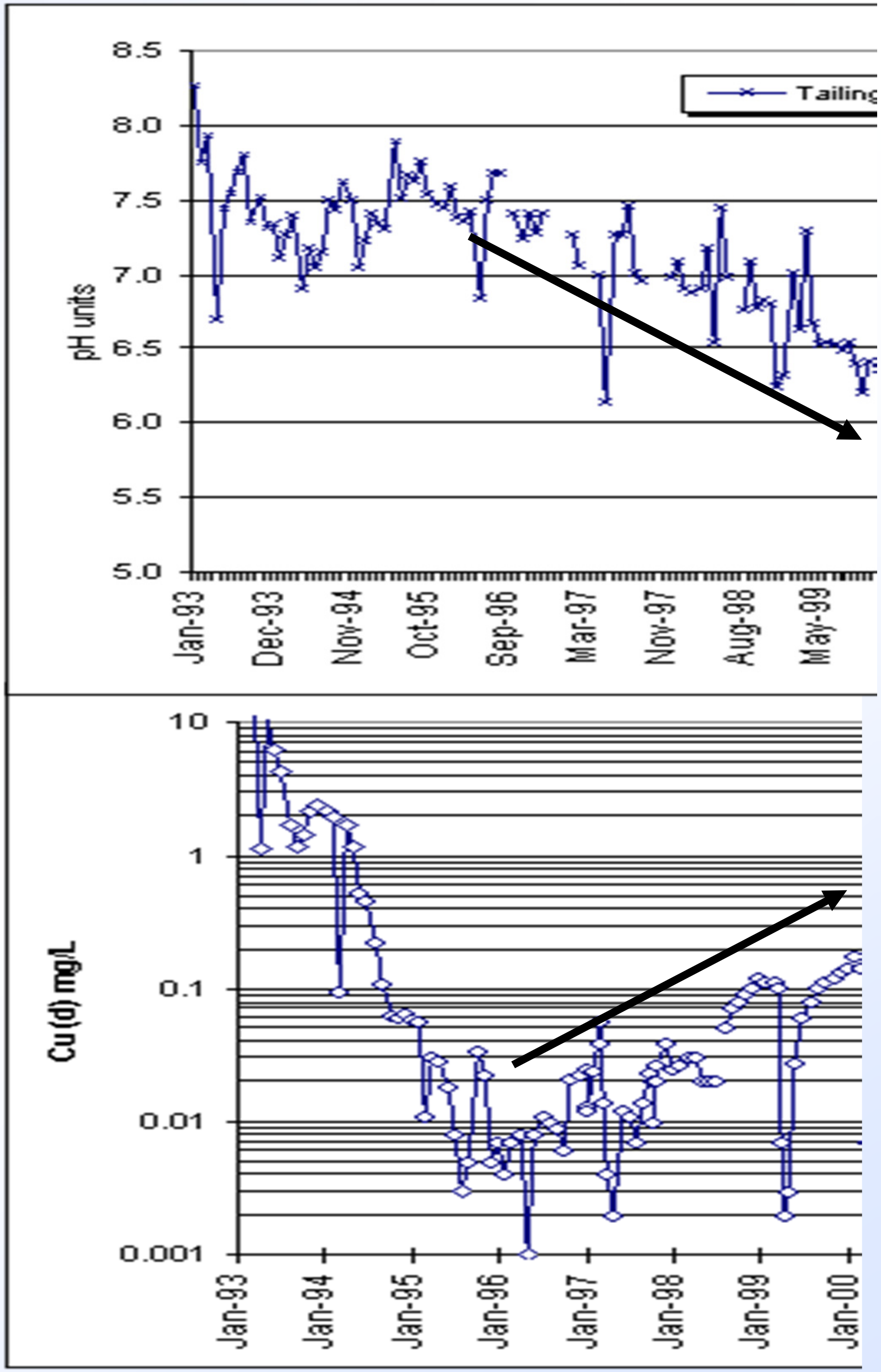


In 1997, the impoundment pH started to decrease and dissolved Cu and Zn started to rise.

By 2000, pH had decreased from 7 to 8 to less than 6.5 and dissolved Cu(d) had increased from 0.01 mg/L to 0.2 mg/L.

A pH decline was attributed to:

- depletion of lime added with process water and treatment sludge when the mine was operating and
- acidity inputs in the pH 5.5 incident precipitation.



Source of Cu

Three peepers were inserted in tailings to locate the source for increasing Cu. The peeper in the corner of sludge disposal fell over.

Based on results from the peeper near the #1 Dam, it was postulated that the probable source of Cu was remobilization of pH sensitive hydroxides [$Cu(OH)_2$] precipitated when the #1 Dam ARD was pumped into and neutralized in the impoundment.

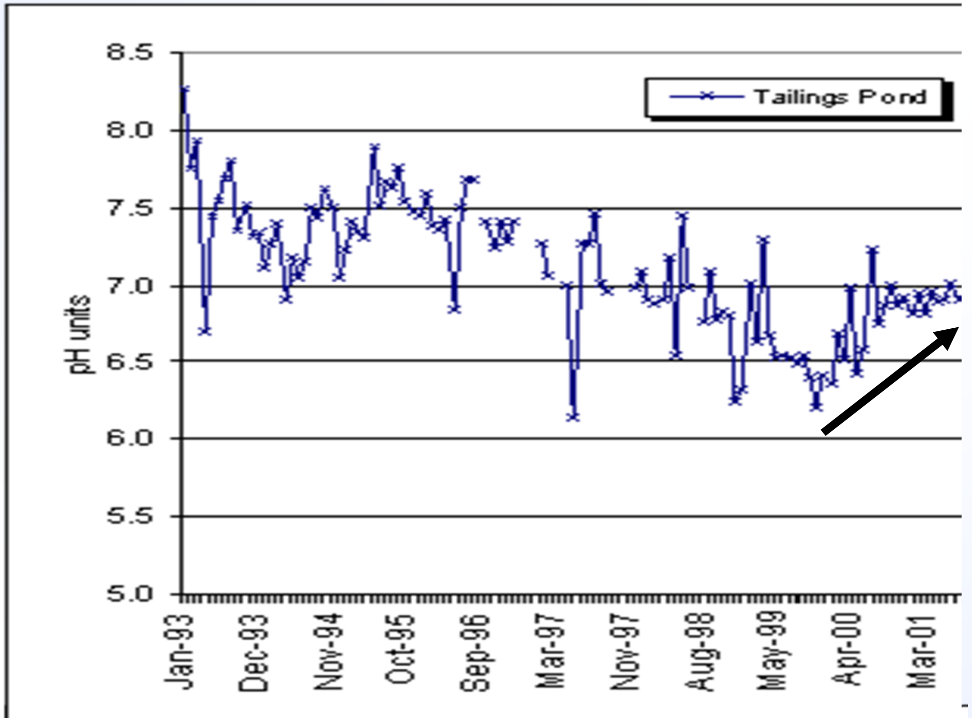
Other potential Cu sources are lime treatment sludge and 738 kg/d of $CuSO_4$ added in process water.

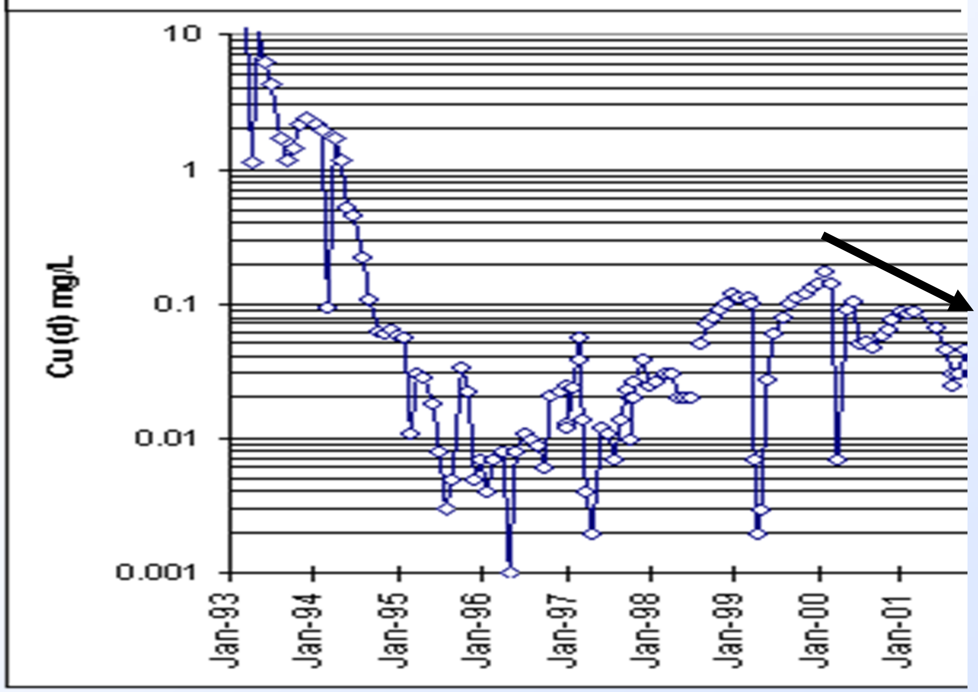
Mitigation

To raise the water cover pH, 51 and 23 tonnes of lime slurry were added from tanker trucks in 2000 and 2001.

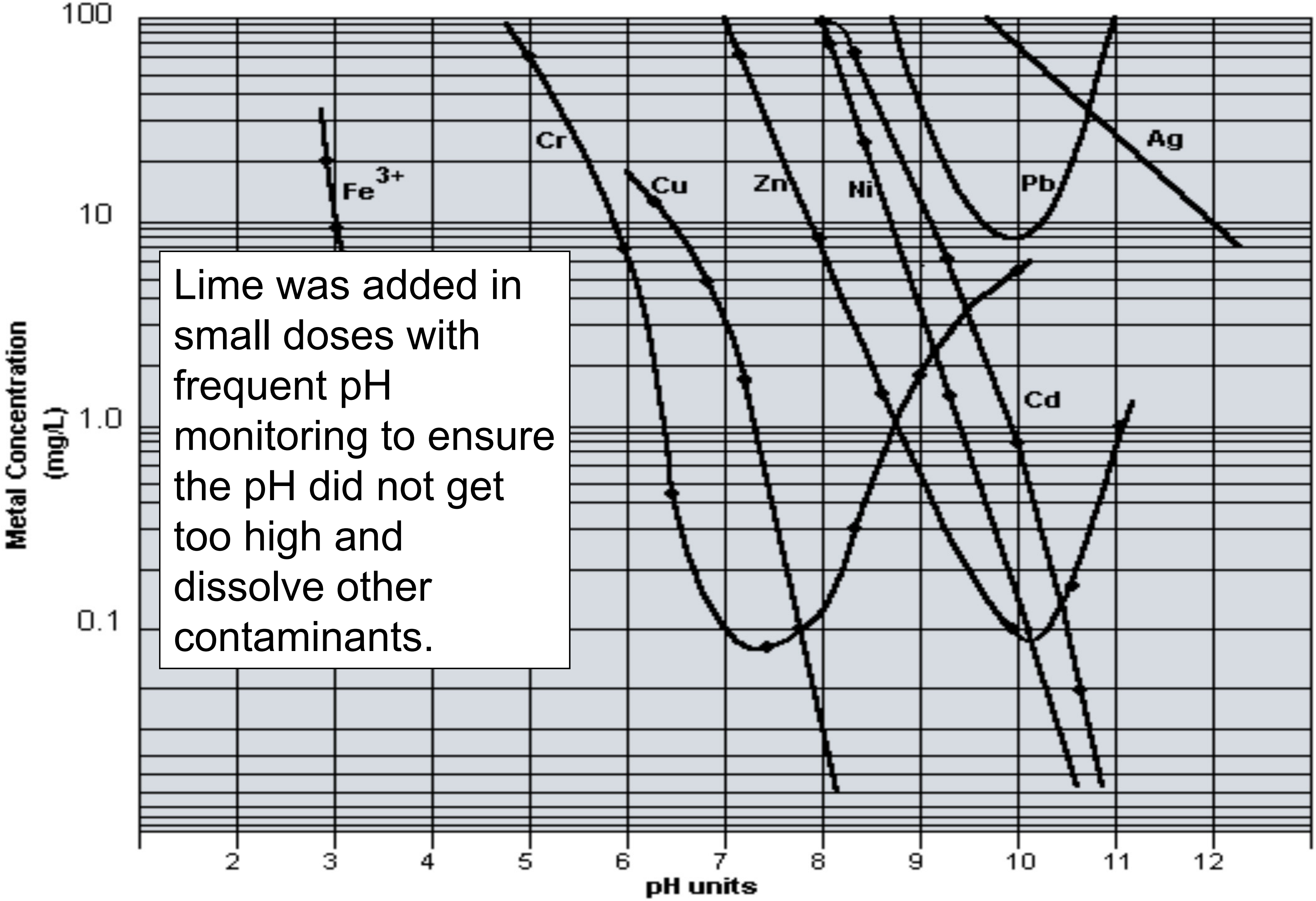
The amount of lime was calculated to neutralize acidity in 5 years of rain and snow.

By the end of 2001, the addition of lime had increased the pond pH to > 6.8 and decreased Cu to < 0.06 mg/L.





Source: http://www.hofflandenv.com/hydroxide-precipitation/

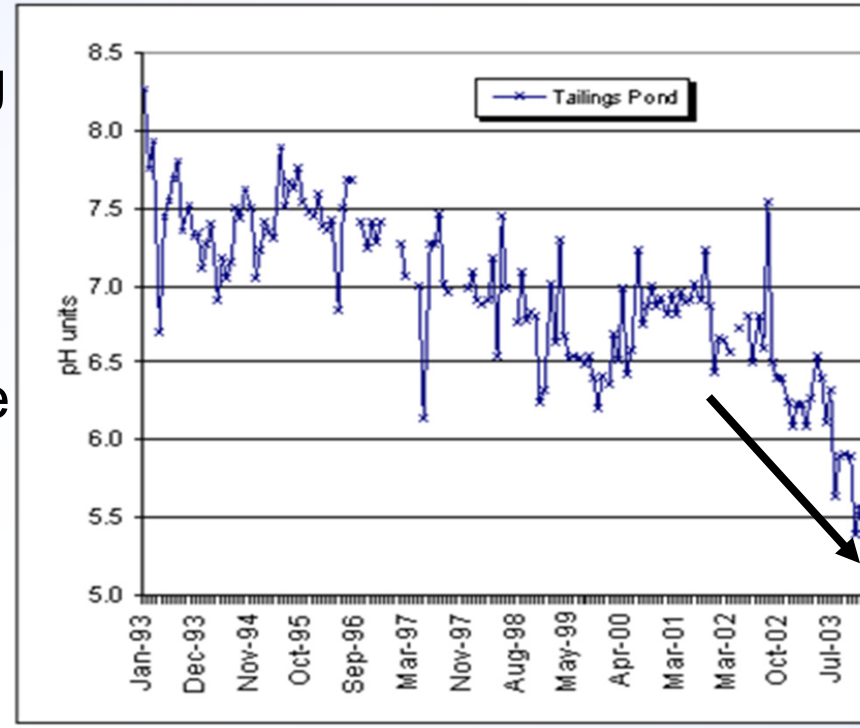


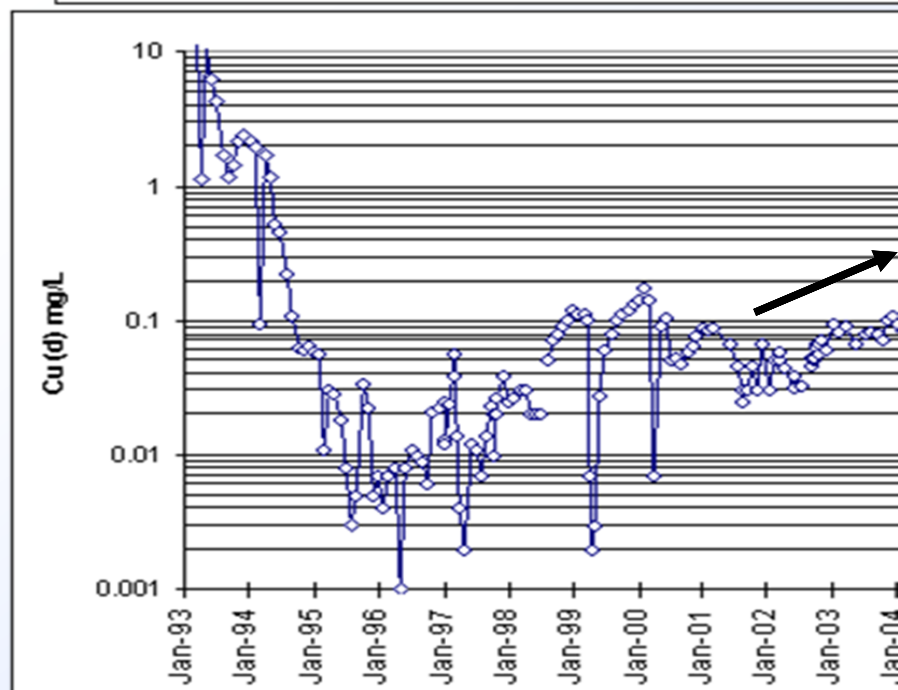
Lime was added in small doses with frequent pH monitoring to ensure the pH did not get too high and dissolve other contaminants.

Starting in 2002, the trend of increasing pond pH reversed and decreased to 5.4 and Cu increased to > 0.1 mg/L.

Regulatory suggestions confirmed by limnocorral results indicated the decline in pH resulted from acid produced by the oxidation of NH_4^+ (nitrification).

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O$$

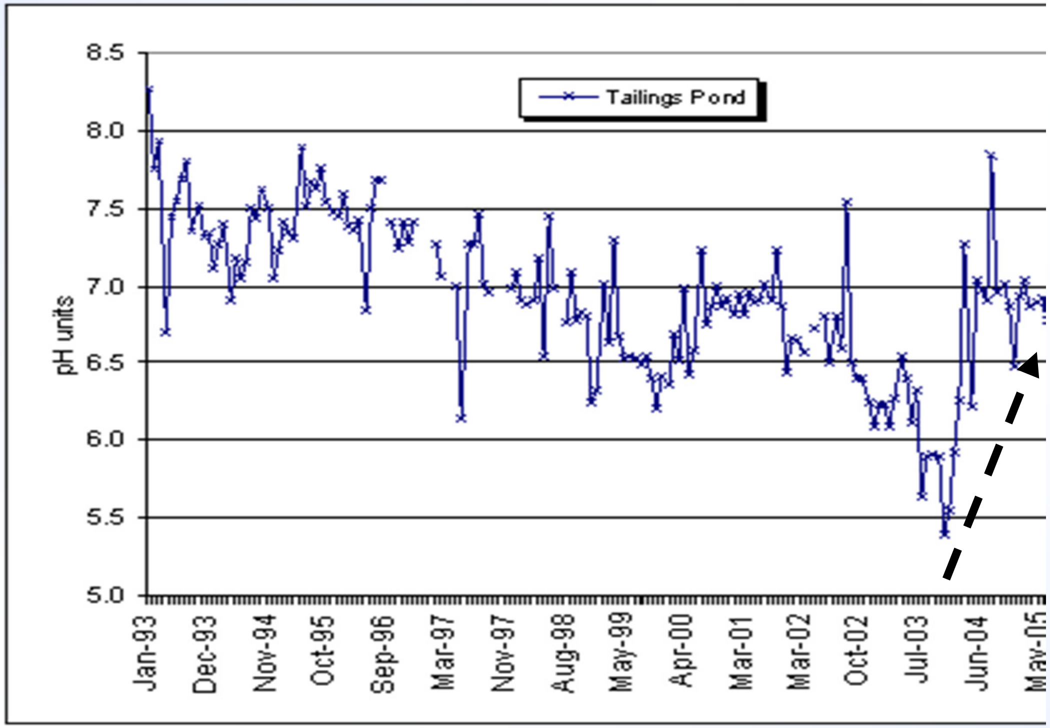


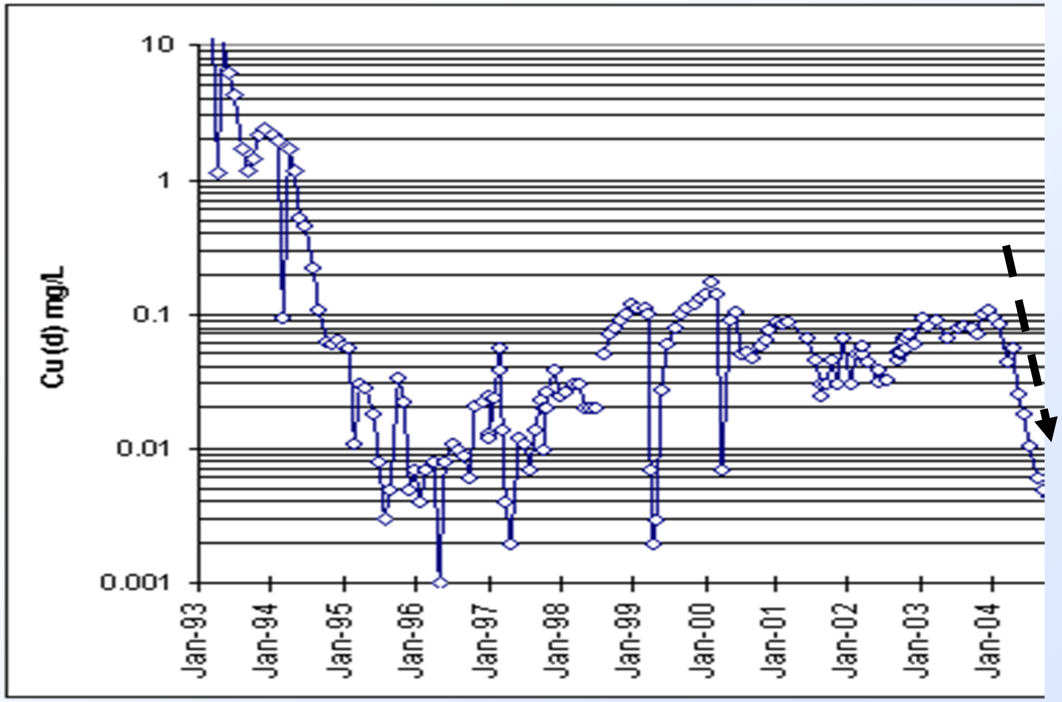


A modeling exercise was used to predict how much lime was required to neutralize acid from the oxidation of NH_4^+.

88 and 35 tonnes of lime slurry were added to the tailings pond in 2003 and 2004.

This new lime addition caused the pH to increase to an average of 6.8 and copper to decrease to 0.005 mg/L.



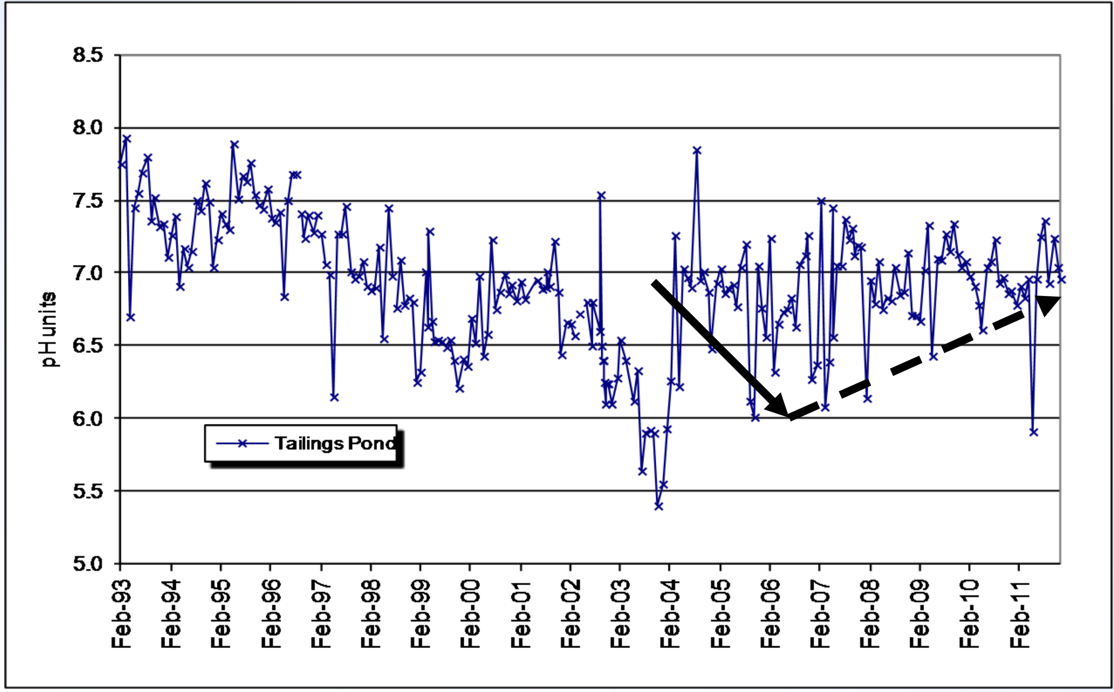


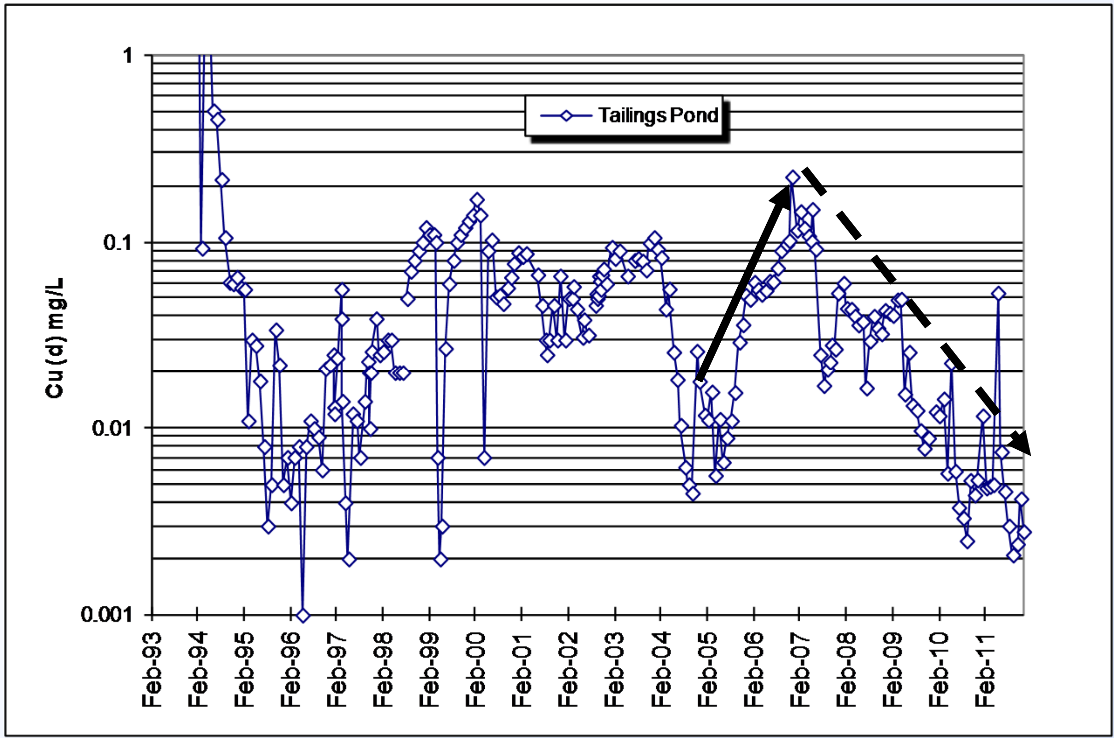
In 05/06, the pH again decreased to < 6.5 and Cu increased to > 0.1 mg/L.

To counteract this, 8 tonnes of lime slurry was added in 2006 and 32 tonnes in 2007.

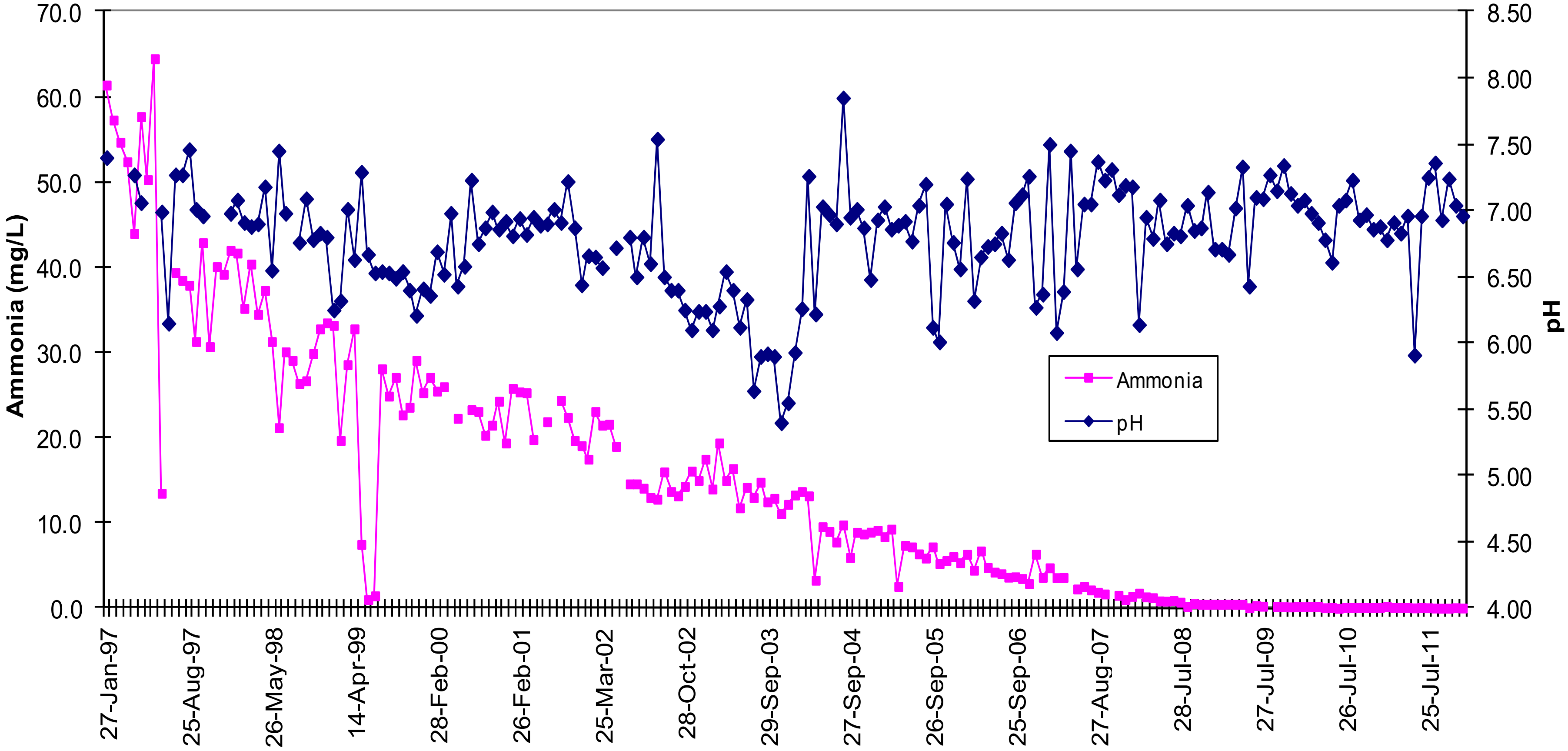
Since the lime addition in 2007, pH has remained above 6.5, averaging between 6.8 and 7.0.

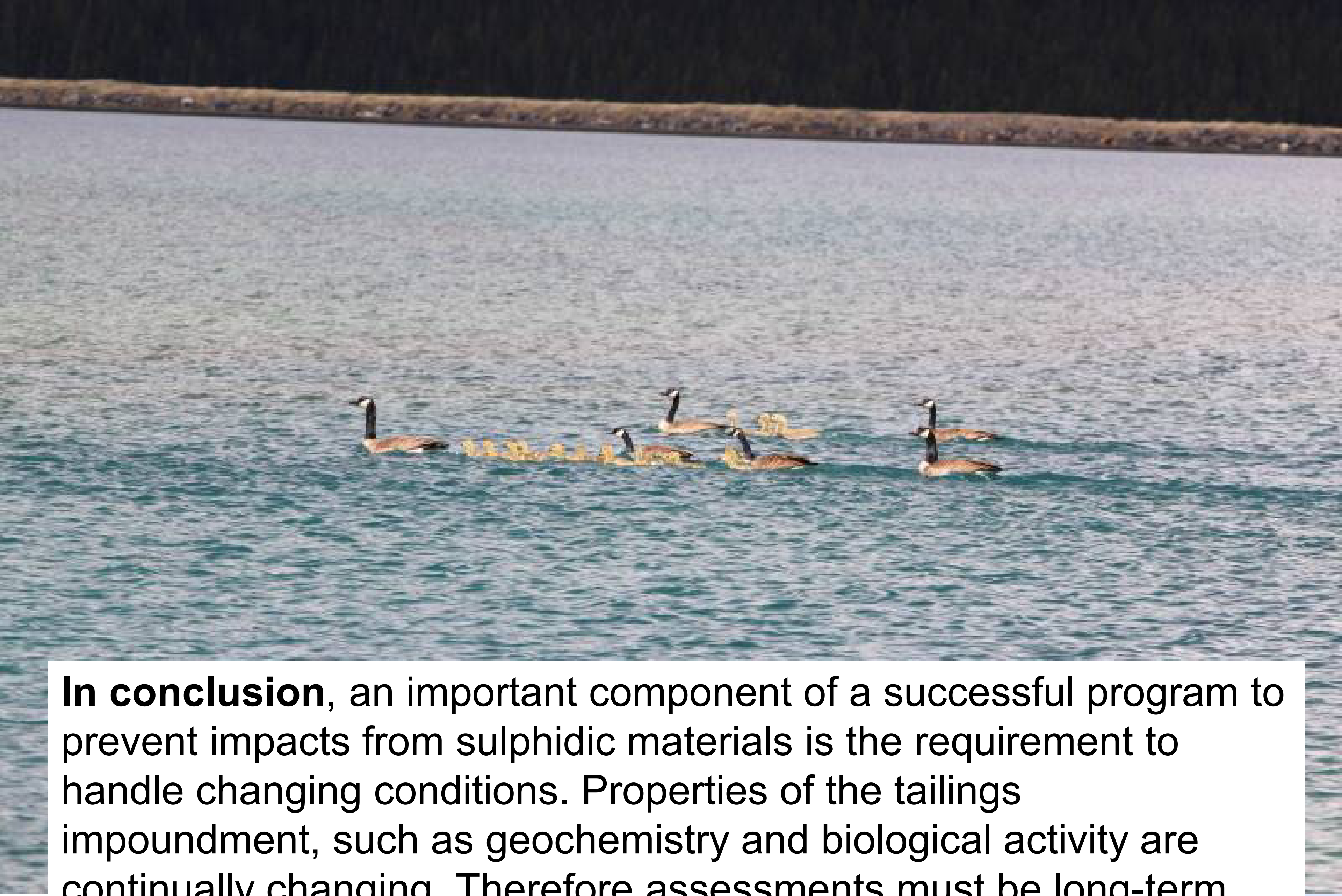
Dissolved Cu has steadily decreased, averaging 38 µg/L in 2008, 25 µg/L in 2009 and below 10 µg/L in 2010 and 2011.





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 not incident precipitation. The steady decline in dissolved Cu since 2007 suggests soluble Cu precipitates at the surface of the flooded tailings have been depleted.





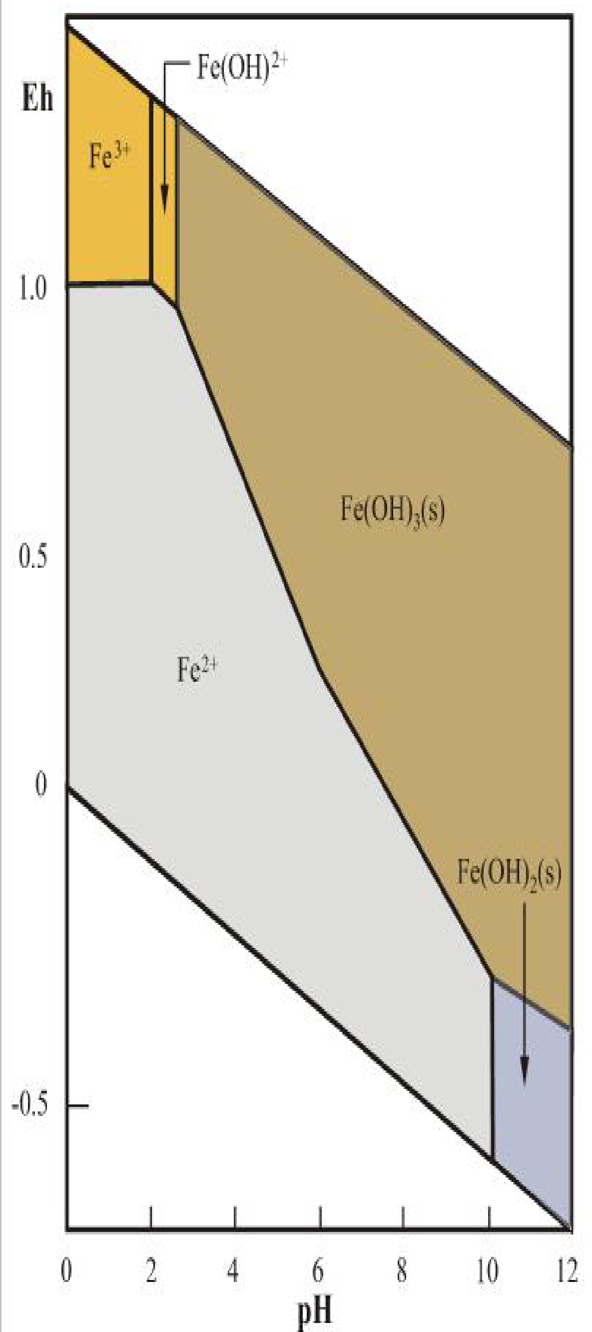
In conclusion, an important component of a successful program to prevent impacts from sulphidic materials is the requirement to handle changing conditions. Properties of the tailings impoundment, such as geochemistry and biological activity are continually changing. Therefore assessments must be long-term and multidisciplinary.

An important consideration is the stability of wastes under post-closure chemical conditions.

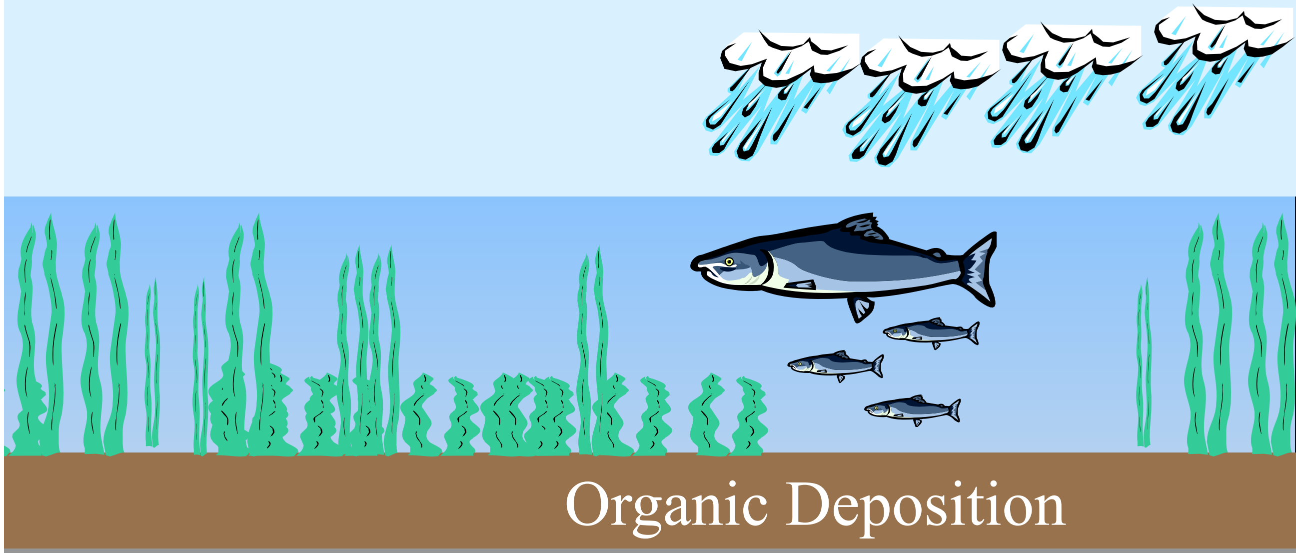
Another important consideration is that tailings impoundments are often used as a general disposal site and don’t just contain tailings.

In this impoundment, drainage chemistry was influenced by unstable Cu precipitates formed from ARD pumped into the impoundment.

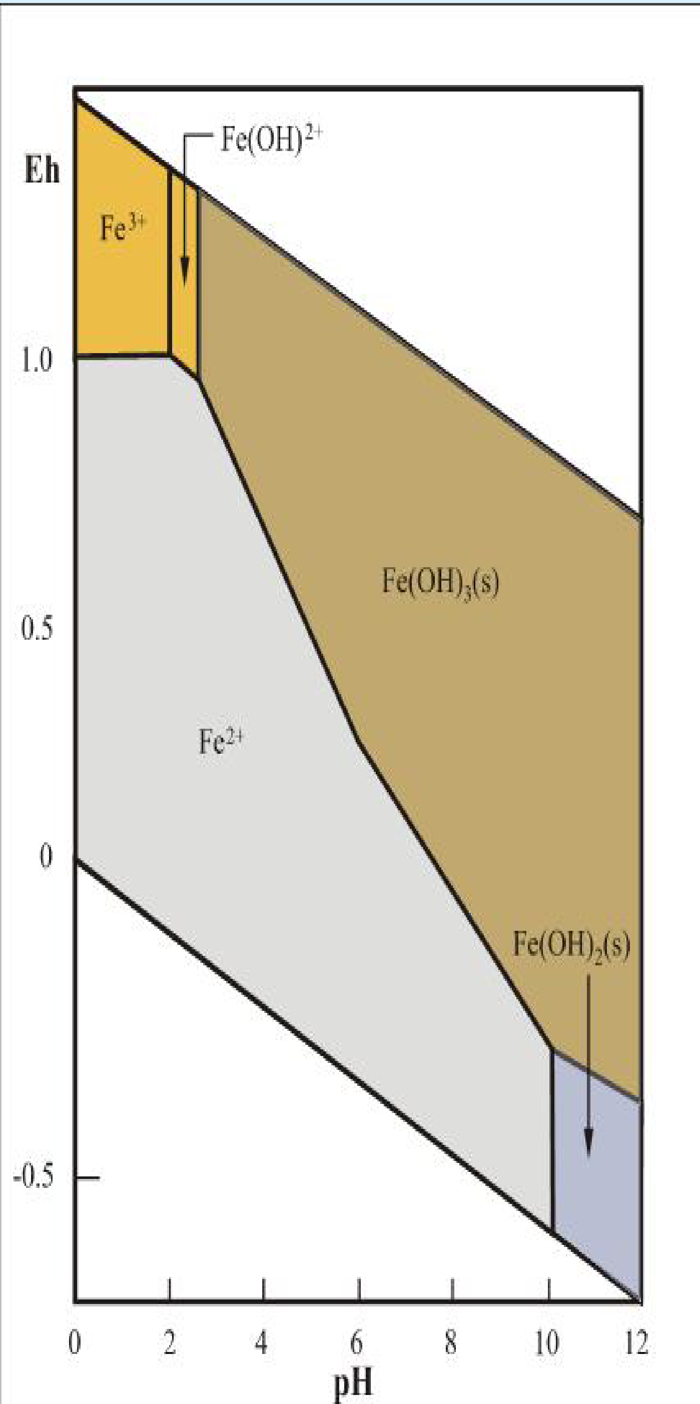
Another waste product that is a future geochemical concern is the lime treatment sludge.



Presently there is very little aquatic vegetation. Future plant invasion is expected to increase the sediment organic content creating more reducing conditions, potentially converting insoluble $Fe(OH)_3$ in lime treatment sludge into soluble Fe^{2+}.

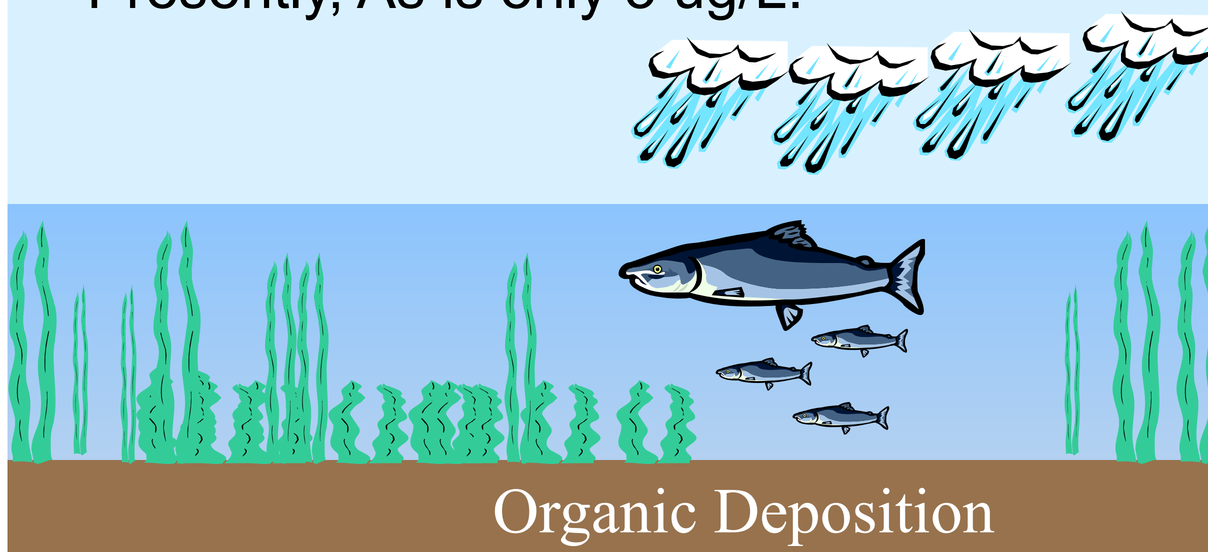


Dissolution of $Fe(OH)_3$ in lime treatment sludge will release co-precipitated trace elements into pore water.



Trace elements released from treatment sludge into pore water may re-precipitate in-situ as sulphides or released into the water cover.

One element of concern is As. Presently, As is only 3 ug/L.



If treatment was required, tailings pond water would be routed to the HDS plant.

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. The Berzilius Diversion limits drainage inputs from the higher natural ground on east side above the impoundment. Consequently, there is very little additional catchment beyond the impoundment itself. 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 flows into Foxy Creek at the north end of the property.

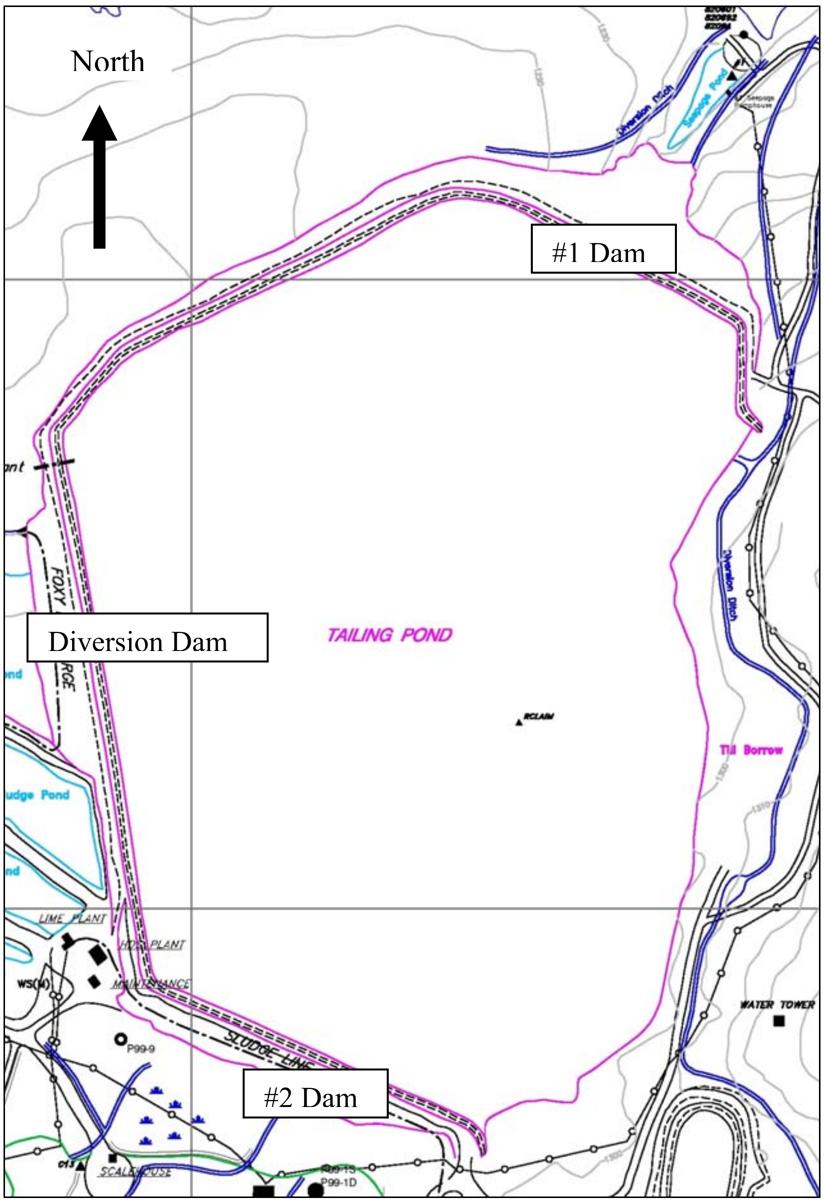

Figure 1. Map of Tailings Impoundment

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. The water cover abuts the dams and rip-rap protects the till dam above the tailings from erosion by wave action. The mine did not initially recognize the ARD potential of the waste rock and potentially acidic waste rock was used to construct the core 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. Identification of NPAG rock was based on visual inspection and its geology. There was no operational characterization by regular sampling and analysis.

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 wastes stored in the impoundment since closure results from the 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, capable of increasing the pond elevation by 0.21 m/yr (AMEC 2012). Low seepage losses result from the water retaining, impervious till membrane on the upstream slope of the rock fill. Most of the runoff from the ground above the impoundment is intercepted by the Berzillius Diversion. 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 at closure 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 core 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 plant site. 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. A decrease in drainage acidity has not been observed in drainage from the waste rock dumps. Explanations for the decrease in acidity from the #1 Dam are the much smaller mass of rock, depletion of finer, more reactive sulphides and a higher ratio of drainage to exposed rock than the large waste rock dumps. The average volume of seepage from the #1 Dam is 68,076 m^3/yr. This is 20% of the total 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. A portable pump was added to increase pumping capacity during extremely high run-off in 2011.

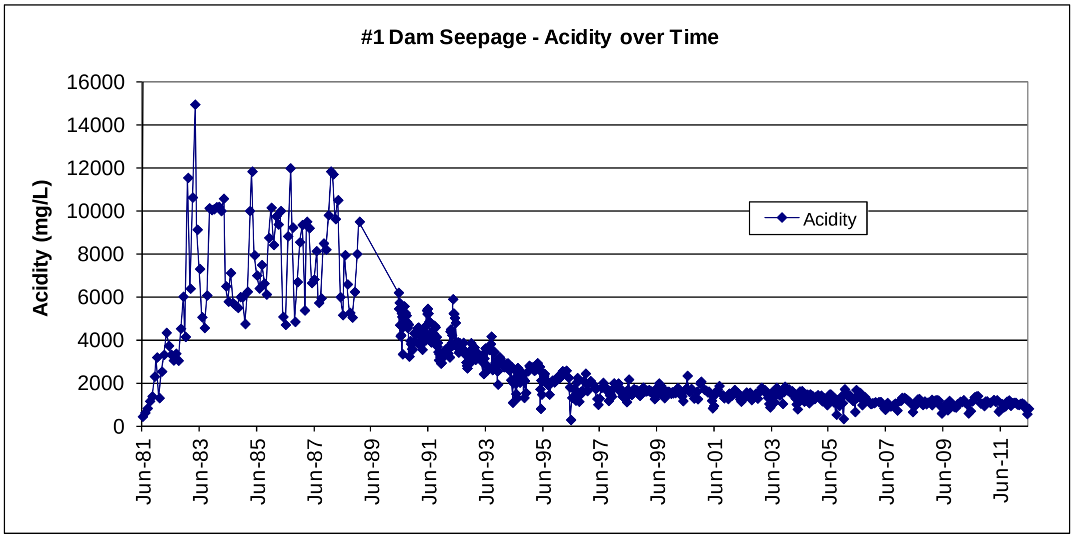

Figure 2. Concentration of acidity in drainage from #1 Dam

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 (As) and antimony (Sb) 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 molybdenum conversion produced any waste products and if so where they were disposed.

The mill initially processed approximately 7,000 tonnes of ore per day. This was increased to 10,000 tonnes per day from 1987 to 1990 and then decreased to approximately 9000 tonnes per day. Limited sampling in 1995 indicates tailings are strongly potentially net acid having an AP of 155 to 275 kg $CaCO_3$ eq/t (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 significant 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

Sampling of the water cover is done around the sides of the impoundment or from the discharge during decant/pumping periods. Anomalously low ammonium (NH_4^+), copper (Cu), zinc (Zn) and pH values (Figures 3, 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 values at these times reflect the chemistry of on-land runoff and snow melt rather than changes to the chemistry of water cover.

After the mill closed, cyanide (CN) continued to be reduced by natural degradation. By 2003, ten years after closure, natural degradation had decreased cyanide concentrations in the waste cover 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). Cyanide decomposition increased ammonium (NH_4^+) concentrations to 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.

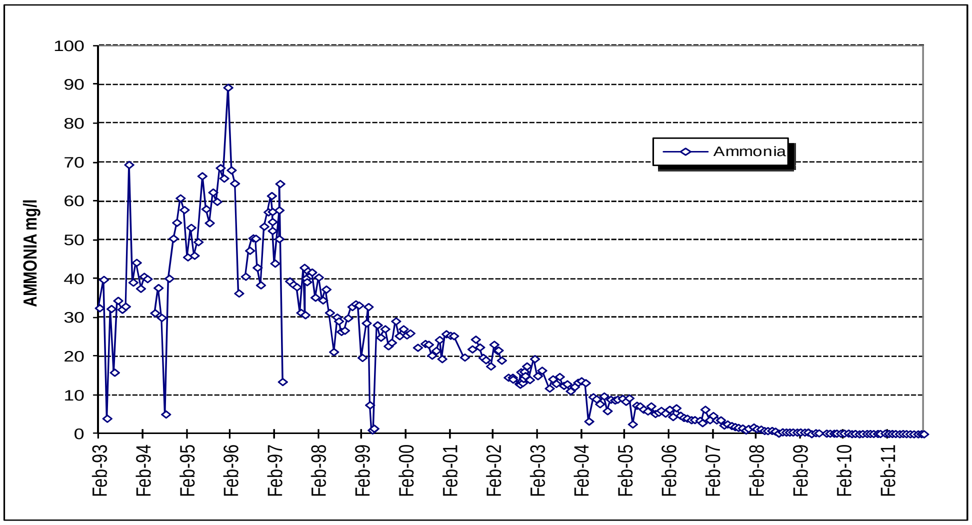

Figure 3. Concentration of ammonium in tailings pond (Aziz and Meints, 2012)

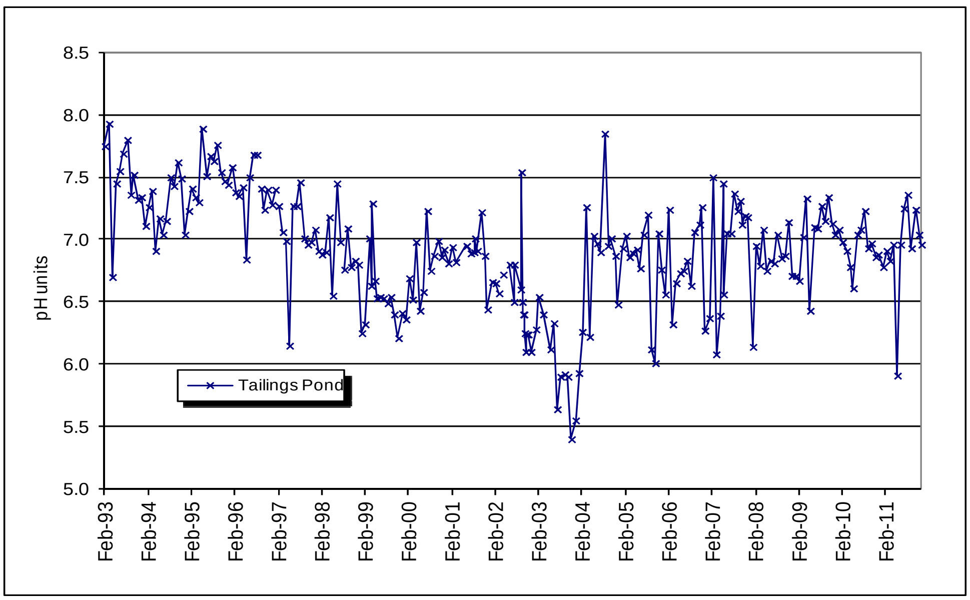

Figure 4. pH of tailings pond (Aziz and Meints, 2012)

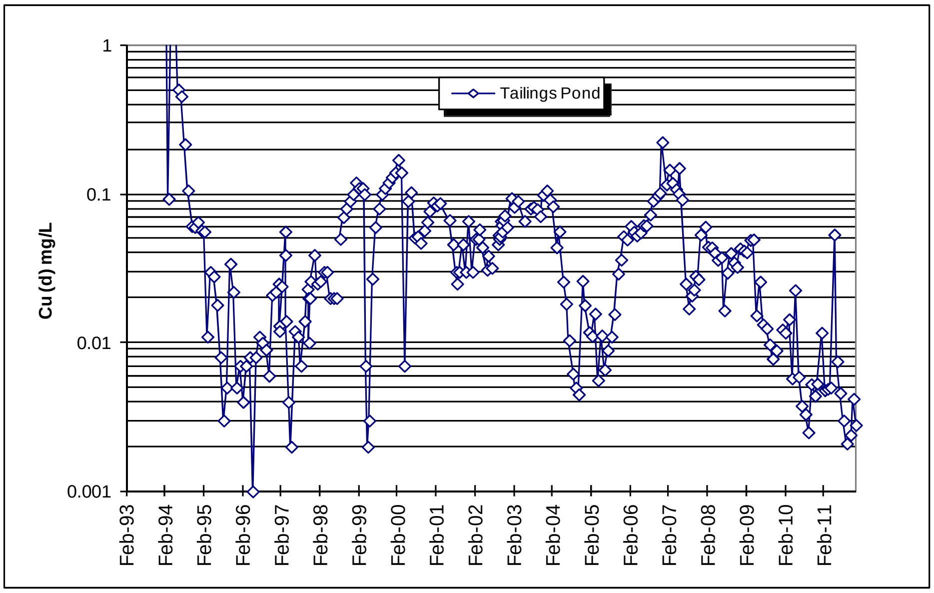

Figure 5. Concentration of copper in tailings pond (Aziz and Meints, 2012)

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 dissolved Cu and Zn 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.

Peepers, boards containing rows of permeable cells designed to measure concentration gradients of metals in pore water and overlying water cover over short distances at the sediment water interface (Martin et al. 2003), were inserted in the sediment at three locations in the impoundment 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 concentrations 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 NH_4^+ 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 Zn 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 NH_4^+ oxidation rather than incident precipitation (Figure 6). The low NH_4^+ concentration indicates relatively little acidity will be generated in the future by the nitrification of NH_4^+. A decline in pH may still result from acidity inputs from the pH 5.5

incident precipitation, but 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.

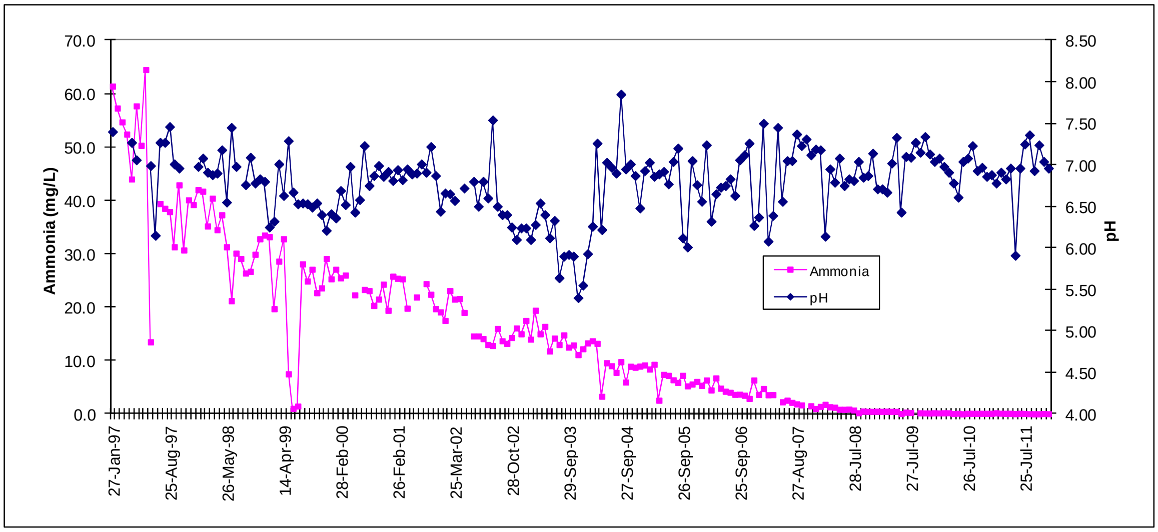

Figure 6. Changes in ammonia and pH over time

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 (As) co-precipitated within lime treatment sludge. Released elements may re-precipitate in situ as sulphides or be released into the water cover. The As 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.

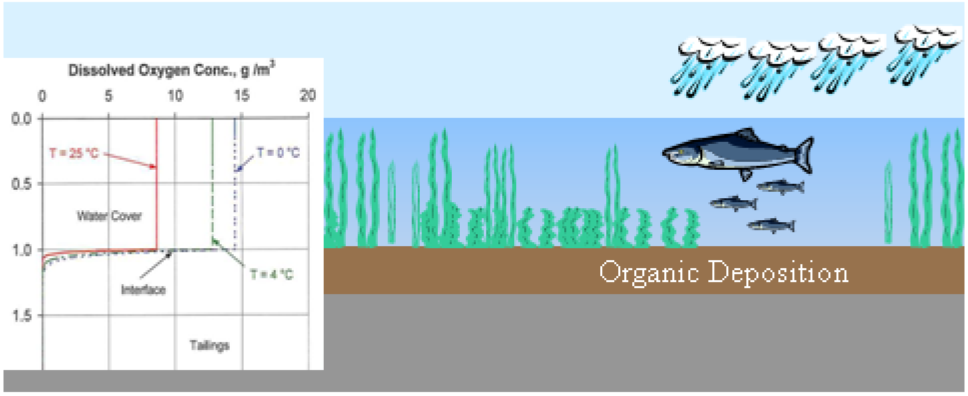

Figure 7. Schematic depiction of the impact of increasing biological activity in the tailings impoundment

One management option for the tailings impoundment that has been considered, but that has proven feasible, has been reprocessing 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. In addition to silver and gold recovery, tailings reprocessing will have to address a number of environmental issues. These include the subsequent disposal location, geochemical conditions and drainage chemistry of the resulting tailings, lime treatment sludge and other potentially soluble components presently intermingled with tailings, and their impact on discharge water quality.

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