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Government of Yukon-Energy, Mines and Resources

Mount Nansen Mine
Water Treatment Study

Prepared by:

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Project No.: 2940 045 00 (4.6.1)

Date: January, 2009

DRAFT

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January 9, 2008

Project No. 2940 045 00 (4.6.1)

Mr. Frank Patch
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Energy, Mines and Resources
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P.O. Box 2703 (K-419)
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Dear Mr. Patch:

Re: Mount Nansen Mine Water Treatment Study

AECOM Canada Ltd. is pleased to submit a draft of our water treatment study report to the Government of Yukon.

Should you have any queries, please do not hesitate to contact Barry Williamson, P.Eng. directly at 204-284-0580.

Sincerely,

AECOM Canada Ltd.

Ron Typliski, P.Eng.
Vice-President, Manitoba District
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Revision Log

Revision #	Revised By	Date	Issue / Revision Description
1	B. Williamson	January 9, 2009	Draft

Signature Page

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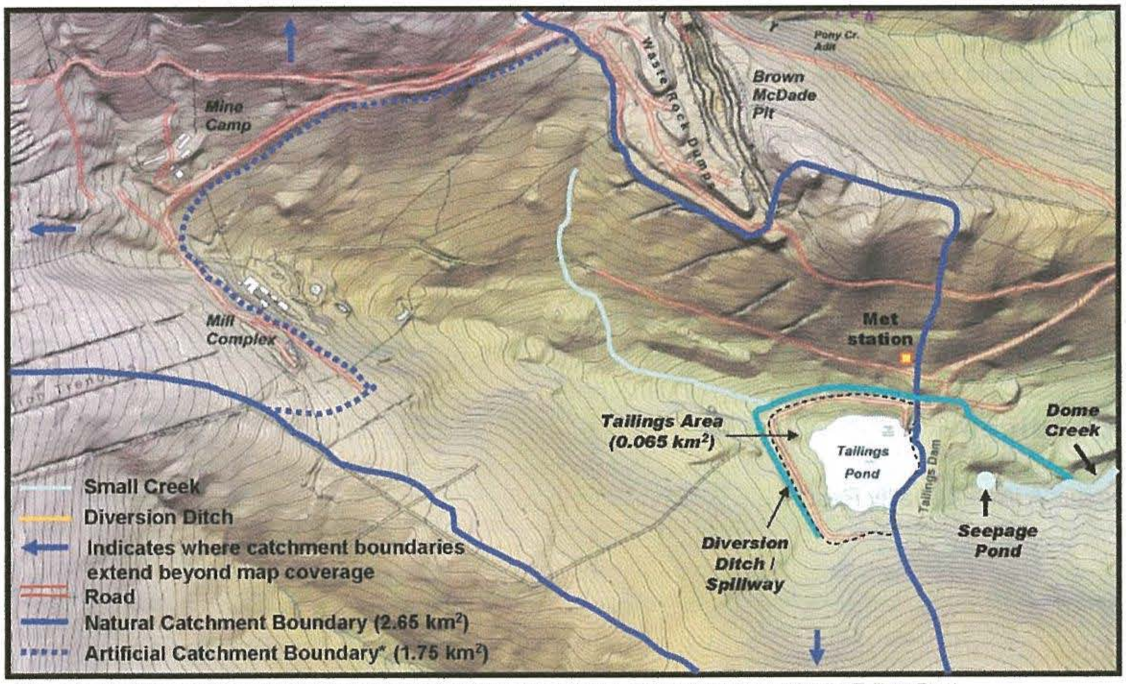
Appendix A Water Quality Results

1. Introduction

1.1 Background

Mount Nansen Mine is a former gold and silver mine that is currently under the care of the Government of Yukon. The Mount Nansen property is located 60 km west of Carmacks and 180 km north of Whitehorse, Yukon and is within the traditional territory of the Little Salmon Carmacks First Nation. The general layout of the mine site is shown below in Figure 1.



* The artificial catchment boundary is due to a diversion ditch that captures all runoff up-valley from entering the Tailings Pond.

Figure 1 – Mount Nansen Mine General Layout (GLL, 2005)

In 1999, the mine owner, BYG Natural Resources (BYG), was unable to meet the requirements of the water licence and as a result, the mine was closed down. Immediately after shutdown, BYG appointed a receiver. On July 28, 1999, the receiver abandoned the property, leaving a significant environmental liability. Since this time, the government has taken responsibility for care and maintenance of the property.

During operations, tailings pond water had to be pumped up to the mill site on a seasonal basis for treatment prior to discharge to Dome Creek. After the site was abandoned in 1999, the Department of Indian Affairs and Northern Development (DIAND) converted some of the mill process tanks into an improved water treatment system and continued to treat tailings pond water on a seasonal basis with a modified INCO SO_2 process. In 2005, treatment prior to discharge ceased when it was determined that cyanide and metal concentrations were below discharge criteria for the mine's operational water licence.

The Government of Yukon and the Government of Canada along with Little Salmon Carmacks First Nation are actively involved in the planning for the final closure of this mine. The overall goal is to bring Mount Nansen to closure as soon as possible. AECOM recently submitted the *2008 Geotechnical Inspections* report, which identifies three potential closure options for Mount Nansen:

1) Upgrade the existing Tailings Management Area (TMA) structures in accordance with the 2007 CDA Guideline and include a permanent long term closure plan for the tailings (soil cover)

2) Dispose of tailings in the Brown-McDade pit and breach the existing dams to restore Dome Creek valley

3) Excavate and redistribute a sufficient volume of tailings to allow the tailings dam to be breached and the Dome Creek valley restored

If the Second option were selected, tailings from the TMA would be relocated to the Brown-McDade Pit and a cover of clean soil or waste rock would be used to cap the tailings. To accomplish this, water from the pit, water accumulating in the tailings pond, and the tailings' porewater would need to be removed and treated before the tailings could be relocated. Depending on the change in water quality during tailing relocation, the water in the seepage pond downstream of the TMA may also require treatment before being discharged to the environment.

As with option two, if the third option were selected, porewater contained within the tailings would likely have to be collected and treated prior to breaching the dams.

1.2 Scope

The purpose of this study is to summarize the existing water quality information from the pit lake, tailings pond and seepage pond, and to identify suitable water treatment systems. These systems will be evaluated based on capital and operational cost, constructability and performance. The study will also provide expected sludge volumes to be produced by the recommended treatment system, and recommendations for sludge management.

2. Review of Background Information

A considerable amount of information was provided to AECOM for our use in preparing this report. Where applicable, the following reports are referenced throughout this document, as is anecdotal information provided by the Government of Yukon:

- AECOM – 2008 Geotechnical Inspections report (Draft), November 2008
- Government of Yukon – Options for Closure of Mt. Nansen Mine, Technical Review Version, July 2008
- Lorax Environmental – Tailings Porewater Assessment, April 2008
- Gartner Lee Limited – 2005 Water Balance for the Mount Nansen Mine Tailings Pond, Yukon, February 2006
- Lorax Environmental – Mount Nansen Bioremediation Assessment (Draft), February 2006
- Gartner Lee Limited – Mt. Nansen Mine Site, Brown-McDade Pit Desktop Hydrogeological Study, May 2007

The reader is encouraged to read these documents for more thorough discussions on previous engineering and environmental assessments and investigations.

3. Water Treatment Objectives

3.1 Treated Water Quality Objectives

To determine the most appropriate treatment objectives, three sets of standards were evaluated:

- BYG's water use licence
- Department of the Environment's Metal Mining Effluent Regulations (MMER)
- Canadian Council of Ministers of the Environment (CCME) Canadian Environmental Quality Guidelines

Table 1 outlines the licence and MMER limits as well as the related CCME guidelines.

Table 1 – Discharge Regulations and Guidelines

Parameter	Licence Limits[a]	MMER Limits[a]	CCME Guidelines[a]
pH	6.0 – 8.5 (pH units)	6.0 – 9.5 (pH units)	6.0 – 9.0 (pH units)
Total Suspended Solids (TSS)	50	15	
Toxicity (LC50)	100%	100%	
Arsenic (total)		0.50	0.005
Arsenic (dissolved)	0.15		
Antimony (total)	0.15		
Barium (total)	1.0		
Cadmium (total)	0.02		0.017 µg/L
Chromium (total)	0.04		
Chromium (trivalent)			0.0089
Chromium (hexavalent)			0.001
Copper (total)	0.2	0.30	0.004[b]
Cyanide (total)	0.3	1.0	
Cyanide (WAD)	0.1		
Cyanide (free)			0.005
Iron (total)	1.0		0.3
Lead	0.1	0.20	0.007[c]
Manganese	0.5		
Mercury	5.0 µg/L		
Mercury (Inorganic)			0.026 µg/L
Methylmercury			0.004 µg/L
Nickel (total)	0.3	0.50	0.15[d]
Silver	0.1		0.0001
Zinc (total)	0.3	0.50	0.03

[a]all units mg/L unless otherwise noted
[b]CCME copper guideline = 4 µg/L at water hardness > 180 mg/L (very hard) as $CaCO_3$
[c]CCME lead guideline = 7 µg/L at water hardness > 180 mg/L (very hard) as $CaCO_3$
[d]CCME nickel guideline = 150 µg/L at water hardness > 180 mg/L (very hard) as $CaCO_3$

The water quality objectives outlined in this section were developed for treatment process selection only. Discharge water quality objectives for the site should be discussed with the appropriate regulators and stakeholders as a continuing part of the closure planning process.

In general, the licence limits are more stringent than the MMER limits, except in the case of total suspended solids (TSS). The water use licence also provides water quality limits for several deleterious substances not covered by the MMER. The CCME guidelines are more stringent than both the licence and MMER, and are even more stringent than the Guidelines for Canadian Drinking Water Quality for each of the substances of concern.

Currently, water discharged from site is required to meet the water quality standards outlined in the licence. It is expected that once the tailings have been relocated, further water treatment will not be required. As discussions continue regarding closure however, it may be decided that the MMER limits should be met in case ongoing treatment is deemed necessary. The CCME guidelines will not be included in the treatment objectives, as reference samples taken from surrounding areas, including Dome creek and Victoria creek, indicate that some parameters are naturally above the CCME guidelines. This is most likely due to mineralization, and not from effects of mining activities. In addition, the CCME guidelines are so stringent that achieving such low concentrations at Mount Nansen is most likely not feasible. Therefore, only the licence limits and MMER limits have been used to develop water quality objectives, as shown below in Table 2. Where the licence and the MMER were in disagreement, the more conservative values were selected. Existing water quality is discussed in greater detail in Section 4.

Table 2 – Treatment Objectives

Parameter	Effluent Concentration Objectives[a]	Existing Water Quality (*all units mg/L unless otherwise noted)*			
		Brown-McDade Pit	Tailings Pond	Tailings Porewater	Seepage Pond
pH	6.0-8.5 (pH units)	7.27-8.75	1.6-11.6	7.16-8.8	6.51-11.6
Total Suspended Solids (TSS)	15	1-375	1-236		1-490
Toxicity (LC50)	100%				
Arsenic (total)	0.50	0.0081-0.24	0.01-1.86	0.0407-22.9	0.01-0.5
Arsenic (dissolved)	0.15	0.00216-0.0199	0.0025-0.141		0.00137-0.0549
Antimony (total)	0.15	0.0007-0.1	0.01-2.18	0.00045-0.589	0.0008-0.5
Barium (total)	1.0	0.005-0.04	0.005-0.258	0.0032-0.435	0.031-0.262
Cadmium (total)	0.02	0.00305-0.029	0.00025-0.028	0.000073-0.0012	0.0003-0.025
Chromium (total)	0.04	0.00025-0.005	0.00025-0.013	0.00138	0.0005-0.062
Copper (total)	0.2	0.005-0.095	0.005-105	0.00114-7.57	0.005-36.8
Cyanide (total)	0.3		0.0025-0.248	0.00136-22	0.0189-0.532
Cyanide (WAD)	0.1		0.001-140		0.001-34
Iron (total)	1.0	0.015-8.45	0.0025-38.3	0.04-36.6	0.375-18
Lead	0.1	0.0006-0.116	0.0025-1.44	0.00091-0.0142	0.00005-0.125
Manganese	0.5	0.0408-9.58	0.123-26.6	0.0345-15.9	0.116-16.9
Mercury	5.0 µg/L				
Nickel (total)	0.3	0.0016-0.025	0.0005-0.869	0.0041-0.0883	0.00024-0.222
Silver	0.1	0.0002-0.01	0.00011-0.238	0.000015-0.0184	0.00002-0.122
Zinc (total)	0.3	0.16-2.26	0.0002-5.01	0.0086-0.206	0.0005-0.888

3.2 Expected Water Treatment Volumes and Flow Rates

The volume of water in the pit lake is estimated to be approximately 8000-10 000 m^3 (Yukon Energy Mines and Resources, 2008). The maximum volume of water expected within the TMA has been estimated at 156 000 m^3 with approximately 140 000 m^3 existing as porewater within the tailings (Gartner Lee, 2006). Since the volume of water in the TMA is an order of magnitude greater than in the pit, this is the volume for which an estimated treatment plant flow rate will be developed.

To determine the approximate flow rates that the treatment system will be required to meet to treat the tailings water, it is necessary to estimate approximately how long it would take to move the tailings. This approach assumes the treatment of the tailings water will be preformed concurrently with the earth moving operations.

Assuming the relocation of 300 000 m^3 of materials would be required (Yukon Energy and Mines, 2008), if four trucks with 10 m^3 capacities worked 10 hours a day, and each truck was capable of completing approximately 2 loads per hour, it should take about 375 days to move the tailings from the TMA to the Brown-McDade Pit. Therefore, the minimum daily flow rate that the treatment plant would be required to treat is:

$$\frac{156\ 000\ \text{m}^3}{375\ \text{days}} = 427\ \text{m}^3/\text{day}$$

Since the water removal must occur ahead of the earth moving operations, the tailings dewatering technology selected for the closure plan should be capable of providing a water removal rate greater than 427 m^3/day. Consequently, a higher flow rate through the treatment system should also be used. For this reason, the treatment systems being investigated will be sized to treat a flow rate of at least 1000 m^3/day, more than double the 427 m^3/day minimum required flow rate. This should allow any treatment system selected to meet the flow rates that will be produced during the dewatering, ensuring earth moving operations will not be held up by the water treatment process.

The Government of Yukon has indicated that it would like to dewater the pit during the summer a year before moving the tailings so that a useful water balance for the pit can be developed. Given a treatment plant with a 1000 m^3/day capacity, the pit dewatering should only take about 8-10 days. This should allow ample time for a water balance investigation to be undertaken during one summer.

4. Raw Water Quality

4.1 Brown-McDade Pit

Water quality data at varying depths has been recorded on a monthly basis since Dec. 5, 2005. Concentrations of constituents that exceed the licence and MMER limits in the pit lake are presented in section 1 of appendix A.

The data provided by the Government of Yukon indicates that water quality does vary slightly with depth, with manganese and zinc regularly surpassing the water quality limits. Both lead and cadmium have also surpassed the limits on occasion, but for the most part are satisfactorily low. The pH typically falls within the acceptable range for discharge, however it slightly exceeded the licence limit in the summer of 2007. However, pH remained within the MMER limits during the entire recording period.

4.2 Tailings Pond and Seepage Pond

Water quality sampling from the surface water in the tailings pond (pond water) is performed biweekly on a year-round basis, as is sampling from the water in the seepage pond (seepage water). Unfortunately, very little data is available with respect to the tailings porewater quality. In September 2007, eleven porewater samples were collected from five locations in the TMA for comparison to the pond and seepage water (Lorax, 2008). Water quality results for the pond water, porewater and seepage water are presented in section 2 of appendix A.

In general, the concentrations of the deleterious substances in pond water, porewater, and the seepage water follow each other closely. Concentrations and trends followed by the deleterious substances found in these bodies of water are discussed in greater detail in sections 4.2.1-4.2.5, below.

4.2.1 pH

Typically, pH levels in the porewater, pond and seepage waters are neutral to slightly basic. According to the data provided, pH levels frequently exceeded the licence limit prior to 2001, but apart from one anomalous spike, appear to have stabilized. The pH in the porewater was somewhat elevated in two samples, slightly exceeding the licence limit, however the majority of readings show the porewater to be fairly consistent with the pH of the pond and seepage water.

4.2.2 TSS

The licence limit for TSS is relatively high in comparison to the TSS concentrations regulated by the MMER (Licence TSS: 50 mg/L, MMER TSS: 15 mg/L). There is a gap in sampling records for TSS from Jan. 2004 to May 2008. Prior to this gap, TSS concentrations of the pond water were generally well within the licence limits, and only exceeded MMER limits on a few occasions. Since sampling resumed in May 2008, however, TSS concentrations have varied widely, regularly exceeding MMER limits, and surpassing the licence limit on one occasion as well.

The TSS concentrations in the seepage water appear more erratic than the pond water's, however they still seem to follow the same rough trends. In general, the TSS concentrations were above MMER limits but only exceeded the licence limits on a few occasions.

Because the sampling technique used to extract the porewater involved a filtration step, TSS values were not taken on the porewater samples. The concentration of TSS in the porewater will most likely be dependant on the dewatering method selected for the tailings during the development of the final closure scenario.

4.2.3 Cyanide

Concentration data for the weak acid dissociable (WAD) cyanide goes back to January 1999. Early testing indicated extremely elevated WAD cyanide concentrations (up to 140 mg/L), however these levels dropped significantly over the next few years, and by April 2002, had levelled out below the licence discharge limit, spiking on only a few occasions. This indicates that significant natural attenuation of the cyanide has taken place, and that the source of WAD cyanide is finite and being depleted (Lorax, 2008).

The results for the total cyanide in the system only go back to 2005, but support the theory that the cyanide is being depleted. The total cyanide concentration since readings began show only one instance where levels exceeded the licence limit of 0.3 mg/L, and all concentrations are well below the MMER limit of 1.00 mg/L.

In general, this appears to be the case in the porewater as well, with the exception of an anomalous reading of 22 mg/L in one of the samples. This is an important reading, as it may represent isolated porewater from operations; a theory that is supported by the anomalous pH, sodium and thiocyanate concentrations also recorded at this location. This means that elevated levels of deleterious substances, including cyanide, may be encountered within the tailings. However, these pockets appear to be rare and isolated, as all other samples taken contained less than 0.1 mg/L cyanide (Lorax, 2008).

4.2.4 Arsenic

The test results show very low levels of total arsenic in the pond and seepage waters, however the concentrations appear to be increasing steadily in the pond. The porewater results show arsenic concentrations many times higher than either the pond or seepage waters. The majority or porewater readings taken were in excess of the pond and seepage values, and as highs as 22.9 mg/L. These high concentrations are believed to reflect the remobilization of arsenic bearing iron oxyhydroxides (Lorax, 2008). The increase in the dissolved arsenic in the pond water in recent years may also be partly due to the remobilization of arsenic in the tailings.

4.2.5 Other Metals

For the majority of the metals being investigated, the porewater, pond and seepage waters all follow very similar concentrations and trends. Apart from some higher readings prior to December 2002 and a large one-time spike recorded in December 2005, cadmium, nickel and silver concentrations are well within the licence limits, with barium staying well below the licence limit since sampling began. The metals of highest concern are iron and manganese, which consistently surpass the effluent limits set out in the water use licence.

Antimony, copper, lead and zinc concentrations are much closer to the licence limit, occasionally surpassing it. In the porewater, one sample contained an uncharacteristically high concentration of copper (7.57 mg/L). This was the same sample that exhibited the high levels of cyanide, discussed above in section 4.2.3. Again, this indicates that pockets of higher metals concentrations may exist throughout the tailings; however, they appear to be rare.

5. Evaluation of Treatment Options

5.1 Pre-treatment for Cyanide

Several treatment options are available for treating cyanide. These options rely on chemical, physical or biological processes to reduce cyanide levels. Cyanide can be destroyed and converted to harmless substances with the addition of oxidants including chlorine gas, sodium or calcium hypochlorite, ozone, hydrogen peroxide or sulphur dioxide and air, i.e. SO_2-INCO process. The by-products of these reactions include cyanate, carbon dioxide, bicarbonate, nitrogen, nitrate, ammonia and sulphate. Cyanide can also be precipitated with the addition of iron which leads to the formation of insoluble metal cyanides. The precipitate accumulates as sludge that would then require disposal, as discussed below in section 5.4 - Sludge Management Options.

Currently, based on the water sampling data, it is assumed that cyanide removal at the pit lake is unnecessary. At the TMA, it appears from the data that significant natural attenuation of the cyanide in the water has already occurred. It is expected, however that the concentrations of cyanide may increase as the treatment of the porewater begins if many pockets containing cyanide are encountered within the tailings.

If it is decided that pre-treatment for cyanide is necessary, to avoid adverse affects such as unwanted chemical interactions, any pre-treatment options for cyanide should be chosen based on the primary treatment process selected.

5.2 Pre-treatment for Arsenic

Arsenic is the primary metal of concern in the tailings pond as it is present in relatively high concentrations in the tailings solids (Lorax, 2006). Arsenic does not currently appear to be an issue in the surface waters, as the recorded concentrations have been below the licence limits for discharge. As treatment of the porewater begins, however, this concentration is expected to rise significantly.

Arsenic is a metalloid that is found naturally in water, most commonly present as arsenite, As(III), and arsenate, As(V). While metals scans typically target the total or dissolved arsenic, the speciation of arsenic as either As(III) or As(V) is significant because of the differences in removal efficiencies. The preoxidation of As(III) to As(V) is commonly used to facilitate the removal of arsenic, as it is typically more efficient to remove As(V). Therefore, if it is determined that As(III) is predominant, a pre-oxidation step should be considered for the treatment system to ensure efficient arsenic removal.

5.3 Primary Treatment Options

In general, the concentrations of metals in the surface waters are low enough to allow discharge directly to the environment, especially in recent years. As water levels decrease, as tailings are disturbed, and as porewater is drawn out of the tailings for treatment, it is expected that higher concentrations will be seen, requiring treatment.

Besides the ability to treat the pit and tailings porewater to meet the current water licence limits and possible future effluent criteria, additional plant requirements must be considered when selecting a suitable treatment option. For Mount Nansen, the most important factor to consider when selecting the treatment system will be the flexibility. There are several bodies of water to be treated, each with their own unique water quality characteristics. Further to that, each body of water shows varying concentrations of deleterious substances at different depths. For this reason, selecting a flexible treatment system is essential.

5.3.1 Conventional Clarification

Conventional clarification typically involves the removal of particulate matter, chemical floc and precipitates from suspension through gravity settling. Chemicals are added to raw water to adjust pH and assist precipitation, causing precipitates to settle. The treated water rises vertically where it overflows the weir of a discharge channel at the tank's surface. The settled solids are then removed mechanically. These systems have a large footprint and slow reaction time compared to other treatment options, but they are capable of handling large quantities of water, and they are relatively simple to operate and maintain. However, because of the large space requirement and slow reaction time, conventional clarification is not recommended for Mount Nansen mine and will not be discussed further.

5.3.2 High Rate Clarification

High rate clarification refers to clarification systems that can be loaded at higher rates than is typical for conventional clarifiers. The two types of high-rate clarification systems being considered for Mount Nansen include solids contact/slurry recirculation and ballasted flocculation.

5.3.2.1 Solids Contact/Slurry Recirculation

Solids contact/slurry recirculation units typically combine mixing, flocculation and sedimentation in a single compartmented tank. A typical solids contact clarifier injects coagulant and softening chemicals in the influent and mixes the water under a center cone-shaped skirt, where a high floc concentration is maintained. Flow then passes through a sludge blanket at the bottom of tank to promote the growth of larger clusters. Then, as in conventional clarification, the treated water continues to rise vertically where it is collected in discharge troughs or channels at the surface.

These systems have a smaller footprint than conventional clarifiers, however because they typically must maintain the sludge blanket, they are limited in their operational flexibility. They are most commonly used in systems with uniform water characteristics and consistent flow rates.

The solids contact system being considered for use at Mount Nansen is the Contrafast CF-350 (Figure 2). This system is a high rate clarification/thickening system with a 1900 m^3/day (350 gpm) nominal design rate. This system is capable of producing sludge with more than 20% solids by weight, making additional sludge thickening unnecessary.

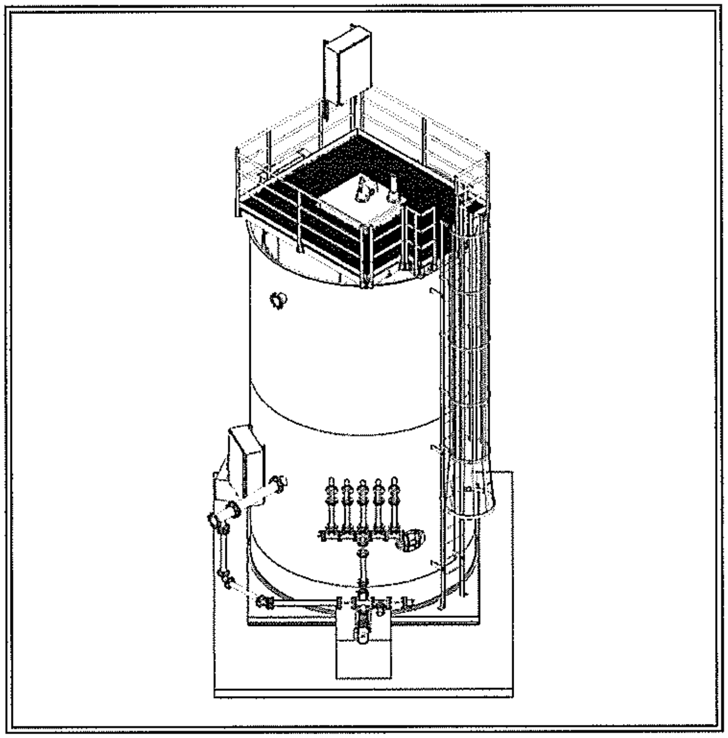


Figure 2 – CF-350 Contrafast Unit (courtesy of Siemens Water Technologies Corp.)

As shown in the flow diagram in **Error! Reference source not found.** on the following page, raw water combined with recycled sludge and treatment chemicals enter the center draft tube (1). There they are mixed and recirculated within the reactor (2) by the variable speed impeller. The impeller aids in accelerating solids formation and densifying the sludge. A high-velocity upflow port prevents settling in the reactor and transfers the water to the settling chamber. The water passes under a baffle and continues upward through the settling tubes (3) and into the effluent collection launder (4). The dense sludge settles to the basin floor where it is continually scraped and further thickened, until it is removed from the unit (5).

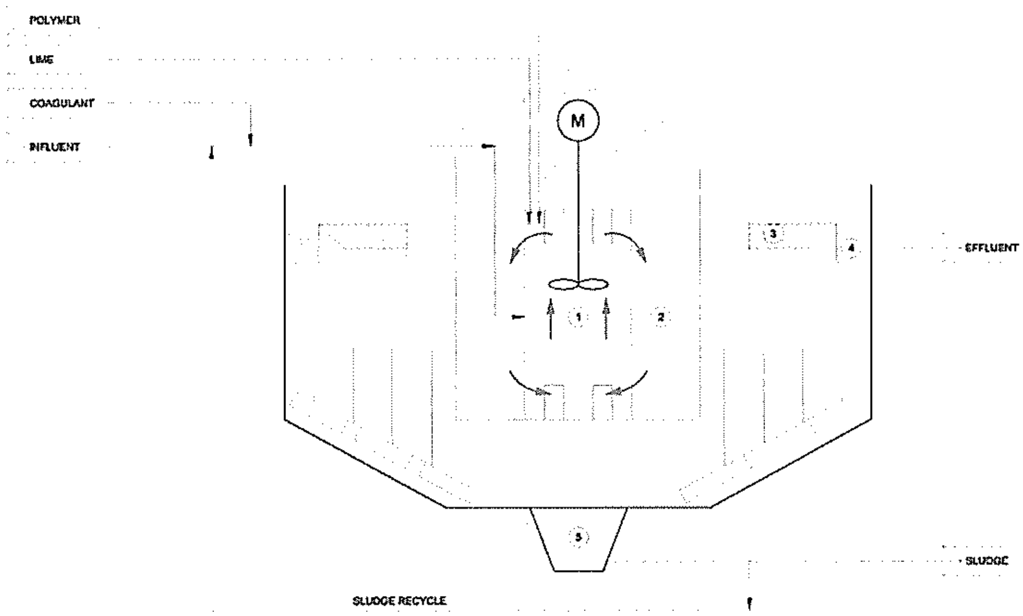


Figure 3 – Contrafast Process Diagram

5.3.2.2 Ballasted Flocculation

In this process, microsand is added after chemical coagulation but before flocculation to act as a basis for floc formation. The microsand improves both the settling velocity and the speed at which floc formation takes place. These systems require a substantially smaller footprint than conventional solid contact clarifiers and can react quickly to varying flow rates and water quality. With the small space requirement and operational flexibility, this technology could be well suited to the conditions at Mount Nansen.

A trailer mounted Actiflo ballasted flocculation system, shown in Figure 4, is currently being considered to treat the water at Mount Nansen. The trailer is divided into two sections: one for the Actiflo unit and the chemical dosing systems and one for the laboratory area. Actiflo systems are currently being used at a number of mine sites in both Canada and the United States to treat mining wastewater.

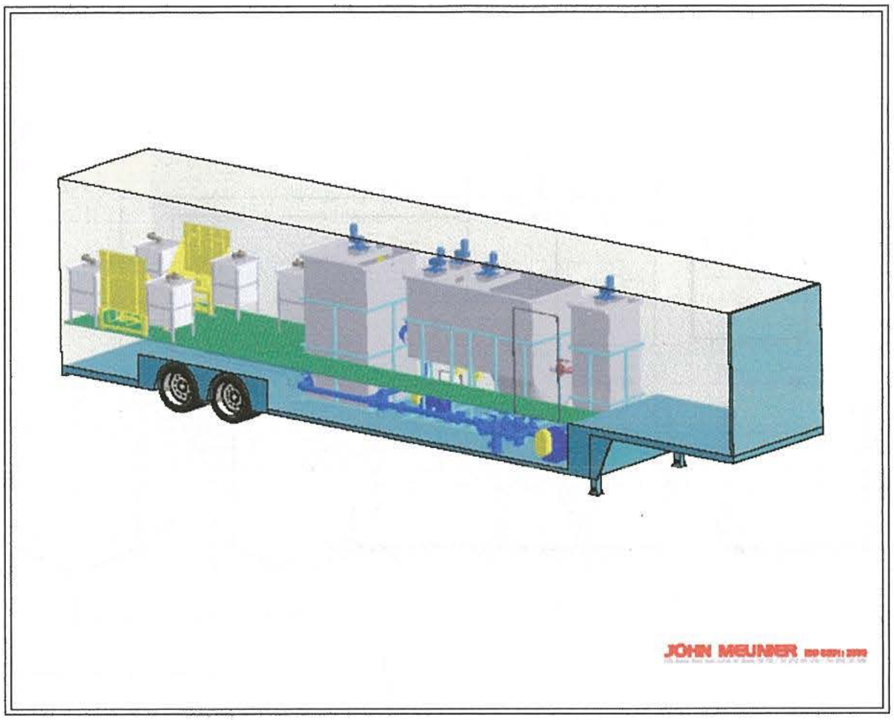


Figure 4 – Mobile Actiflo Metals Removal Unit (courtesy of Veolia Water)

The mobile unit includes a reaction tank for enhanced metals precipitation, and an Actidyn sludge thickener. This design has the flexibility to allow for mobility of the plant while providing the same treatment capability of a permanent Actiflo plant. The design treatment rate for this system is 1025 m^3/d at 80 m/h. The unit can treat up to 115 m/h; however, this must be validated for the individual application. The benefits to employing this system at Mount Nansen include flexible treatment, a small footprint, minimal site preparation, and a quick set-up and start-up time.

As shown in the acytiflo process diagram in Figure 5, lime softening is initially performed in the reaction tank (1). From there, the water enters a coagulation chamber (2) equipped with a mixer, where coagulant may be added. From the coagulation chamber, the coagulated water overflows to the injection chamber where the microsand and polymer are injected to form the ballasted floc. The overflow from the flocculation chamber then flows upward through the lamella gravity settlers (4). Scrapers force the sludge collected at the bottom of the clarifier chamber into the center cone, from which it is continuously withdrawn and directed to the Actidyne thickener (5) where sludge is conditioned and thickened. From the thickener, the sludge is pumped to the hydrocyclone where sludge and microsand are separated by centrifugal forces. The microsand is then recycled to the injection tank and the sludge is returned to the Actidyne thickener. Part of the sludge is also recycled back into the reaction chamber to enhance the crystallization kinetics and maximize the density of the settled sludge. The thickened sludge is then discharged outside of the system for handling.

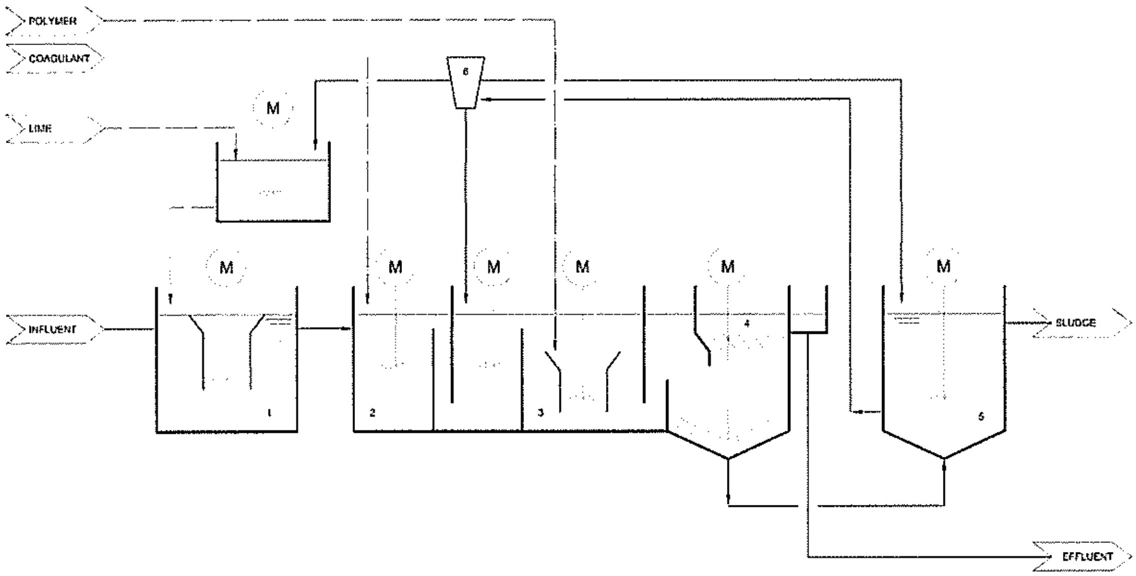


Figure 5 – Actiflo Process Diagram

The Actidyn sludge thickener included in the mobile plant typically achieves solids concentrations of 4-6% solids. This solids content is too low for transportation and disposal in a landfill. However, it would be suitable for pumping to another location, such as back to the TMA or to the pit for disposal with the tailings. Sludge management options are discussed in greater detail in section 5.4.

5.3.3 Membrane Filtration

In comparison with conventional treatment, membrane technology has been shown to provide superior discharge quality of mine effluent while offering lower capital and operating costs. Membrane technology cannot, however, completely replace conventional treatment as it is not a standalone technology. Pre-treatment would still be required, however the footprint, capital costs and chemical consumption can be substantially reduced.

Membranes are categorized by pore size ranging from microfiltration (MF) to ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO). Typically, membrane filter units have a higher capital cost than other treatment options, but they require little supervision and minimal operator training. Membrane systems can also treat varying water quality, however membrane fouling has been found to be a significant issue with heavy metals removal. With appropriate pre-treatment, this risk can be mitigated to a degree.

Discussions with a supplier familiar with membrane treatment for mining applications indicated that a mobile UF/RO or MF/RO system with oxidation and coagulation for pre-treatment of Mn and As could be used at Mount Nansen. However, the reject stream would be equal to about 25% of the total flow. Because of this poor estimated process efficiency, this option will not be discussed further.

5.4 Sludge Management Options

With the exception of the Contrafast system that can produce sludge with more than 20% solids, the treatment options presented above are capable of producing sludge with about 2-10% solids depending on the influent water quality. A sludge disposal scenario will need to be developed to manage the sludge. This may be accomplished through disposal with the tailings in the pit or through transportation to a landfill. For transportation and disposal in a landfill, further dewatering of the sludge will be required. If it is decided that sludge may be disposed of with the tailings, additional thickening may not be required, and maintaining a lower percent solids would facilitate pumping the sludge to the final location. Because the final closure scenario, including the sludge management, has yet to be developed, the sludge dewater information discussed in section 5.4.1 below is being provided for information only, and will not be included in the final costs and recommendations for the water treatment facility at this time.

5.4.1 Sludge Dewatering Options

5.4.1.1 Centrifuge

In a typical centrifuge, sludge is fed into a rotating drum that separates it into a sludge cake and a dilute called 'centrate'. The centrate contains fine low-density solids and is typically returned to the wastewater system. These systems can produce dense sludge cakes (10-30% solids) which makes this technology suitable for applications where sludge must be trucked away or landfilled. Additional advantages include fast startup and shutdown capabilities and a relatively small footprint. The disadvantages of this type of system are that skilled operators and maintenance personnel are typically required. The high suspended solids content in the centrate also mean that the centrate must be returned to the wastewater system for retreatment, marginally reducing the overall treatment system efficiency.

5.4.1.2 Belt-filter Press

Belt filter presses are continuous-feed dewatering devices that may apply chemical conditioning, gravity drainage and mechanically applied pressure to dewater sludge. In most systems, the first step is to drain free water from the sludge by gravity, sometimes with a slight vacuum to assist drainage and reduce odours. Next, a low-pressure section squeezes the sludge between two opposing porous cloth belts. In some systems, the low-pressure section is followed by a high-pressure section that squeezes the sludge between a series of rollers. These rollers produce shearing forces that release additional quantities of water from the sludge. Finally, the sludge cake is removed from belts by scraper blades.

These systems can achieve 15-30% solids in the sludge cake. Typically, they have low energy requirements and low mechanical complexity, therefore they tend to be relatively easy to maintain. Unfortunately, they tend to be very sensitive to incoming sludge feed characteristics. Wide variations in sludge characteristics can reduce dewatering efficiencies.

5.4.1.3 Recessed-plate Filter Press

In a plate filter press, dewatering is achieved by forcing the water from the sludge between recessed plates under high pressure. A typical recessed-plate filter consists of a series of vertical rectangular recessed plates on a frame with a fixed and movable head. A filter cloth is hung or fitted over each plate, and the plates are pressed together with sufficient force to seal them and withstand the pressure applied during the filtration process. Sludge is then pumped into the space between the plates and pressure is applied and maintained for 1-3 hours, forcing the water through the filter cloth and plate outlet ports. The filtrate is typically returned to the influent of the treatment plant. The plates are then separated and sludge is removed. Of the dewatering options being investigated for Mount Nansen, recessed-plate filter presses may achieve the highest cake solids concentration (20-50%) with low suspended solids in the filtrate. The primary disadvantage of this system is that a lot of operator attention is required, especially during feed, discharge and wash intervals.

5.4.1.4 Drying Beds & Freeze Thaw Ponds

In a typical sludge drying bed, sludge is dewatered through two main mechanisms: evaporation, and drainage through sand and an under-drainage system. Subjecting the sludge to freeze-thaw cycles can further reduce sludge volumes, though this would require a time commitment of at least one annual cycle.

These system typically have a low capital cost, low energy consumption and can provide a high solids content of dried product. The disadvantages are that a large space is required, and solids removal can be expensive and labour intensive.

5.4.1.5 Geotextile Tubes (Sludge Tubes)

Geotextile tubes, commonly known as sludge tubes, are used extensively for sludge dewatering on water treatment projects. This technology is often the most inexpensive and economical route to consider for treating a specific sludge stream. The benefits of using sludge tubes include:

- Minimal equipment required
- Simple to operate with no complicated procedures or parts
- Typically, the most economical approach to sludge dewatering

The sludge tubes should be left in left in place to dewater over a period of time to achieve the best volume reduction. It may also be necessary to use a polymer to achieve optimal sludge thickening. The correct use of polymer can reduce total thickening time and provide savings on a sludge tube system, but must be carefully monitored during the tube filling operation. Once the sludge is sufficiently thickened, the tube material can be trucked off-site for disposal or used as fill.

6. Estimated Costs (Class C Estimate)

The estimated capital, operation and maintenance costs for the two options being considered are compared below in Table 3.

Table 3 – Estimated Cost Comparison

COST ITEM	CONTRAFAST High Rate Clarifier/Thickener	ACTIFLO/ACTIDYN MOBILE UNIT Ballasted Flocculation Clarifier & Thickener
Capital Costs		
Packaged Treatment Plant	$560,300	$860,000
Chemical Feed Equipment	$15,000	Included
Foundations and Equipment Pads	$100,000	Not Required
Mechanical/Electrical Installation	$130,000	$75,000
Subtotal	$805,000	$935,000
Contingency (40%)	$322,000	$374,000
Engineering (15%)	$169,050	$196,350
Total Capital Costs	**$1,296,050**	**$1,505,350**
Operation and Maintenance Costs		
Labour @ $50/hr including benefits	$18,200	$18,200
Consumables	$14,500	$14,500
Total Annual Costs	**$32,700**	**$32,700**
Life Cycle Costing		
Capital	$1,296,050	$1,505,350
Operation and Maintenance	$87,907	$87,907
Total	**$1,383,957**	**$1,593,257**

To develop these costs, the following assumptions were made:

- Annual costs are averaged out over three years treatment, six months per year
- Discount rate of 4.4% applied
- Operator required about two hours a day, seven days a week during treatment season
- Existing raw water pumps can be reused to supply treatment plant

These costs do not include additional sludge thickening, start-up or commissioning costs.

7. Recommendations and Conclusions

7.1 Treatment Process Recommendation

Though the Contrafast clarifier has a lower cost and is capable of producing a denser sludge without secondary thickening, the flexibility, mobility, and minimal construction required for the Actiflo system makes Actiflo better suited to meet the treatment needs at Mount Nansen.

High rate clarification systems like Contrafast perform best with relatively consistent influent water quality, whereas the Actiflo system is able of adapting quickly to varying water qualities. Because it is expected that the water quality of the pit, tailings pond, porewater and seepage pond waters will all have different water quality characteristics, the Actiflo system would be the more suitable technology. In addition, because the Actiflo unit being considered is mobile, it can be parked directly adjacent to the body of water being treated. A fixed plant would require extensive piping across the mine site to be able to treat water from all three locations; the pit, the TMA and the seepage pond.

The Contrafast system would also require the construction of a concrete pad and supports prior to placement, and installation would be relatively complicated, requiring a crane rental and qualified construction contractor to be brought to site to complete the work. The Actiflo trailer simply needs to be parked on a flat surface capable of supporting 27,215 kg (60,000 lbs).

Another benefit of the Actiflo system is that, because it is mobile, once the final closure project is complete, the system can easily be relocated to another site and reused with minimal decommissioning at Mount Nansen, and minimum set up at the next site. Or, if deemed necessary, the system can remain in place to continue treatment.

The main disadvantage of the Actiflo system is that, even with the Actidyn thickener in operation, sludge density would most likely not exceed 4-6% solids. The Actiflo system would be expected to produce roughly 27 m^3 of sludge per day before thickening (1-2% solids). Depending on the final closure scenario selected, dewatering of the tailings in the TMA will most likely be occurring at the same time as the water treatment operations, therefore, simply returning the sludge to the TMA to be dewatered and placed with the tailings may be an acceptable and inexpensive sludge management solution. An alternate solution would be to dewater the tailings using geotextile tubes as discussed previously in section 5.4.1.5. Geotextile tubes are a very simple and economical way to dewater sludge. The thickened sludge could then be trucked off-site for disposal or used as fill.

The Actiflo system will require an adequate supply of Ferric chloride (34%), Lime, Hydrex polymer and microsand to operate. These items are not included with the mobile unit, and will need to be brought in to site before treatment operations can begin.

7.2 Recommendations for Ongoing Testing

Ongoing water sampling of the pond and seepage water is recommended, as well as additional sampling of the porewater at different locations and depths to gain a clearer picture of the conditions that will be faced when treatment begins. One particular item of interest is the frequency of which pockets of cyanide might be encountered within the tailings. This could have an effect on whether or not pretreatment for cyanide will be required.

The speciation of arsenic should also be determined. Currently, it is not known if As(III) or As(V) is predominant in the tailings pond, seepage pond or porewater. As discussed previously in section 4.2.4, if it is determined that As(III) is predominant, a pre-oxidation step should be considered for the treatment system to ensure efficient arsenic removal. Because this has not been confirmed, the pre-oxidation step is not being considered in the treatment recommendations or costs at this time.

7.3 Estimated Construction Schedule

The current estimated construction schedule is summarized below in Table 4. This schedule assumes a February 2009 project initiation, at which time detailed design will commence.

Table 4 – Estimated Construction Schedule

Task	Date
Project Initiation – Detailed Design Begins	February, 2009
Tender	April 2009
Construction and Commissioning	November 2009

Appendix A
Water Quality Results

Section 1 – Brown-McDade Pit Lake

Section 2 – Tailings Pond and Seepage Pond

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Section 1 - Brown-McDade Pit

Figure A1-1. Brown-McDade Pit pH at Varying Depths Over Time

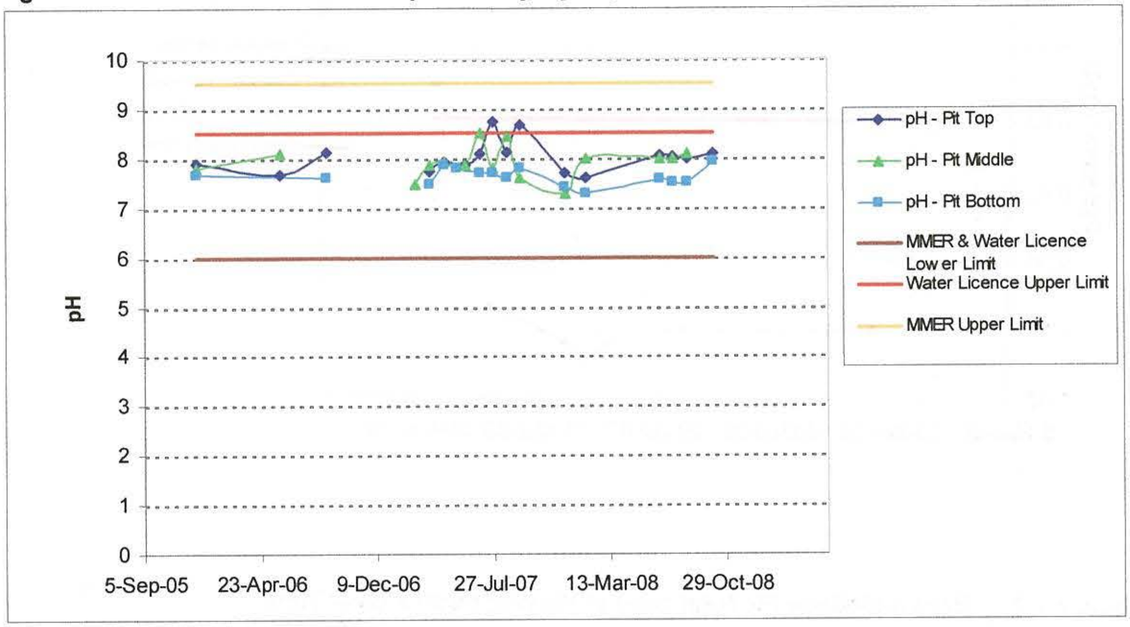


Figure A1-2. Brown-McDade Pit TSS at Varying Depths Over Time

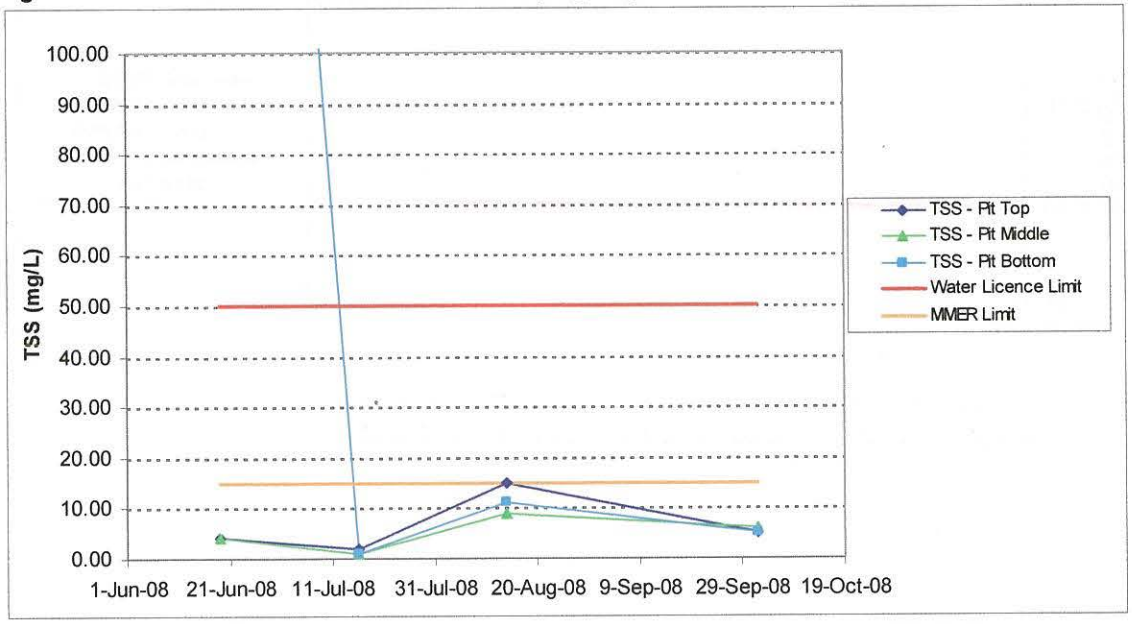


Figure A1-2. Brown-McDade Pit Total Cadmium at Varying Depths Over Time

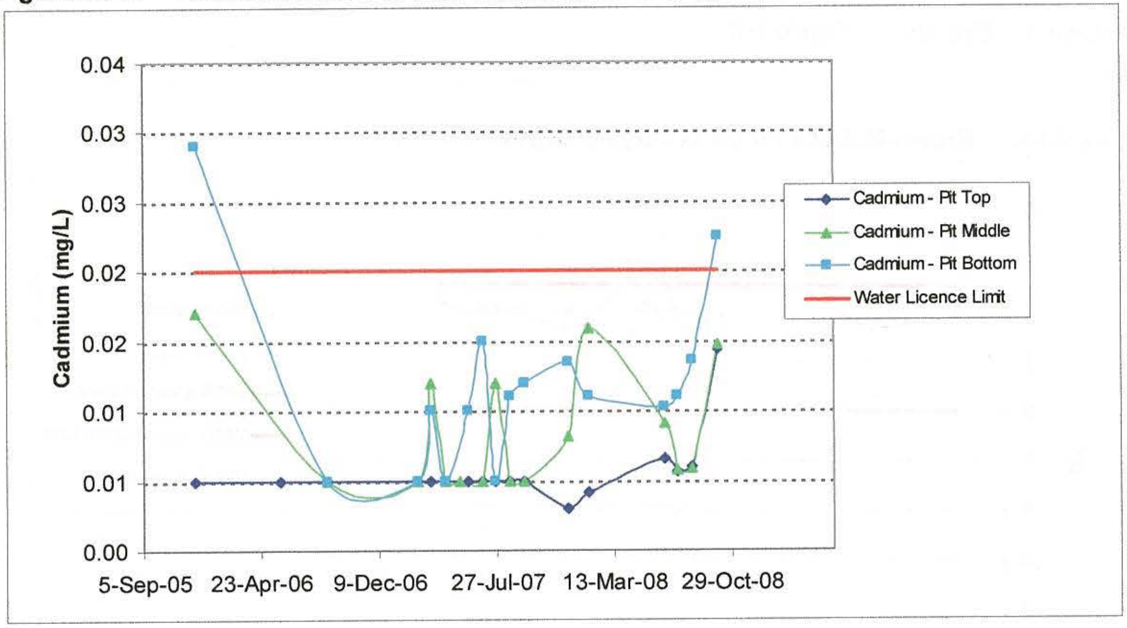


Figure A1-3. Brown-McDade Pit Total Lead at Varying Depths Over Time

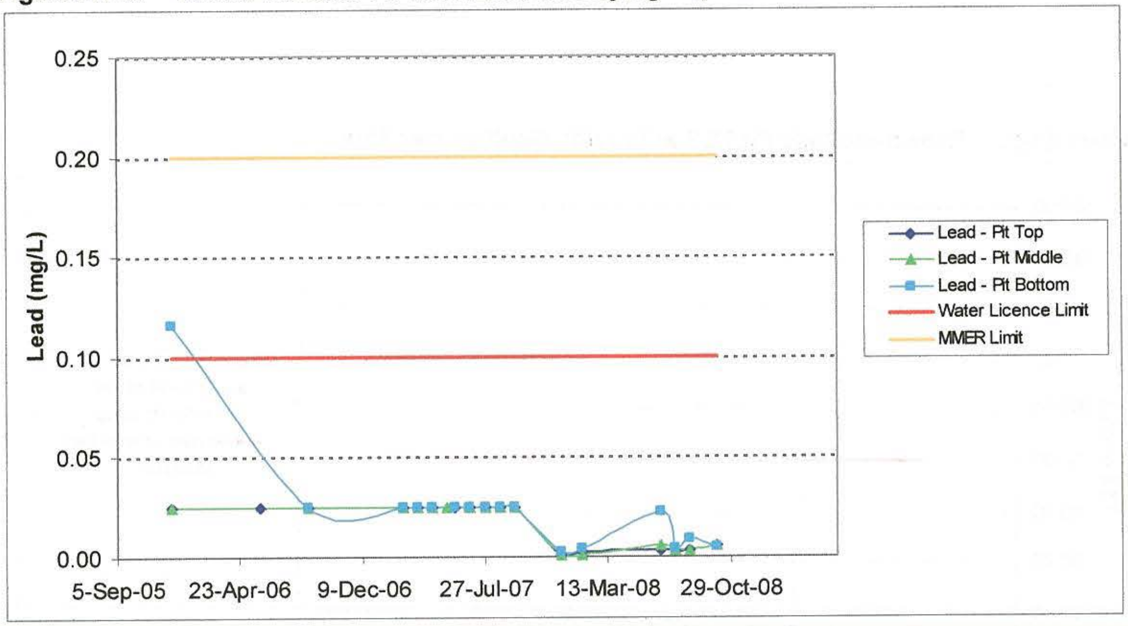


Figure A1-4. Brown-McDade Total Manganese pH at Varying Depths Over Time

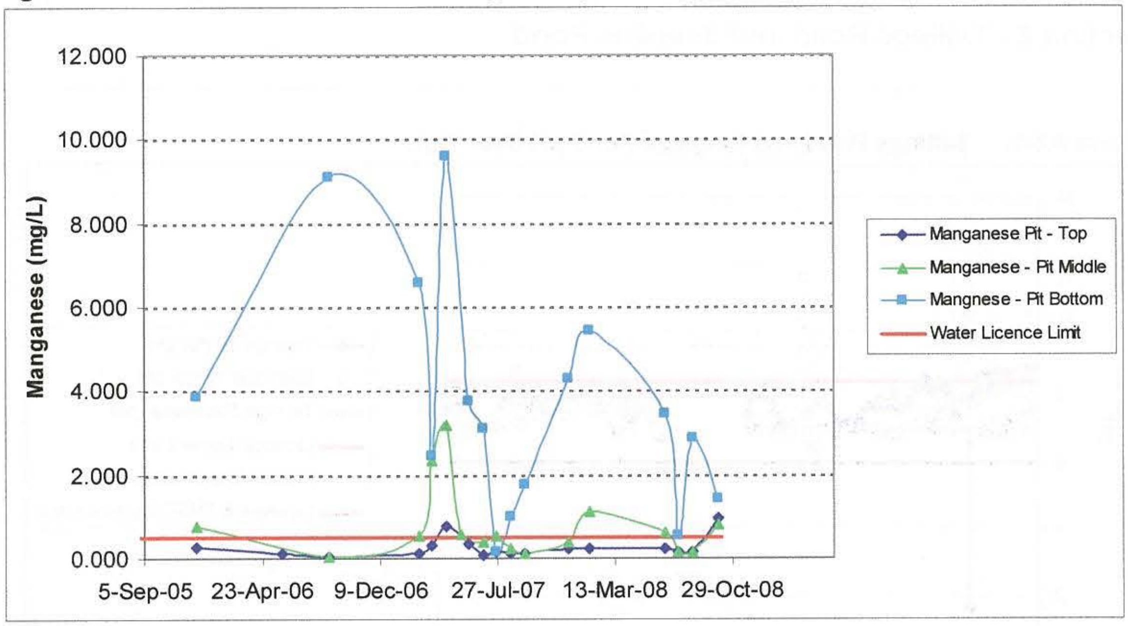
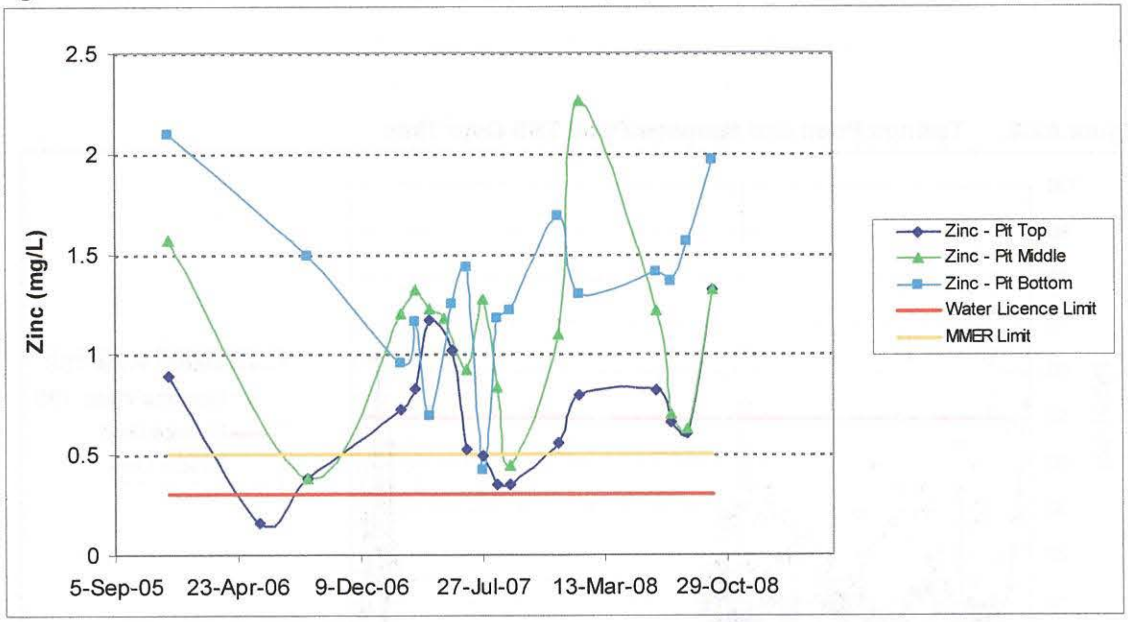


Figure A1-5. Brown-McDade Pit Total Zinc at Varying Depths Over Time



Section 2 - Tailings Pond and Seepage Pond

Figure A2-1. Tailings Pond and Seepage Pond pH Over Time

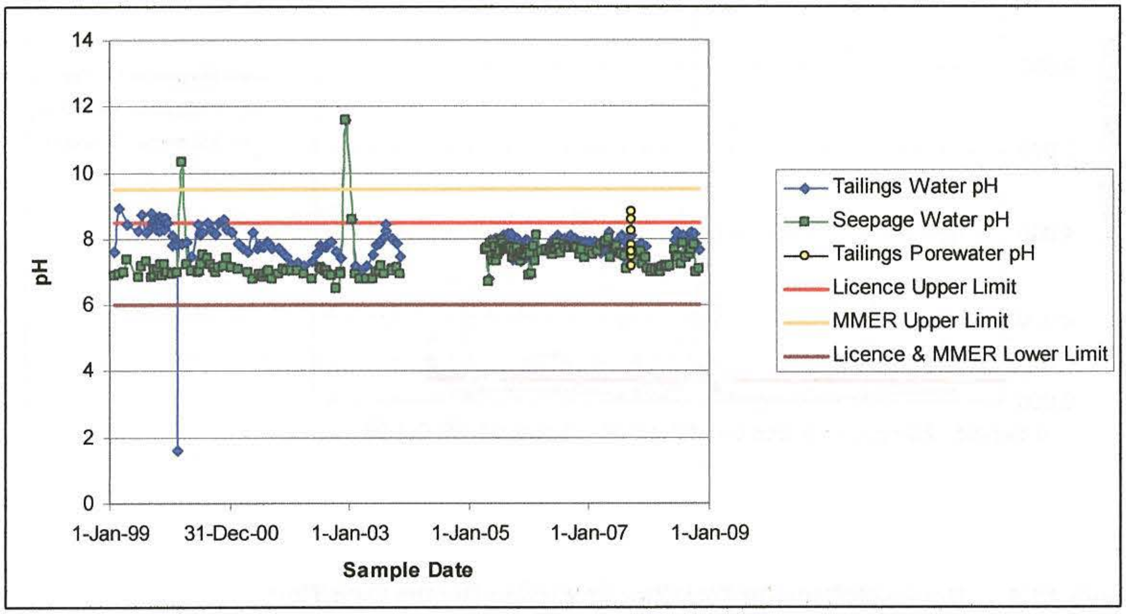


Figure A2-2. Tailings Pond and Seepage Pond TSS Over Time

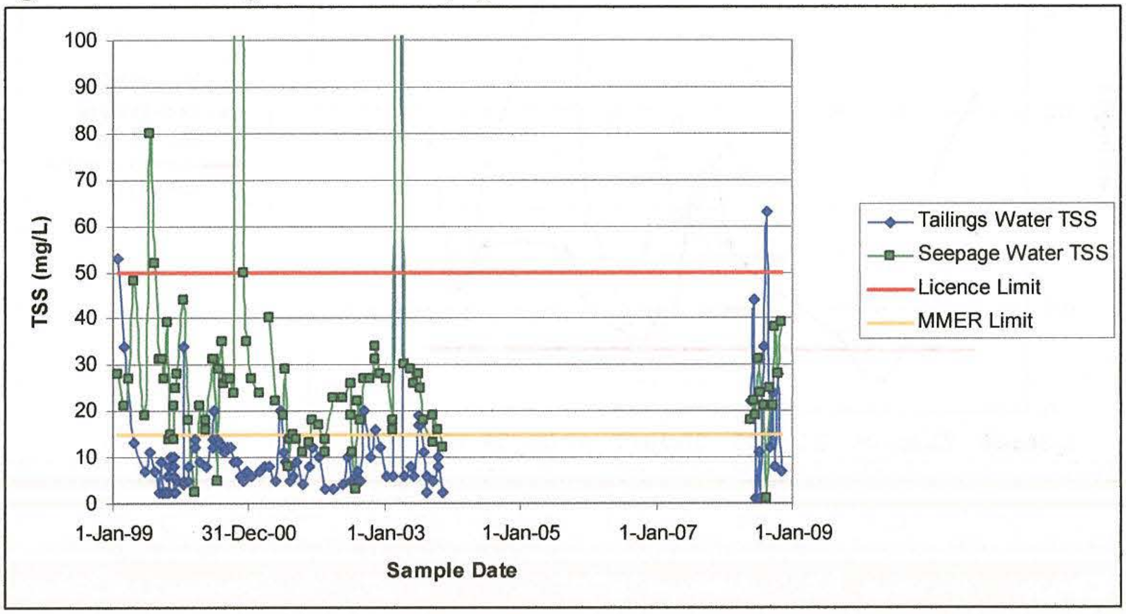


Figure A2-3. Tailings Pond and Seepage Pond WAD Cyanide Over Time

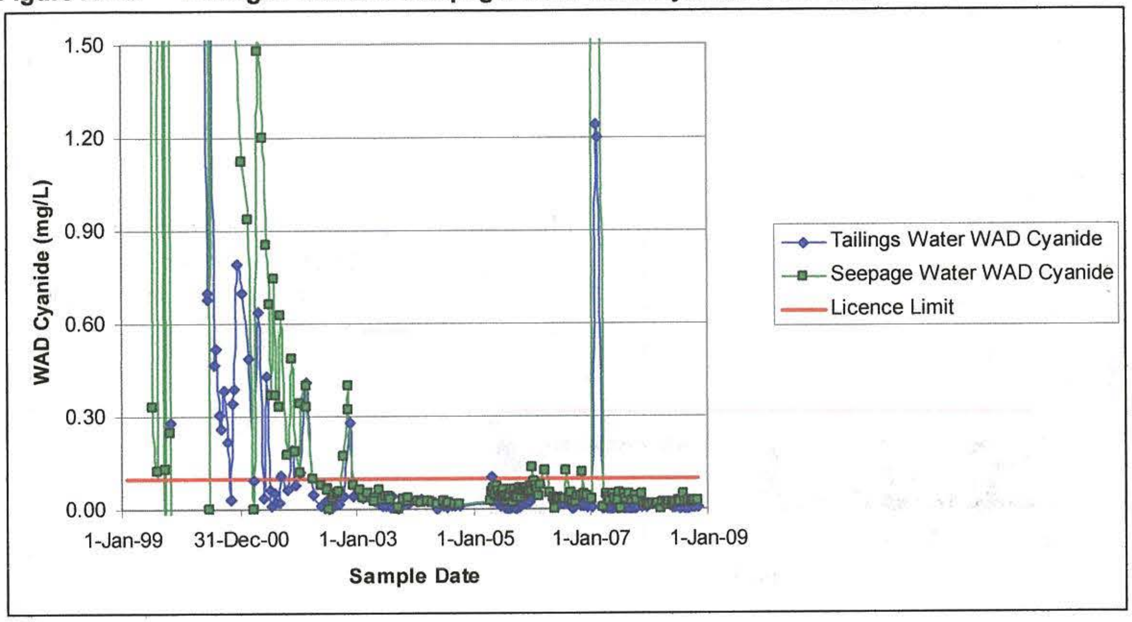


Figure A2-4. Tailings Pond and Seepage Pond Total Cyanide Over Time

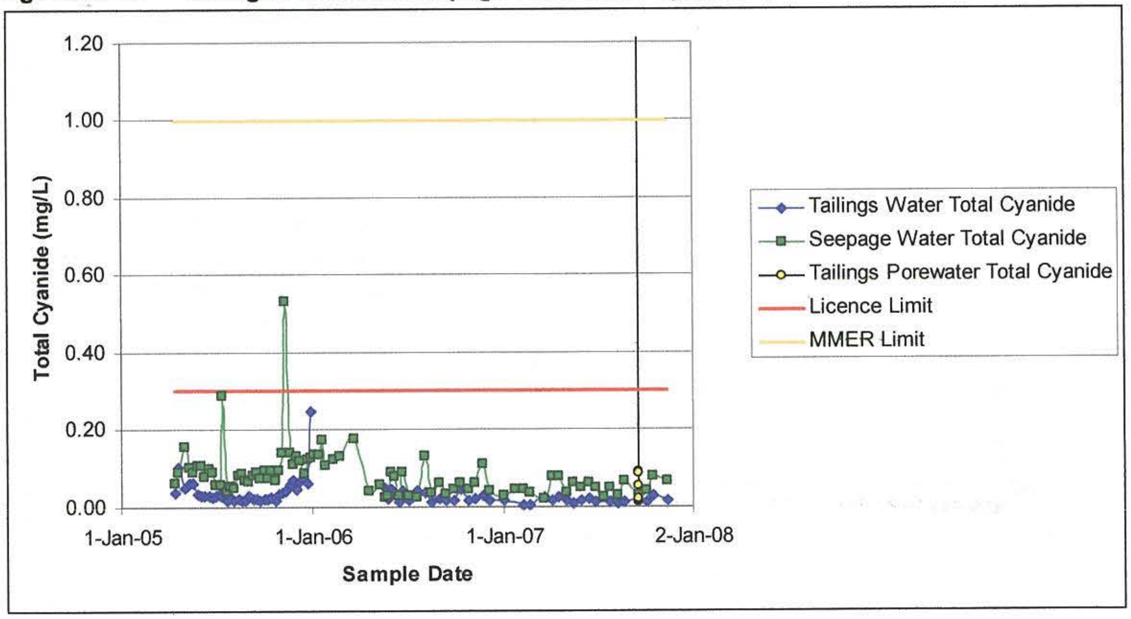


Figure A2-5. Tailings Pond and Seepage Pond Total Antimony Over Time

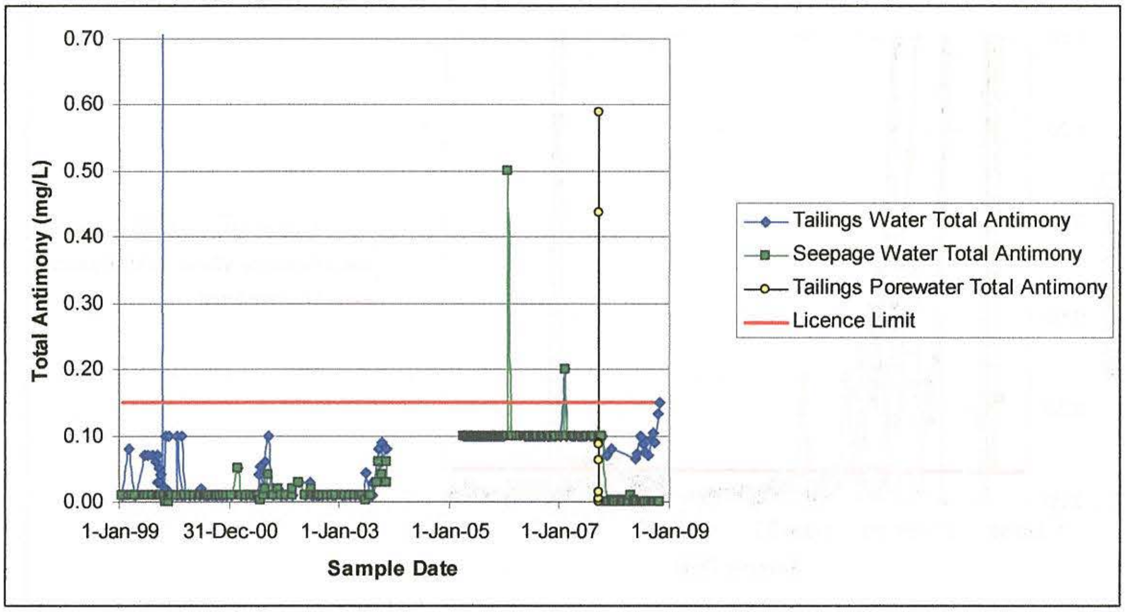


Figure A2-6. Tailings Pond and Seepage Pond Total Arsenic Over Time

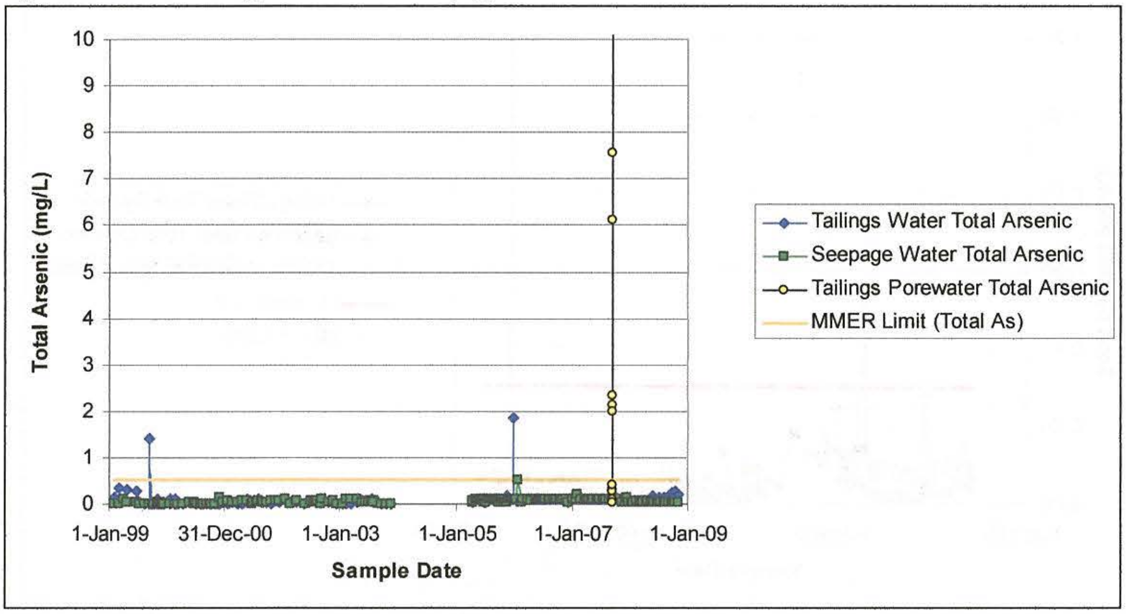


Figure A2-7. Tailings Pond and Seepage Pond Dissolved Arsenic Over Time

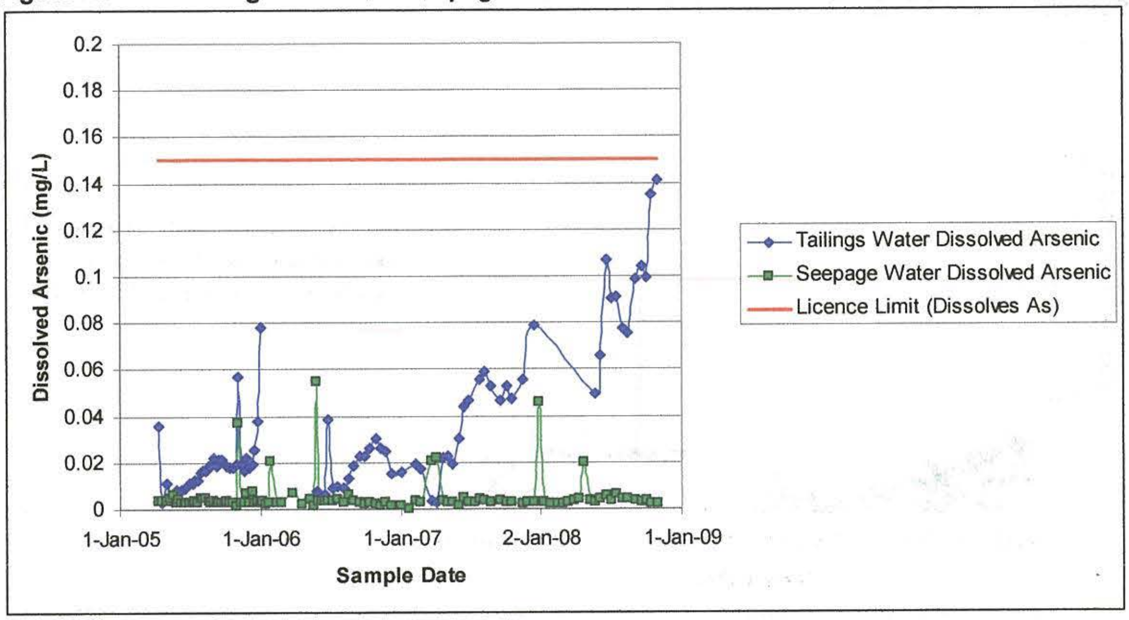


Figure A2-8. Tailings Pond and Seepage Pond Total Barium Over Time

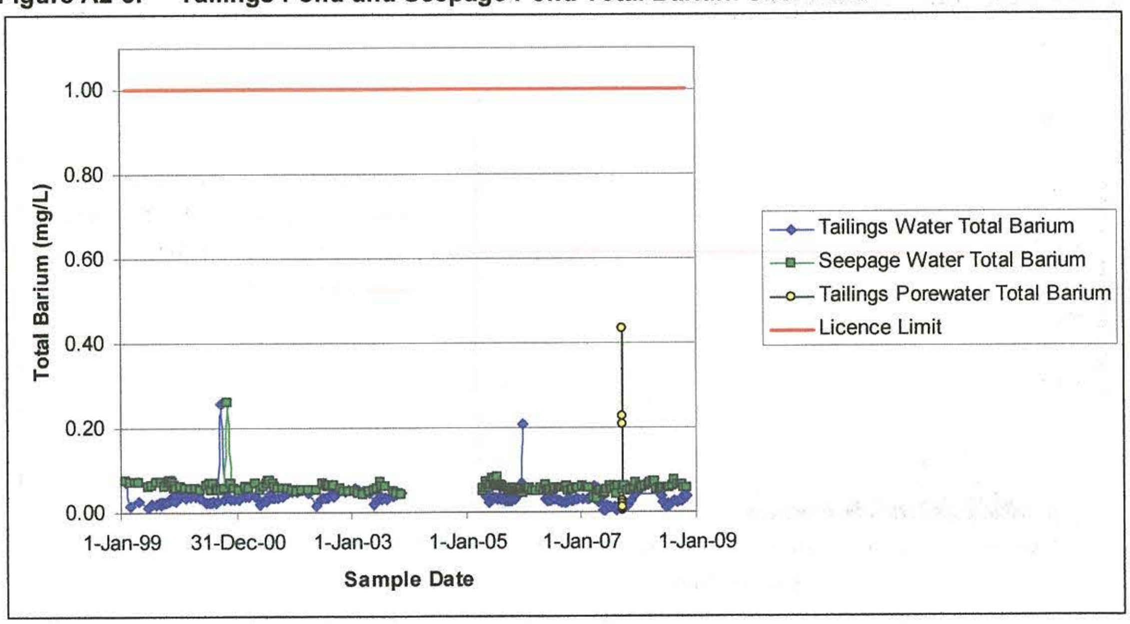


Figure A2-9. Tailings Pond and Seepage Pond Total Cadmium Over Time

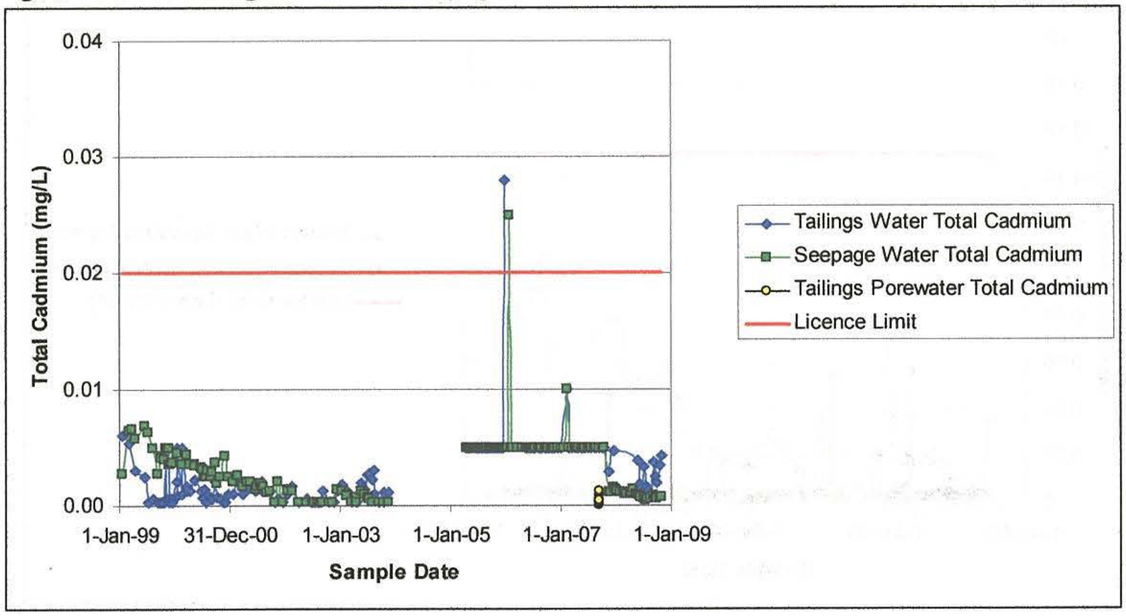


Figure A2-10. Tailings Pond and Seepage Pond Total Chromium Over Time

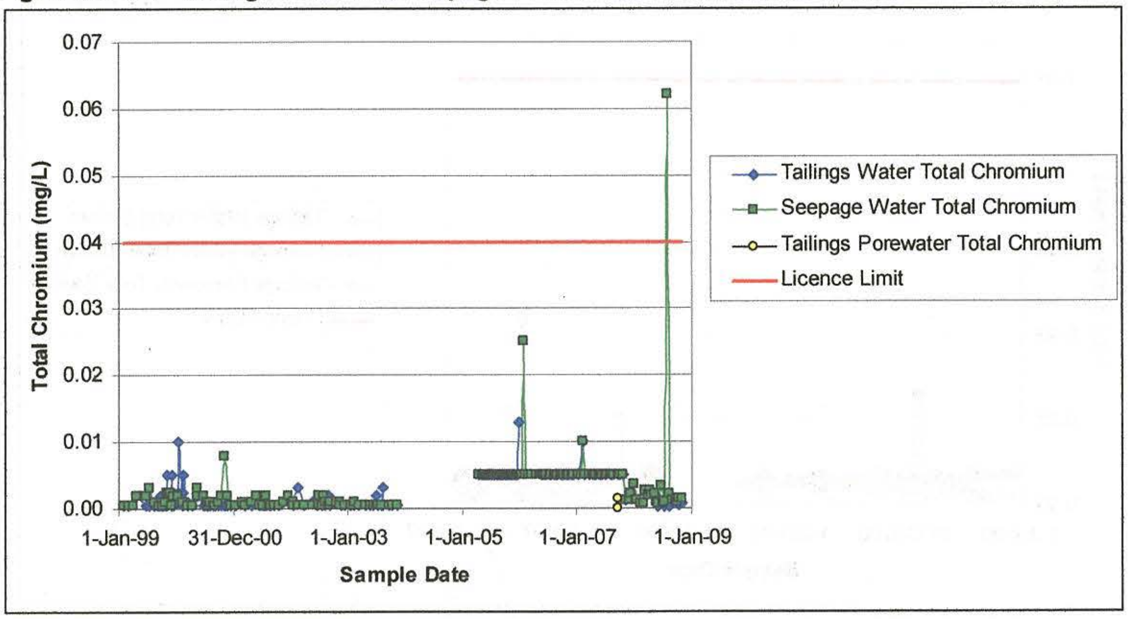


Figure A2-11. Tailings Pond and Seepage Pond Total Copper Over Time

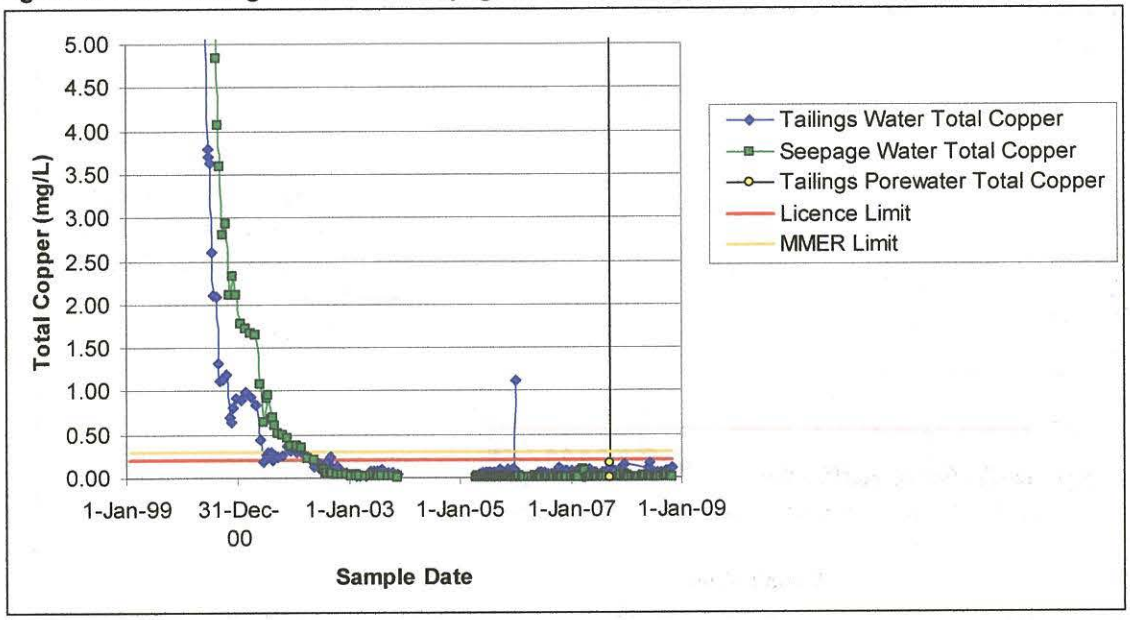


Figure A2-12. Tailings Pond and Seepage Pond Total Iron Over Time

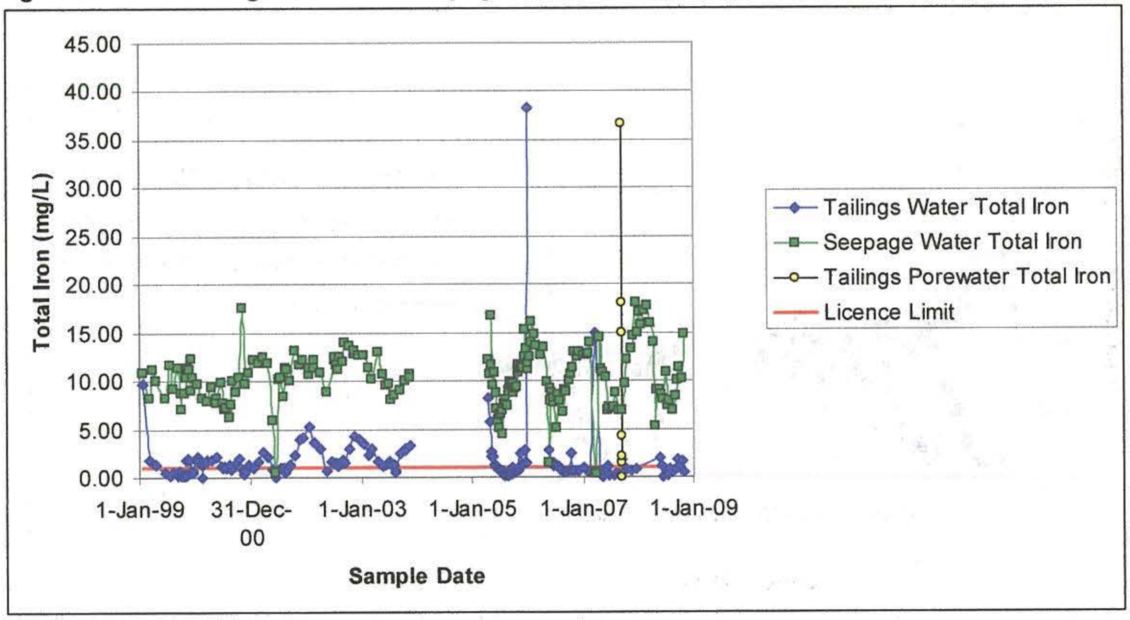


Figure A2-13. Tailings Pond and Seepage Pond Total Lead Over Time

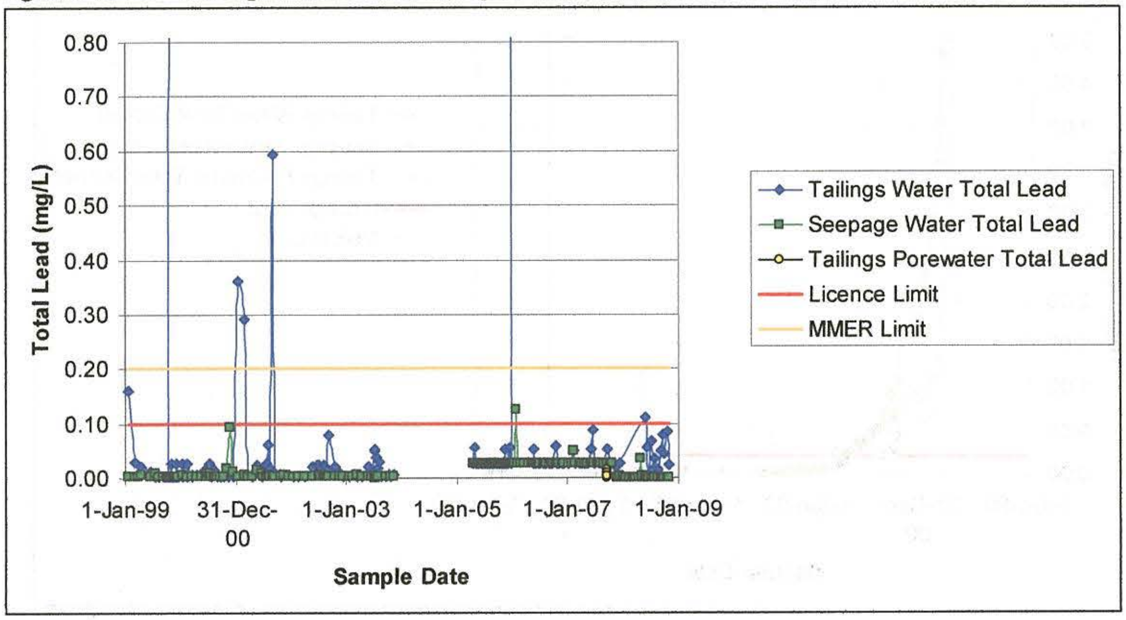


Figure A2-14. Tailings Pond and Seepage Pond Total Manganese Over Time

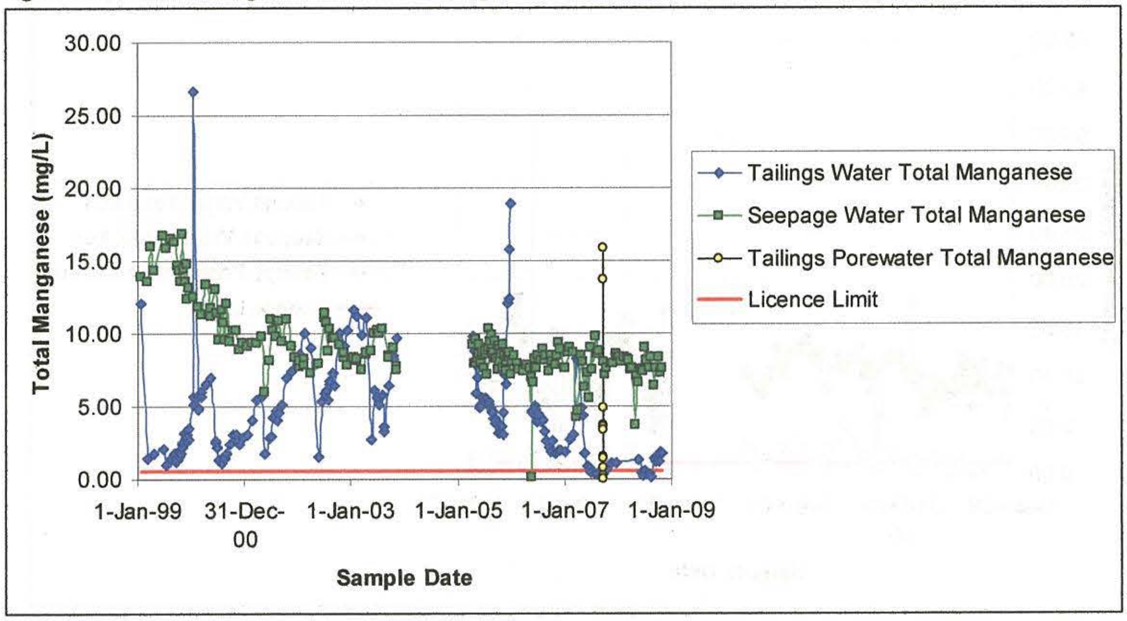


Figure A2-15. Tailings Pond and Seepage Pond Total Nickel Over Time

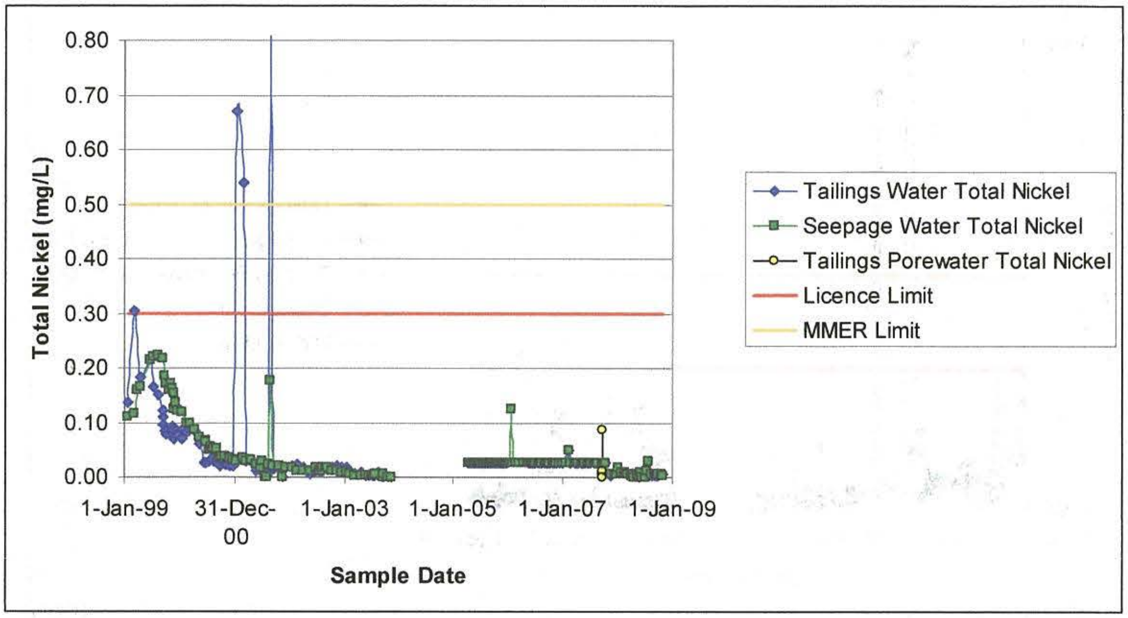


Figure A2-16. Tailings Pond and Seepage Pond Total Silver Over Time

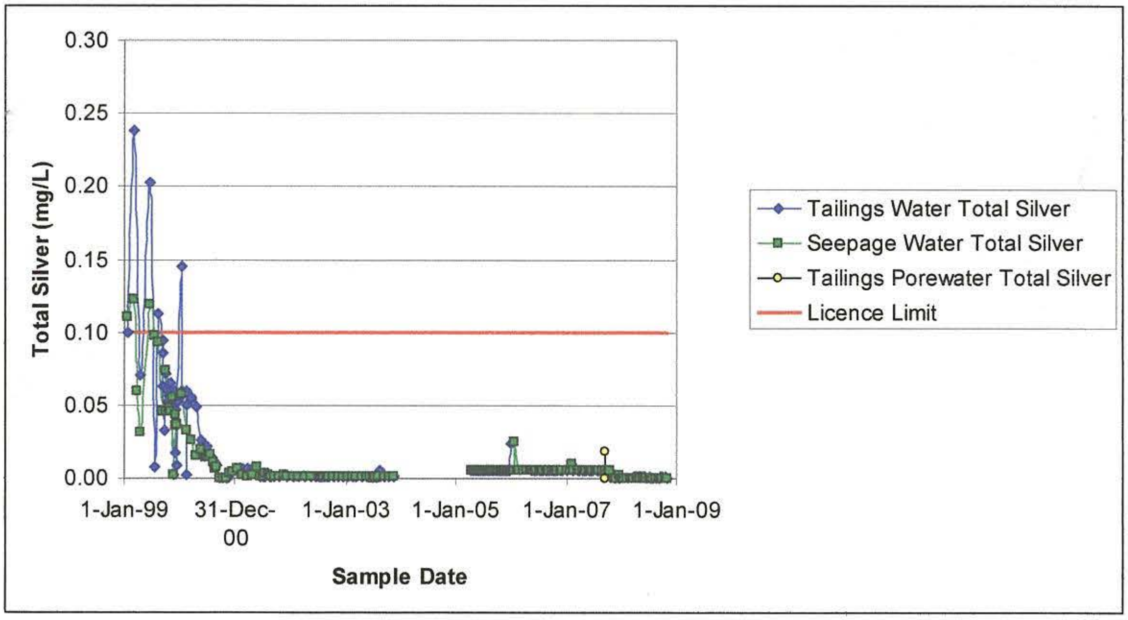


Figure A2-17. Tailings Pond and Seepage Pond Total Zinc Over Time