Water Management and the Use of Natural Degradation in a Gold Mine Tailings Management Facility, Holt-McDermott Mine, Ontario

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Abstract

Since 1988, Barrick Gold Corporation has operated a gold mine, mill and a Tailings Management Facility (TMF) at the Holt-McDermott Mine in north-eastern Ontario. The mill utilizes cyanide in a carbon-in-leach (CIL) circuit to process the gold ore. The milling rate has increased over the years to its current nominal value of 3000 tonnes per day.

Ferric sulphate addition has recently been introduced to suppress arsenic associated with a new custom ore feed. Prior to that, the TMF has successfully met effluent guidelines without relying on chemical treatment. Natural degradation processes have historically reduced cyanide and ammonia concentrations to acceptable levels before release. Adequate retention time is provided within the TMF by transferring water through up to 4 separate ponds. 18 small dams form the ponds.

The TMF has evolved almost continuously over the past 14 years to support a number of changes in the water management, which were made in response to changes in the milling rate or ore feed. This paper provides a case history that demonstrates that natural degradation processes can be successfully applied to gold mine TMFs. It is important that the TMF has adequate pond volumes, flexible water management, and that changes be planned several years in advance.

Key Words: gold mining, tailings, water management, natural degradation, cyanide, ammonia.

Introduction

The Holt-McDermott Mine (48º30'N, 79º45'W) is located in north eastern Ontario, just west of the Quebec border, on Hwy. 101, approximately 50 km northeast of Kirkland Lake, Ontario. It comprises an underground gold mine, a mill and a Tailings Management Facility (TMF). Gold production at the mine commenced in 1988, and the mill is currently operating at a nominal capacity of 3,000 tonnes per day. Approximately 60% of the mill feed is derived from off-property sources, mainly Newmont Canada's adjacent Holloway Mine.

Ferric sulphate addition has recently been introduced to the TMF to suppress arsenic associated with a new custom ore feed. Prior to that, the TMF successfully met effluent guidelines without relying on chemical treatment. Natural degradation processes have historically reduced cyanide and ammonia concentrations to well below applicable effluent discharge limits before release. The necessary retention time is provided within the TMF by transferring process water and runoff through any or all of the 4 individual ponds. 18 small dams form the TMF ponds.

Site Conditions

Prior to the construction of the Holt-McDermott mine in 1988, the site was undeveloped land, situated in the boreal forest. The TMF crosses two watersheds. The northern watershed drains north into the Mattawasaga River, while the southern watershed drains south into the Magusi River. The discharge of final effluent from the TMF occurs through a final effluent control point (FECP) to the Magusi River.

The TMF is situated in typical Canadian Shield terrain. The tailings ponds themselves are situated in poorly drained lowland areas, which are underlain by extensive clay deposits of glacio-lacustrine origin. The ponds are surrounded by low hills, which contain outcrops of pre-Cambrian bedrock. The flanks of the outcrops are typically mantled with thin deposits of glacial till.

The climate is continental, with warm summers and cold winters. The long term average annual rainfall of 785 mm significantly exceeds the annual average pond evaporation 528 mm. The maximum runoff normally corresponds to the spring thaw and to the fall rains.

Ore and Geochemistry

The Holt-McDermott Mine is located on the legendary "Porcupine to Destor Break", which has historically hosted dozens of gold mines. Both the Holt-McDermott and Holloway mine ores are hosted in volcanic rocks.

Comparisons between the Holt-McDermott and Holloway ore types show that concentrations of both calcium and magnesium are higher in the Holt-McDermott Mine ore, and that sulphide content is higher in the Holloway Mine ore. The combination of lower neutralizing potential (NP) and higher acid production potential (AP) for Holloway Mine ore, compared with Holt-McDermott Mine ore, results in a lower NP:AP ratio for Holloway Mine ore.

Currently, it is assumed that the average NP:AP ratio of 1.19:1 of the Holloway Mine ore is indicative of a potential for the development of AMD conditions. By comparison, Holt-McDermott ore, which exhibits NP:AP ratios averaging 3.75:1, is not believed to have AMD potential. When the two ores are blended together (at the expected proportion of 40% ore feed from Holt-McDermott and 60% ore feed from Holloway), the mix shows an NP:AP ratio of approximately 2.2:1 and an average net neutralization potential (NNP) of >50 tonnes of $CaCO_3$/1000 tonne. These results are ambivalent with respect to the potential for the blend to generate AMD. According to MEND (1994), the 2.2:1 ratio indicates an uncertain potential; while according to BC AMD Task Force (1989), an NNP greater than 20 indicates that acid generation should not occur.

Arsenic concentrations in Holloway ore are also elevated in comparison to those of Holt-McDermott ore. To date, (under conditions of continued mill throughput), arsenic concentrations in the final tailings effluent have been well below applicable final effluent discharge limits. This condition is expected to continue through the remainder of mill operations, (i.e. as long as there is active deposition on any exposed tailings beaches). However, to prevent the possible future mobilization of arsenic following mine closure, the tailings beaches will be flooded to limit the rate of oxidation of arsenopyrite.

Tailings Management Facility

As shown on Figure 1, the Holt-McDermott TMF currently comprises four individual ponds, as follows:

- North Tailings Pond;
- Southwest Tailings Pond;
- Southeast Tailings Pond; and
- South Polishing Pond.

The ponds are bounded by a total of 18 dams. This includes 14 perimeter dams and 3 internal dams (i.e. Dam 5 between the North Pond and the Southwest Pond, Dam 10 between the Southwest and the Southeast Pond, and Dam 6 between the Southwest Pond and the South Polishing Pond). Golder Associates is the Engineer-of-Record for the dams, having designed all of them, and also having inspected their construction. The construction of the TMF as it exists today was accomplished in five stages. The sixth stage of construction will be completed in 2003 – 2004. Currently, no additional construction is planned beyond the sixth stage except that related to the closure of the TMF, which is expected to occur in 2006.

Water Management

Mill tailings are pumped through a slurry pipeline system. The pipeline system discharges the tailings slurry into the TMF at a number of deposition points. For the first 13 years of operation, almost all of the tailings were deposited into the North Tailings Pond. After June 2001, tailings deposition was switched into the Southwest Tailings Pond.

The TMF not only provides storage for tailings solids, but it also provides treatment of the discharged mill process water through a process known as “natural degradation”. This process involves retaining the discharged mill process water for a period of time sufficient to allow for the natural volatilization and subsequent breakdown of cyanide, and for the associated precipitation of heavy metals that were previously complexed with the cyanide. The rate of cyanide breakdown is very slow in the winter, because of the very cold temperatures and the ice cover on the ponds. As a consequence, all process water must be held through the winter and allowed to naturally degrade during the summer prior to being release. The major portion of the natural degradation process occurs within the three tailings ponds, with the South Polishing Pond providing the final cleanup or “polishing”.

Figure 2 shows a typical annual water balance for the TMF. The TMF has an overall watershed area of about 3.39 km^2; the net runoff from this watershed typically adds a significant volume of fresh water to the TMF. (Under long-term average precipitation and evaporation conditions, the net runoff would be about 2.03 Mm^3 per year). Within the TMF, water is transferred sequentially from one pond to another by pumping, or in some cases by gravity transfer.

The final effluent from the TMF is discharged seasonally into the Magusi River. According to the Certificate of Approval (C of A) for the TMF, the effluent discharge rate cannot exceed one-tenth of the flow in the Magusi River in the summer months and one-fifth during spring freshet and in the fall. Discharge from the South Polishing Pond to the environment is accomplished by gravity discharge through a decant structure. The decant structure is equipped not only with stop logs (to control the pond water level), but also with a knife valve, which allows the precise control of the discharge rate within a range of 0 to 100,000m^3/day. All off-site discharge passes through the Final Effluent Control Point (FECP), which contains two weirs (i.e. a V-notch weir and a rectangular weir in parallel) to allow for precise flow measurement throughout the discharge range (Photo 1).

In a typical year, approximately 2.90 Mm^3 of water are transferred through the various ponds of the TMF, and eventually discharged to the environment. This requires careful planning several years in advance. The mine maintains (and frequently updates) a comprehensive water balance model, which is used to predict monthly water levels in each pond several years in advance. The water balance model considers the following:

- The stage versus storage curves for each pond, (taking into account the effects of ongoing tailings deposition in the North and Southwest Tailings Ponds),
- The maximum storage capacity of each pond (associated with a defined Maximum Operating Water Level based on the freeboard requirements of individual dams),
- The variable components (i.e. net precipitation and spring thaw runoff), and
- The variability of discharges to the Magusi River (i.e. to respect applicable mixing ratio limits for variable river flows).

Recent Environmental Performance

The effluent quality is documented herein for the years 1996 – 2001. As summarized in Table 1, the total discharge volume has varied considerably from year to year. This is due to climate variability, as well as atypical water retention (to suit construction activities, etc.). At the same time, there has been a significant trend to reduce loadings in the final effluent.

From an environmental perspective, the key water quality parameters are: total cyanide, copper, ammonia, and arsenic. The concentrations of cyanide and copper within the tailings pond vary considerably throughout the year. This variation is due mainly to seasonality in the rate of the natural degradation of cyanide, and the consequent seasonality in the precipitation of copper formerly complexed with cyanide. Spring reductions in ammonia are due mainly to melt-water dilution. Ammonia concentration increases following the spring melt are due to the conversion of a portion of the cyanide to cyanate, which then hydrolyzes to form ammonia.

As shown on Figure 3, total cyanide and arsenic concentrations have been well below 0.05 mg/L in the final effluent discharge. Copper levels have averaged about 0.07 mg/L, (which is well below the applicable allowable monthly average discharge limit of 0.3 mg/L). It is particularly notable that the final effluent concentrations of arsenic have remained essentially stable, while the concentrations of copper and total cyanide have generally decreased. This has occurred despite a 53% increase in mill tonnage throughput between 1996 and 2001. The un-ionized ammonia has increased since 1999, but this has not triggered any rainbow trout mortality.

Sound environmental performance can be attributed to the following factors:

- Evaluating historical data,
- Establishing and maintaining an accurate water balance,
- Evaluating contingency measures,
- Optimizing retention time and tailings storage,
- Evaluating water management strategy,
- Pre-discharge planning, and
- Operator awareness and training.

As summarized on Table 1, results of both acute and chronic toxicity testing have met regulatory requirements throughout the years 1996 – 2001. (The regulatory requirements for acute toxicity are ≤50% mortality). Rainbow trout test organisms experienced zero mortality throughout the period. This is usually indicative that the ammonia concentration in the effluent is below toxic threshold. Daphnia magna test organisms experienced zero mortality in 1996, 2000 and 2001; they experienced moderate average mortality of ≤15% in 1997 through 1999. The non-zero levels of daphnia magna mortality, (which are still within acceptable limits), appear to be correlated to copper concentrations in the final effluent. Measures were taken in 2000 to reduce both arsenic and copper concentrations reporting in the effluent.

Cyanide (Total)

Cyanide is a principal mill process contaminant both in and of itself, and through its ability to form metallo-cyanide complexes, most notably copper cyanide complexes.

Cyanide has not been a concern at Holt-McDermott as the maximum observed concentration was measured at 0.12 mg/L as compared to an applicable monthly discharge limit of 1 mg/L.

Copper (Total)

Throughout the operation, copper has been the critical parameter in the final effluent. Between 1996 and 2001, final effluent copper concentrations have averaged 0.10 mg/L, with the maximum-recorded monthly average discharge concentration being 0.15 mg/L. Since 1999, the monthly average copper concentration of the effluent discharged has been maintained below 0.05 mg/L.

Arsenic (Total)

Levels of arsenic in the final effluent, (Figure 3), have historically been well below the applicable monthly average discharge limit of 0.5 mg/L (calculated as a monthly average). However, there is a potential for arsenic levels to increase, because of increases over time in the levels of arsenopyrite in the Holloway Mine ore, and in particular, if the tailings are allowed to oxidize to an appreciable extent.

Arsenic can occur in several forms, most notably the oxidized As^{5+} species, the reduced As^{3+} species, as well as methylated species. Inorganic forms tend to be more toxic than organic forms, and reduced inorganic As^{3+} is more toxic than oxidized As^{5+} (N.E Corte and Q.Fernando ,1991). The reduced species are more soluble than the oxidized species. Arsenic liberated from arsenopyrite oxidation has the potential to become water-soluble. During open water periods, when surface waters are well oxygenated and redox potentials are high, arsenic (in the As^{5+} form) exhibits a strong tendency to co-precipitate with (or to be adsorbed onto) hydrous ferric oxides, most notably hydrated FeOOH, but also hydrated $Fe(OH)_3$. This presumes that sufficient ferric ion is available. Under ice cover, if strong reducing conditions develop, there is a potential for arsenic to be released from sediments, in the As^{3+} form.

The keys to arsenic control are:

1. limiting the potential for tailings oxidation,

2. ensuring that there is sufficient ferric ion available to precipitate arsenic, and

3. ensuring that strong reducing conditions are avoided in the period leading up to effluent discharge. (Based on site monitoring data, reducing conditions do not appear to be an issue).

The following measures have been implemented to control effluent arsenic concentrations:

1. Tailings deposition plans have been modified to minimize the surface area of exposed tailings.

2. A system has been installed to allow ferric sulphate to be added to process water as it is transferred from the Southwest Tailings Pond to the Southeast Tailings Pond. [Note - The stability and solubility of arsenates depends on the ratio of iron to arsenic. The larger the ratio, the more insoluble the precipitate (G.B Harris, 1994). Testing at Holt-McDermott suggests that an addition rate of 6:1 is effective; however the ferric arsenate sludge is rendered more stable at values of 10:1].

Ammonia

Ammonia in the Holt-McDermott TMF effluent is derived from either the breakdown of cyanide, or from the use ammonium nitrate fuel oil explosives. The proportion derived from the use of explosives is transferred to the TMF in mine water, which is used to slurry the tailings.

Total ammonia levels within the pond actively receiving tailings have historically peaked at approximately 15 mg/L, with a pronounced seasonal decline to about 8 mg/L, coincident with the spring melt. Ammonia levels decline within the South Polishing Pond as a result of: volatilization, uptake by nitrifying bacteria, and through uptake (in the form of ammonium ion) as a nutrient by algae.

Since 1996, the un-ionized ammonia concentration in the effluent has averaged 0.012 mg/L; the maximum observed concentration was measured at 0.08 mg/L in 1999.

Potential Contingency Measures

Possible contingency measures that have been considered and that could be employed at the Holt-McDermott Mine for improved water quality are listed in the following section. The TMF flow control and monitoring system has been modified and provides the opportunity to:

1) extend effluent retention time to ensure that any given parameter does not exceed legislative limits; or

2) increase receiving water to effluent mixing ratios to lessen the impact on the receiver.

Cyanide (Total)

Possible contingency measures that could be employed at the Holt-McDermott Mine for improved cyanide control include the following:

1. TMF pond pH adjustment to optimize cyanide volatilization;
2. in-plant treatment of tailings slurry using the SO_2/AIR process; and,
3. liquid effluent treatment between transfer points within the TMF using H_2O_2 or SO_2/AIR processes.

Copper (Total)

Historical operating data have shown that copper concentrations in discharged effluent continue to decline with increased holding time during the late summer/early fall period. If necessary, the TMF has the capacity to hold effluent over the winter period and into the following spring. Past operating experience prior to 1996 has shown that copper levels do indeed continue to decline over the winter and into the spring. The spring decline is mainly a result of melt-water input. This provides a contingency against elevated copper values.

Other possible contingency measures that could be employed at Holt-McDermott for improving copper control include the following:

1. lime addition to the tailings transfer water, to raise the pH from the current levels (i.e.

approximately 7.5-8.0) to approximately 9.0 in order to optimize copper precipitation;

2. ethylenediaminetetraacetate (EDTA) addition, to complex copper (and other cations) so as to render them non-toxic; or

3. ferric sulphate addition (currently being undertaken).

Arsenic (Total)

Possible contingency measures for improved arsenic control are to:

1. ensuring that tailings solids are not allowed to oxidize excessively; (this is accomplished by maintaining saturation on both the old and active tailings surfaces); and

2. adding ferric sulphate at a Fe^{3+}/As ratio of 10:1 to produce a more stable sludge (currently being undertaken).

Ammonia

Possible contingency measures for improved ammonia control at the Holt-McDermott Mine include:

1. phosphorus introduction to the TMF, as appropriate, to assist with ammonium ion uptake by algae; and,
2. pond pH adjustment and aeration to strip the ammonia.

It was initially assumed that phosphorus is the limiting nutrient that restricts the growth of algae in the South Polishing Pond. This assumption was based on historical phosphorus measurements taken prior to the TMF expansion. An increase in phosphorus concentrations would promote nitrogen uptake (as NH_4^+ and NO_3^-) by pond algae. In fact, phosphorus concentrations in the final effluent are around 0.2 to 0.3 mg/L naturally. This suggests that algae growth is not limited, and consequently that the conditions in the South Polishing Pond are favourable for the decomposition of ammonia. By the late summer of 2002, the South Polishing Pond was supporting a heavy growth of duck weed around the perimeter.

Closure of the TMF

The mine closure plan provides for the development of shallow (≥1.0m) water cover over the tailings that will exist in the North, Southeast and Southwest Tailings Ponds. The water covers are expected to greatly reduce the contact between oxygen and the submerged tailings solids, thereby minimizing the potential generation of acid and the oxidation of arsenopyrite. The flooding of tailings deposits is widely recognized as a preferred technology for reducing acid generation (Balins et al. 1991; Price and Errington, 1997).

A stochastic drought analysis of the TMF indicated that the planned 1.0 m water cover over the tailings could diminish to 0.79 m under extreme drought conditions (i.e. a 1 in 1000 year return period drought). If provisions are made for an arbitrary adjustment in meteorological conditions to account for possible long-term climatic change (i.e., a 20% decrease in annual precipitation and a 20% increase in annual evaporation), then modelling results indicate that the 1.0 m water cover would be reduced to 0.56 - 0.62 m. The reduction in water cover would be temporary; the water cover depth would recover in subsequent years.

Conclusions

The Holt-McDermott TMF provides a case history of the successful application of natural degradation to treat gold mill effluent. The success can be attributed to several factors:

- The TMF is large in relation to the mill throughput, with the maximum live storage capacity in the 4 ponds currently totalling about 8.0 Mm^3.
- Because process water can be transferred through any or all of the 4 individual ponds, water management in the TMF is inherently flexible. This allows effluent retention to be adjusted to ensure that a superior quality can be achieved for discharge. The TMF can hold water for up to 2 years if an upset condition were to occur. This provides time to implement correctives measures.
- Tailings deposition plans have been modified to minimize the surface area of exposed tailings and, thereby, limit the potential for

tailings oxidation and the mobilization of arsenic and other metals.

- The transfer of water through the 4 ponds and then its discharge to the environment is planned up to 2 years in advance using a comprehensive water balance model, and the plans are modified as necessary to deal with unexpected conditions (such as a heavy spring thaw).
- The need for modifications to the system (i.e. dam raises, construction of Dam 10 to subdivide the former South Pond into the Southwest Tailings Pond and the Southeast Tailings Pond, construction of the South Polishing Pond, construction of emergency spillways, etc.) has always been recognized with sufficient lead-time.
- Past performance is reviewed regularly, and steps are considered to reduce any undesirable conditions / effects that are noted.
- Contingency measures (such as the addition of ferric sulphate) have been identified in advance should a significant deterioration of current effluent quality occur.

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Table 1

Trends in Final Effluent Concentrations, Loadings and Toxicity

			Monthly Average Concentration Limits (mg/L)				Maximum Effluent Discharge Concentration (mg/L)				Average Effluent Discharge Concentration (mg/L)			
Year	**Tonnes Milled/yr**	**Effluent Volume Discharged (m^3)**	**Cu**	**As**	**Un-ionized NH^3**	**Total Cyanide**	**Cu**	**As**	**Un-ionized NH^3**	**Total Cyanide**	**Cu**	**As**	**Un-ionized NH_3**	**Total Cyanide**
1996	656,770	2,444,000	0.30	0.5	-	1	0.14	0.017	0.015	0.015	0.11	0.013	0.004	0.011
1997	654,613	2,110,000	0.30	0.5	-	1	0.15	0.020	0.005	0.120	0.13	0.014	0.003	0.017
1998	812,007	1,900,000	0.30	0.5	-	1	0.09	0.022	0.005	0.005	0.08	0.016	0.002	0.004
1999	883,032	2,500,000	0.30	0.5	-	1	0.09	0.024	0.080	0.009	0.06	0.014	0.035	0.006
2000	921,667	875,000	0.30	0.5	-	1	0.06	0.032	0.027	0.008	0.04	0.027	0.016	0.005
2001	1,003,485	3,100,000	0.30	0.5	-	1	0.03	0.023	0.060	0.005	0.02	0.012	0.012	0.003

			Loading per day of discharge (kg/d)				Acute Toxicity Test Results % Mortality	
Year	**Tonnes Milled/yr.**	**Effluent Volume Discharged (m^3)**	**Cu**	**As**	**Un-ionized NH^3**	**Total Cyanide**	**Rainbow Trout**	**Daphnia Magna**
1996	656,770	2,444,000	5.60	0.71	0.16	0.60	0	0
1997	654,613	2,110,000	7.45	0.82	0.15	1.00	0	10
1998	812,007	1,900,000	4.33	0.87	0.08	0.22	0	15
1999	883,032	2,500,000	2.36	0.53	1.28	0.22	0	15
2000	921,667	875,000	0.87	0.54	0.31	0.10	0	0
2001	1,003,485	3,100,000	0.59	0.32	0.26	0.07	0	0

Figure 1

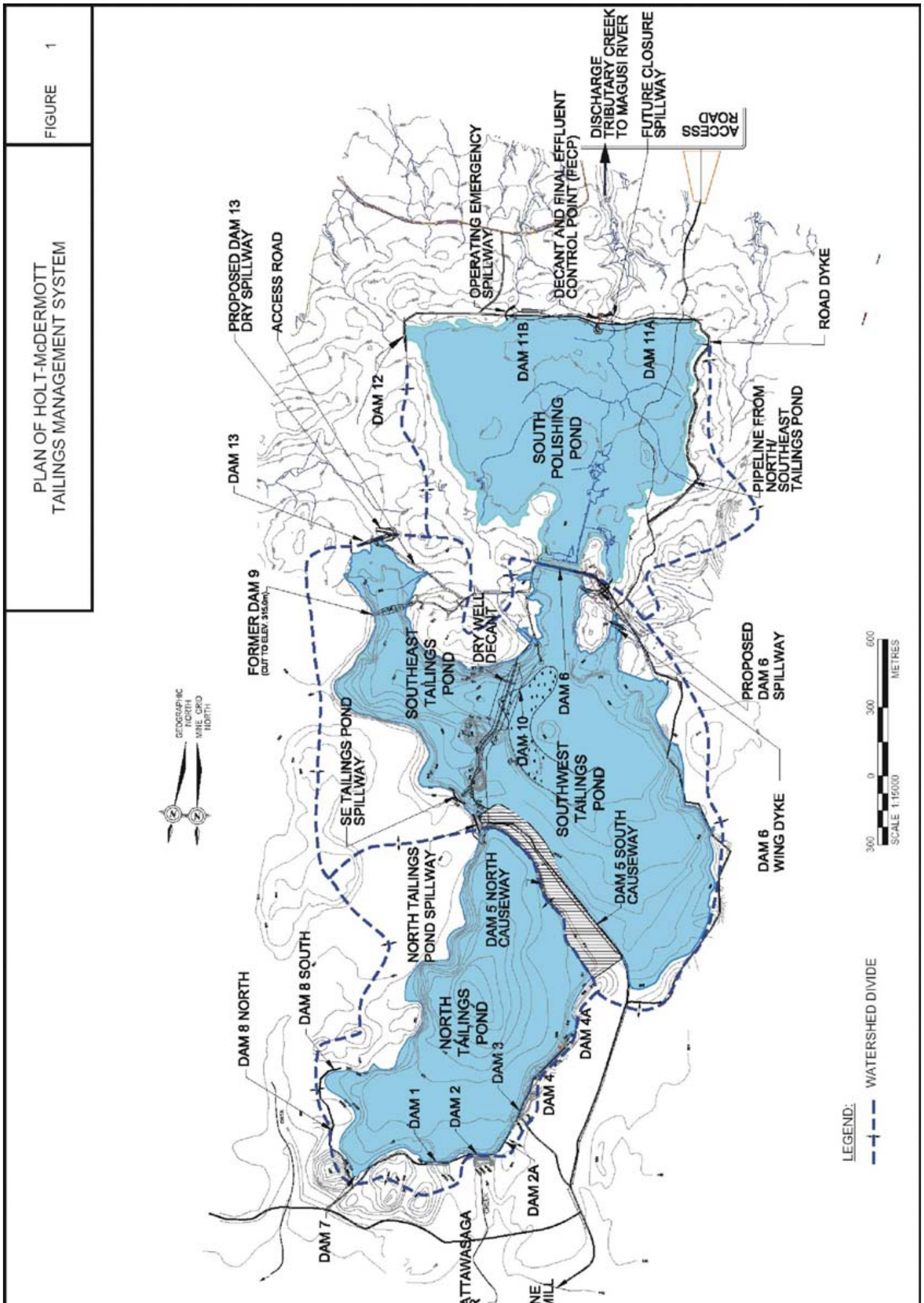
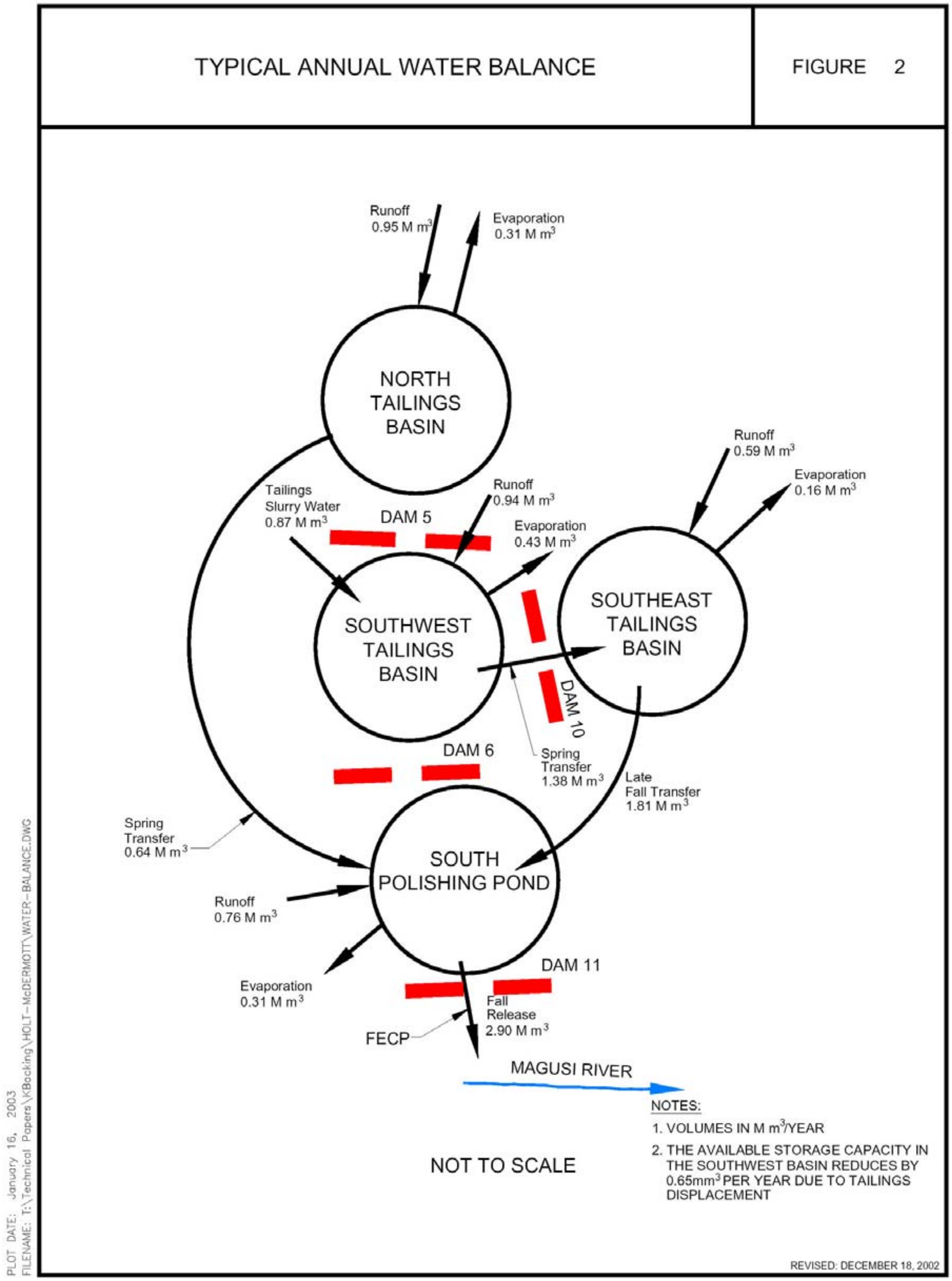

PLAN OF HOLT-McDERMOTT
TAILINGS MANAGEMENT SYSTEM
FIGURE 1
NORTH TAILINGS POND
SOUTHEAST TAILINGS POND
SOUTHWEST TAILINGS POND
SOUTH POLISHING POND
DAM 1
DAM 2
DAM 2A
DAM 3
DAM 4
DAM 4A
DAM 5 NORTH CAUSEWAY
DAM 5 SOUTH CAUSEWAY
DAM 6
DAM 6 WING DYKE
PROPOSED DAM 6 SPILLWAY
DAM 7
DAM 8 NORTH
DAM 8 SOUTH
FORMER DAM 9
(CUT TO ELEV. 315.0m)
DAM 10
DAM 11A
DAM 11B
DAM 12
DAM 13
PROPOSED DAM 13 DRY SPILLWAY
ACCESS ROAD
OPERATING EMERGENCY SPILLWAY
DECANT AND FINAL EFFLUENT CONTROL POINT (FECP)
DISCHARGE TRIBUTARY CREEK TO MAGUSI RIVER
FUTURE CLOSURE SPILLWAY
ACCESS ROAD
ROAD DYKE
PIPELINE FROM NORTH/ SOUTHEAST TAILINGS POND
DRY WELL DECANT
SE TAILINGS POND SPILLWAY
NORTH TAILINGS POND SPILLWAY
TO MATTAWASAGA RIVER
TO MINE AND MILL
GEOGRAPHIC NORTH
MINE GRID NORTH
LEGEND:
WATERSHED DIVIDE
300 0 300 600
SCALE 1:15000
METRES

Figure 2



TYPICAL ANNUAL WATER BALANCE
FIGURE 2
Runoff 0.95 M m3
Evaporation 0.31 M m3
NORTH TAILINGS BASIN
Runoff 0.59 M m3
Evaporation 0.16 M m3
Tailings Slurry Water 0.87 M m3
DAM 5
Runoff 0.94 M m3
Evaporation 0.43 M m3
SOUTHWEST TAILINGS BASIN
SOUTHEAST TAILINGS BASIN
DAM 10
DAM 6
Spring Transfer 1.38 M m3
Late Fall Transfer 1.81 M m3
Spring Transfer 0.64 M m3
SOUTH POLISHING POND
Runoff 0.76 M m3
Evaporation 0.31 M m3
DAM 11
Fall Release 2.90 M m3
FECP
MAGUSI RIVER
NOTES:
1. VOLUMES IN M m3/YEAR
2. THE AVAILABLE STORAGE CAPACITY IN THE SOUTHWEST BASIN REDUCES BY 0.65mm3 PER YEAR DUE TO TAILINGS DISPLACEMENT
NOT TO SCALE
REVISED: DECEMBER 18, 2002
PLOT DATE: January 16, 2003
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FIGURE 3
EFFLUENT DISCHARGE WATER QUALITY
MONTHLY AVERAGES - 1996 to 2001

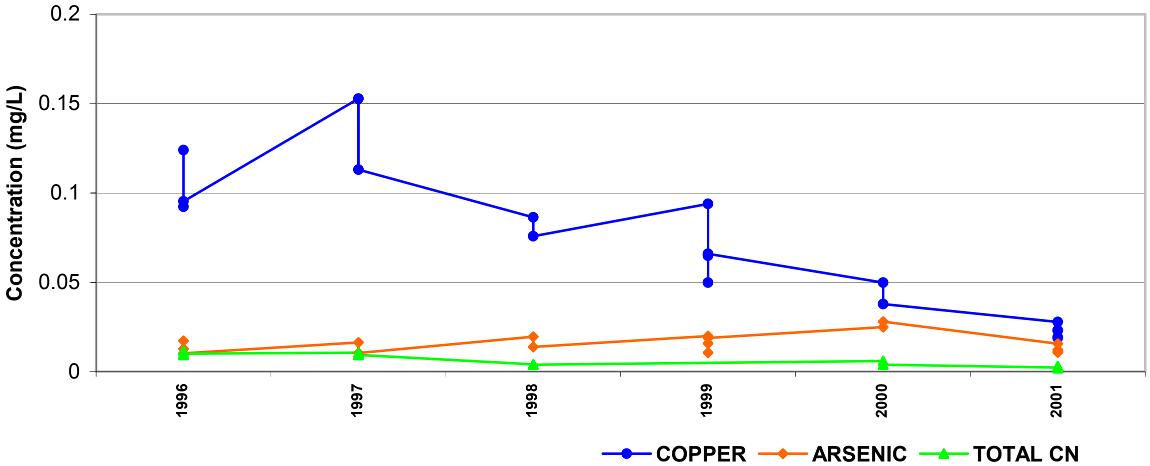

Photo 1: FECP Flow Monitoring Weirs