Water Quality Model, Doris North Project, Hope Bay, Nunavut, Canada

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SRK Project No. 1CM014.008-370

October 2006

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October 2006

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1 Introduction

1.1 Terms of Reference

This report presents the results of the water quality modeling for the Doris North Project owned by Miramar Hope Bay Limited (MHBL). The document provides the water quality model complete with a description of the methodology, input data, sensitivity analysis, as well as the details of the water management strategy for the Tailings Containment Area (TCA). Specific objectives of the water quality model include:

- Assessing contaminant release to the water contained in the TCA;
- Developing a water management strategy for the TCA; and
- Evaluating possible downstream impacts due to water releases from the TCA.

This report has been revised from its original form as submitted to the Nunavut Impact Review Board (NIRB) in 2005 (SRK 2005a), to address as applicable, changes affecting the validity of the water management strategy as previously proposed.

This report has been prepared as part of the Water Licence Application to the Nunavut Water Board (NWB). The drawings referenced in this report form part of a set of drawings completed for the TCA and surface infrastructure designs for the Doris North Project, and are bound as a separate volume, which should be read in conjunction with this report:

- SRK Consulting (2006a). Engineering Drawings for Tailings Containment Area and Surface Infrastructure Components, Doris North Project, Hope Bay, Nunavut, Canada. Drawings submitted to MHBL, October.

1.2 Background

MHBL plans to construct and operate a short-life underground gold mine (the “Doris North Project”), on Inuit Owned Land about 160 km southwest of Cambridge Bay in the West Kitikmeot Region of Nunavut, 5 km south of the Arctic Coast. The nearest communities are Umingmaktok 65 km west and Bathurst Inlet 110 km southwest.

MBHL is proposing to extract about 458,000 tonnes of ore from an underground mine. The ore will be processed at a rate of 668 tonnes per day to yield 306,830 ounces of gold over a 24-month operating period. The mine entrance will be close to the ore processing plant and other surface facilities.

A site plan of the surface facilities is shown on Dwg. G-02 (SRK 2006a). Ore will be trucked to a surface stockpile, crushed and conveyed to an ore stockpile and then fed to a single ball mill. The slurry output from the ball mill will pass through a gravity concentrator to recover the "free milling" gold. Approximately 40% of the gold in the ore will be recovered by gravity. The balance of the gold will be extracted by physical separation of the minerals that contain the gold and then extracting the gold by chemical leaching.

To achieve physical separation, the slurry output from the gravity circuit will be subjected to a froth flotation process to recover gold bearing sulphide minerals in a flotation concentrate. The flotation circuit will reduce the material for further processing to approximately 67 tonnes per day (10% of original ore processed). The remaining 90% (~601 TPD) will be discharged to the tailings impoundment with no further treatment.

As described in the initial project submission to NIRB, the gold in the flotation concentrate would then have been extracted by conventional agitated tank leaching using dilute cyanide solution in a carbon-in-leach (CIL) circuit. The leach slurry from the cyanide leach circuit would have been treated using the Caro's Acid process to decompose the residual cyanide and the treated leach slurry (pyrite concentrate) from the cyanide circuit would then have been added to the flotation tailings slurry and pumped by pipeline to Tail Lake.

In this revised submission, the flotation concentrate will be dewatered partially and the excess water will be discharged with the tailings to Tail Lake. The concentrate will then be leached with cyanide in a conventional agitated leach circuit (not a CIL circuit as previously planned). The leached slurry will be filtered and washed. The gold bearing cyanide solution (filtrate) will then go to either electrowinning or Merrill crow for gold recovery. The filtered and washed flotation concentrate will be placed as backfill in the underground workings and will no longer be discharged with the tailings to Tail Lake. Because there will be a net accumulation of cyanide bearing solution in the leach circuit, it will be necessary to discard a bleed to maintain the overall leach circuit water balance. The clear bleed solution (about 40 % of the leach circuit filtrate) will be treated using the Caro's acid process. The clear treated bleed solution (rather than a slurry as described in the submission to NIRB) from the cyanide detoxification circuit will be mixed with the flotation tailings stream for disposal in Tail Lake. At an average milling rate of 690 tonnes per day, about 2.8 cubic meters per hour solution will be treated in the cyanide detoxification system and discharged with the tailings stream to Tail Lake. At the maximum plant design throughput of 800 tonnes per day, the bleed would be about 3.2 cubic meters per hour.

This report presents a spreadsheet based model that was developed to estimate:

i) total flows to and from Tail Lake (results reported in SRK (2006b);

ii) changes in water quality in Tail Lake as a result of tailings deposition; and

iii) changes in the downstream receiving environment that may result from potential water management strategies identified for the Doris North Project.

2 Tailings Impoundment Water Balance

2.1 General

The water balance forms the basis for the Tail Lake water quality predictions for the operational, closure and post-closure periods. The detailed description of the overall water balance is provided elsewhere (SRK 2006b). This section provides a brief overview of the Tail Lake tailings impoundment water balance as it may pertain to the overall understanding of the water quality predictions. The water balance calculations were not affected by the revised processing strategy because the mill water balance is treated as a single water source and because overall there will be no net change in the total volume of water discharged to the tailings. The revised processing strategy will however result in a 10 % reduction of the mass of tailings that will be deposited in Tail Lake; this equates to volume reduction of about 8 %. The net effect is that the long-term water cover may be marginally deeper than current estimates, but not materially so.

2.2 Input Assumptions

Primary assumptions that were adopted for the water balance include the following:

- Tail Lake will be completely isolated with respect to surface and groundwater from the adjoining Doris Lake and Ogama Lake catchments by two water retaining structures; the North and South Dam respectively.
- Tailings deposition will be sub-aqueous and will be managed such that the final tailings surface will be relatively horizontal.
- Tail Lake will not be pumped out prior to constructing the dams or starting deposition. The volume of Tail Lake at its normal full supply elevation of 28.3 m is about 2,196,000 m^3.
- Annual decant release from the tailings impoundment are anticipated; however, the tailings impoundment area is designed to accommodate full containment (tailings and all natural runoff) for the two-year mine life (at a constant production rate), plus an additional period after mining ceases.
- The water balance is calculated in monthly time steps. The water balance calculations use a year that starts in March and ends in February.
- All values in this water balance are expressed in terms of the dam full supply level (FSL), which excludes any allowance for freeboard.

The impact of varying climate and hydrology on the water balance has been evaluated. The key runs from that sensitivity analysis were repeated for the water quality predictions to assess potential impacts on water quality.

2.3 Water Balance Calculation

The contaminant load and water quality predictions presented herein rely on the tailings impoundment water balance that is presented elsewhere (SRK 2006b). For clarity however, the key input assumptions on which the water balance is based are repeated below. Should the reader require any additional clarifications, the appropriate reference document should be consulted. The input assumptions were as follows.

Total Precipitation

In general the water balance is conducted using average climatic year data; however, it is recognized that extreme events can affect the outcome. The water balance sensitivity analysis therefore includes an evaluation of extreme wet and dry years. These extreme events are documented in MHBL (2005). The average annual precipitation (rainfall and snow water equivalent) is about 207 mm.

Potential Lake Evaporation

The average lake evaporation has been determined to be about 220 mm per year. The sensitivity analysis evaluated evaporation to ±20% of this value.

Water Yield

For the purpose of the water balance, the base case water yield was conservatively assumed to be 180 mm, and the effect of lower water yields (111 mm and 134 mm) were evaluated through sensitivity analysis.

Seepage

Seepage from the tailings impoundment can be via three primary routes; North Dam, South Dam and deep recharge through the lake basin. In reality, the North and South Dams will be frozen core dams, which should not have any seepage.

Average condition theoretical seepage calculations are described in the water balance description and have been used in the tailings impoundment water balance. It was however assumed that all seepage from the North and South Dams would be intercepted and pumped back to the tailings impoundment. The average deep seepage rate is so low that it has been omitted from any water balance calculations.

Tailings Slurry Feed

The average steady state tailings production rate will be about 668 tonnes per day. The specific gravity of the tailings solids will be 2.7. The tailings slurry will be discharged at about 36.1% solids, and will have a submerged in-place tailings void ratio of 1.2. This will result in a daily slurry feed of 1,727 m^3 (544 m^3/day solids and 1,183 m^3/day water).

Reclaim Water

Tail Lake is relatively shallow; a reduced water volume in the lake created by the freezing conditions (lake-ice) may prevent water recovery for mill make-up. Consequently, 100% recirculation water (1,183 m^3/day) is assumed for four months of the year only (June through September). During the remainder of the year fresh water make-up will be from Doris Lake.

Sewage Sludge Volume

The sewage treatment plant outflow will be pumped to the tailings impoundment as part of the tailings feed stream. This volume of sludge is dependant of the size of the camp. For the purpose of this water balance calculation we have assumed a 175-man camp, for a total sewage treatment plant load of about 68.6 m^3/day (supplied by MHBL).

Underground Mine Discharge

Although the two-year Doris North Project would in all likelihood not experience any mine water inflow (SRK 2005b), a conservative assumption has been made that a mine inflow of 235m^3/day would occur for the life of the project. This water would be captured in the mine and pumped to Tail Lake.

Since the concentrate will be filtered prior to placement underground, no porewater release will be expected from the concentrate and the rate of mine water recovery will therefore not be impacted.

Decant Rate

It was assumed that while Tail Lake is actively managed, annual discharge from Tail Lake will occur directly into Doris Creek, at a location immediately upstream of a 4.3 m high waterfall. The allowable rate of decant would be limited to maintain receiving water quality objectives in Doris Creek. The rate of discharge would be determined based on actual water quality in Tail Lake and in Doris Creek, and the flows in Doris Creek. The details of the water management strategy are provided in Section 5 and was derived based on the water quality predictions presented herein.

2.4 Water Balance Results

The primary purpose of the water balance was to determine an appropriate height for the containment dams, such that there would be sufficient storage capacity in Tail Lake. Based on the water balance it was determined that an optimal design full supply level (FSL) in Tail Lake would be about 33.5 m. Under the most conservative water balance assumptions, Tail Lake can operate as a zero discharge facility for just under 5½ years before reaching the FSL. Using more realistic water balance assumptions Tail Lake can operate as a zero discharge facility for at least 7½ years.

The water balance also illustrates that, by allowing an annual discharge the time to reach FSL in Tail Lake is dramatically increased. Allowing as little as 100,000 m^3/year of discharge increases the time to FSL under the base case to just under 9½ years, which is a 27% increase in storage time. If the annual discharge is 500,000 m^3/year, the FSL in Tail Lake will likely not be reached, since the decant rate will exceed the annual inflow. In the next section, the contaminant load and water quality model is developed which is later used to develop and verify the feasibility of the proposed water management strategy.

3 Water Quality Model

3.1 Introduction

The revised processing strategy will impact on the contaminant release to Tail Lake as follows. First, because cyanide solution will be recycled, the amount of cyanide that will be consumed will decrease over the life of the mine. As a result to total amount of cyanide and cyanide treatment compounds (i.e. ammonia, nitrate, nitrite) released to Tail Lake will decrease. Second, because a clear leach solution (filtrate) rather than a flotation concentrate slurry will be treated to remove cyanide, there will be no interaction between the reagents (Caro's Acid) and the metal rich sulphide concentrate, and as a result metal release (e.g. copper) will also be expected to decrease. Third, the volume of treated water released to Tail Lake will decrease. It is therefore anticipated that the water quality modelling submitted to NIRB will overestimate the actual contaminant concentrations in Tail Lake. Nonetheless that water quality model was retained for the overall assessment of water quality impacts and the sensitivity runs because all of the available test data relate to the treatment of the concentrate slurry and no test data were available to support the revised process strategy. However, to support the conclusion that the revised milling process will result in improved water quality in Tail Lake, a sensitivity run was completed as presented and discussed in Section 4.5.8. The remainder of this chapter present and discusses the water quality model and all the source terms that were considered.

3.2 Model Description

The water balance, identifying all the sources contributing to Tail Lake and to Doris Lake, is shown schematically in Figure 3.1. The overall water balance integrates the tailings discharge water balance developed for the Tailings Containment Dam Design (Section 2) with the receiving environment.

The potential sources that may contribute to solute release from the site comprise:

- Quarried rock used as road base, turn-out areas, mill site pad area fill and other infrastructure construction fill;
- Mine waste rock stored on surface for the duration of mining (after which it will be backfilled to the underground workings);
- Ore stockpiled during milling operations;
- Wall rocks and waste rock backfill in the underground workings during mining operations, contributing to the loadings in water recovered from the underground workings;
- Saline drilling fluids, contributing to the loadings in water recovered from the underground workings;

- Blasting residues (from explosives) present in quarried construction rock, waste rock in storage, and in ore;
- Treated sewage effluent discharged to Tail Lake;
- Treated mill tailings discharged to Tail Lake;
- Solute and suspended matter released to Tail Lake from shoreline erosion and re-suspension by wave action; and
- Salinity released to Tail Lake due to thawing where permafrost is present, along the shores of Tail Lake.

As part of the stormwater management strategy (SRK 2006c), the runoff from the mill site including runoff from the fill, waste rock in storage and the ore stockpile, will be collected and pumped with the tailings to Tail Lake. Thus, solute released from these sources will report directly to Tail Lake.

Solute released from road base materials and fill used for infrastructure development will report directly to either Doris Lake or Tail Lake, depending on its catchment.

Losses in saline drilling fluids that will be used during mining will report to the mine water recovered during the dewatering of the underground workings, as will any solute released from the mine wall rocks and waste rock backfilled to the underground workings during operations. The mine water will be pumped directly to Tail Lake. It should be noted that since the mine is not expected to require any dewatering, this is conservative.

Blast residues will be present in all quarried rock, waste rock and ore produced at the site, and will contribute loadings to Doris Lake and Tail Lake as described above. As well, blast residues and spilled explosives will contribute nutrients to the mine water.

Treated sewage, together with the mill tailings will be pumped to Tail Lake.

As the water level rises, permafrost in the banks of Tail Lake will thaw. The porewater from the thawed banks, which are saline, will be released to Tail Lake only once a hydraulic gradient develops to displace the pore water. This will occur once the water level in Tail Lake is lowered.

Some of the contaminants such as cyanide and its derivative compounds (e.g. thiocyanide and cyanate) will be subject to natural degradation reactions where they combine with water and oxygen. These reactions will lead to the formation of nutrients (e.g. ammonia, nitrite and nitrate) which themselves will be subject to nutrient degradation reactions to form innocuous nitrogen. The water quality prediction model has been developed to also address these reactions.

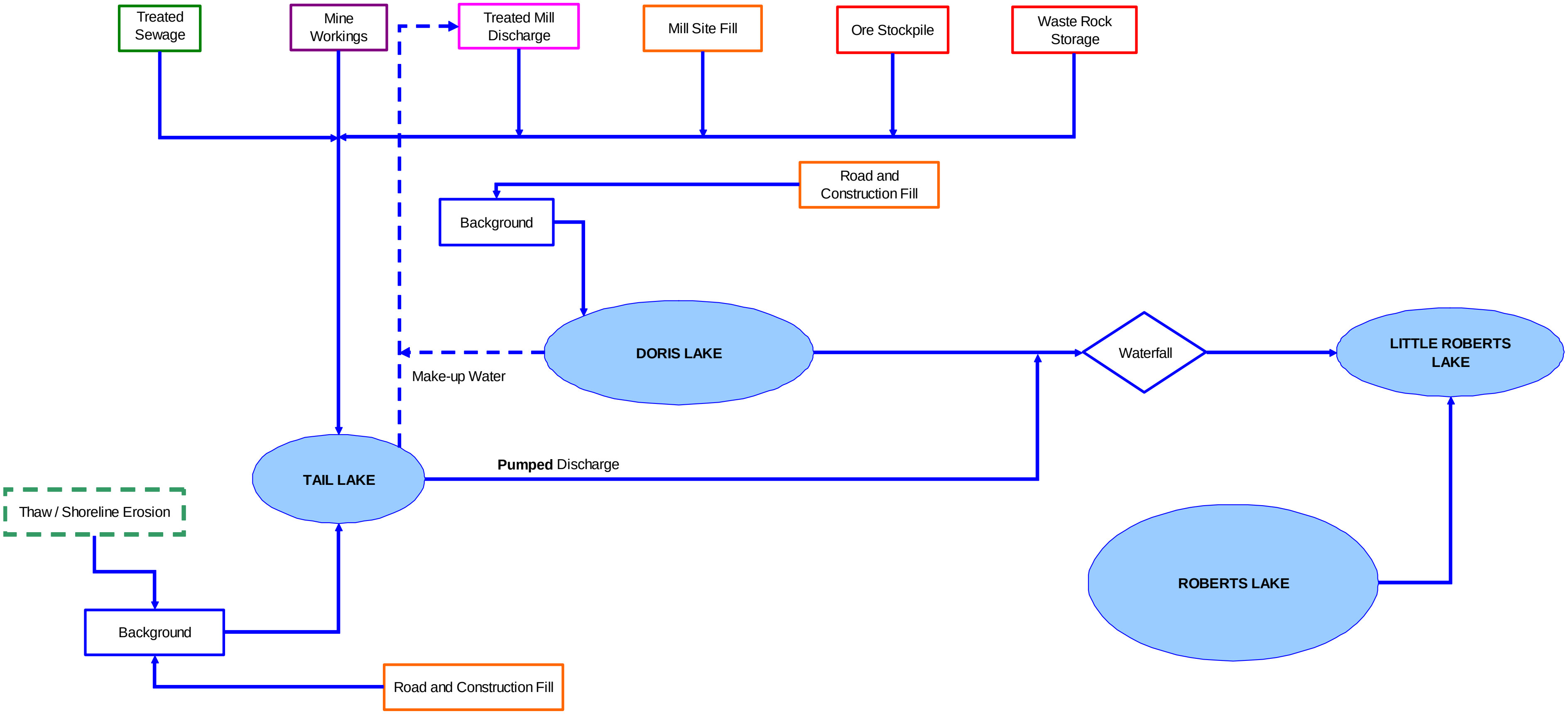

Figure 3.1: Simplified water and load balance

The load balance calculations are based on conservation of mass. The model does not include the potential effects of equilibration reactions that could lead to the formation of secondary minerals, which, in some cases, would result in a net removal of solutes from solution, acting as a solute sink. Solute concentrations for these parameters would therefore be overestimated. The calculation methods for each of the sources are presented and discussed in the following sections.

3.3 Model Input Assumptions and Calculations

3.3.1 Hydrology

The water balance inputs reflect the precipitation and runoff estimates that were developed by AMEC (2003b), MHBL (2005) and most recently updated by Golder (2006), as discussed in Section 2 of this report. The water quality and load balance model has been developed to allow assessment of low, average and high flow conditions.

3.3.2 Background Concentrations

Historical Monitoring Results (1997 – 2003)

The background water quality monitoring results for the site, spanning several years, have been compiled by Golder Associates (MHBL 2005). As will become apparent in later sections, the copper concentration in the outflow from Doris Lake will be an important factor in managing the decant water from Tail Lake. The concentrations of other parameters, including aluminium, chromium and selenium may also constrain the water management strategy for Tail Lake. The following discussion briefly reviews the background water quality monitoring results that have been compiled to 2003. The following is noted for the Doris Lake outflow:

Copper. The 1997 results for June 19, two replicates for July 19, and that for August 20, were all reported as 2 µg/L, with no decimal value shown (Note: CCME guideline is 2 µg/L). The dissolved copper for June and one July replicate were also reported as 2 µg/L (no decimal) and that for the remaining two results were 1 µg/L (no decimal). These results clearly suggest that the values were rounded (up or down) and that the decimal was not reported, even though the detection limit for these results was 1 µg/L. It is further noted that for the replicate samples taken in September 2000, the first returned a total copper of 1.6 µg/L and the second returned a value of 2.3 µg/L. A similar discrepancy was observed for other parameters in the replicate set, including aluminium, calcium, sodium and potassium, suggesting poor quality control on these samples. Only one sample was analyzed in 2003. Disregarding the results that have been rounded, and disregarding the replicate set that yielded poor reproducibility, 5 data points spanning 7 years are available. The copper concentration in these samples ranged from 1.44 µg/L to 1.6 µg/L, with an average of 1.52 µg/L.

Aluminium. The total aluminium concentration in Doris Lake outflow ranged from 19 µg/L to 150 µg/L, with an average 68 µg/L (Note: CCME guideline is 100 µg/L). As noted above, one set of replicates samples resulted in poor reproducibility. It is further noted that the total concentrations on average were five times the dissolved concentrations, indicating that most of the total aluminium is accounted for as suspended solids.

Chromium. The detection limits for chromium ranged from 0.5 µg/L to 1 µg/L (Note: CCME guideline is 1 µg/L). In all but two samples, total chromium concentrations were below detection. The average concentration for the two samples above detection was 0.6 µg/L.

Selenium. The detection limits reported for selenium ranged from 0.5 µg/L to 1 µg/L (Note: CCME guideline is 1 µg/L). Selenium was above the detection limit in only one sample, with a concentration of 0.6 µg/L.

Cadmium. It is further noted that the detection limit for cadmium in all cases was well above the CCME guideline for the protection of freshwater aquatic life. Cadmium concentrations were below detection in all but one sample for Doris Lake outflow.

Total Suspended Solids. Total suspended solids (TSS) ranged from <1 mg/L to 7 mg/L.

Observations similar to those described for Doris Lake in general also apply to Tail Lake outflow and can be summarised as flows:

Copper. Total copper concentrations in Tail Lake outflow in general were lower than in Doris Lake outflow. Rounding of results appears to have occurred over the same period as that described for Tail Lake. Disregarding the rounded results, the total copper concentration ranged from 0.7 µg/L to 1.7 µg/L, with an average of 0.99 µg/L.

Aluminium. The total aluminium concentration in Tail Lake ranged from 14 µg/L to 85 µg/L, with an average of 42 µg/L. Similar to Doris Lake outflow, the aluminium occurred predominantly as particulate matter.

Chromium. The detection limits for chromium ranged from 0.5 to 1 µg/L (Note: CCME guideline is 1 µg/L). All the samples were below the detection limit.

Selenium. The detection limits reported for selenium ranged from 0.5 to 1 µg/L. Total selenium concentrations were above the detection limit in two samples, with an average of 0.55 µg/L.

Cadmium. The detection limit for cadmium in all cases was well above the CCME guideline for the protection of freshwater aquatic life. Cadmium concentrations were below detection in all samples.

Total Suspended Solids. Total suspended solids (TSS) typically was below detection (8 of 13 samples) and ranged from <1 mg/L to 5 mg/L, with one anomalous result of 20 mg/L reported for August 22, 1996.

Water Quality Monitoring Results (2004 – 2006)

During 2004 an intensive background water quality monitoring program was undertaken, with a total of 11 sampling events. The frequency was almost weekly, except for the period spanning mid August to mid September. The intense sampling program was undertaken to provide an indication of the seasonal variation in water quality. Quality assurance was provided by analysing several replicate and blank samples.

Supplemental monitoring was undertaken in 2005 at a biweekly to three-weekly frequency, from late June to mid September. During 2006, additional monitoring was undertaken on a weekly basis from June 18 through September 9. The results from the additional program have, as at the time of writing, not yet been finalized and are considered preliminary. These preliminary results for Tail Lake and Doris Creek are included in Appendix A, but may be subject to change.

The results for the key parameters in Doris Lake outflow were as follows:

Copper. In 2004, the total copper concentrations ranged from 1.06 to 1.53 µg/L, with an average of 1.29 µg/L. Peak concentrations occurred in early July and in September. It should be noted that replicate samples were analysed on July 22 (2), August 15 (2), September 12 (3) and on September 22 (3). Except for the August 15 set, the replicate results provided good reproducibility as follows:

July 22	1.15 and 1.20 µg/L
August 15	1.57 and 0.954 µg/L
September 12	1.45, 1.51 and 1.53 µg/L
September 22	1.44, 1.43 and 1.44 µg/L

The 2005 monitoring results indicated a copper concentration of 2.06 µg/L for the August 20 sample. However, it is noted that this sample had an elevated total suspended solids concentration of 25 mg/L compared to less than 4 mg/L for the remainder of the samples. This strongly suggests that the sample may have been compromised. The copper concentration in the remainder of the samples ranged from 1.1 to 1.4 µg/L, with an average of 1.29 µg/L (inclusive of the result for August 20, the average was 1.4 µg/L). The results indicate that, barring the August 20 sample, the copper concentrations in 2005 were very similar to those observed in 2004.

The 2006 copper concentrations in Doris Creek ranged from about 0.98 µg/L to about 1.53 µg/L. These results compare favourably with the range of results obtained in 2004 and 2005. The more recent results appear to bear out the concerns previously expressed with regard to the historical monitoring results reported for copper.

Aluminium. During 2004, the total aluminium concentrations in Doris Lake outflow ranged from 10 µg/L to about 80 µg/L, with an average of 52 µg/L. Concentrations tended to increase toward the end of summer and into fall. As noted for copper, the 2005 results for August 20 reflected the elevated TSS concentration, with a total aluminium concentration of 774 µg/L. For the remainder of the samples, the results for 2004 indicate an elevated aluminium concentration in spring, with a general decrease in concentrations toward fall. The concentrations ranged from 31 µg/L to 145 µg/L, with an average of 68 µg/L. The results suggest that the average aluminium concentration in 2005 was marginally higher than that observed in 2004.

During 2006, the aluminium concentration in the sample for June 18 was 106 µg /L with a dissolved aluminium concentration of 15 µg/L and that for September 9 was 146 µg/L with a dissolved concentration of 0.76 µg/L (note that these results are in the process of being verified); the results for the remainder of the available data varied little with an average concentration of about 67 µg/L.

Chromium. The total chromium concentrations in 2004 ranged from < 0.03 µg/L to 0.64 µg/L, with an average of about 0.24 µg/L. The maximum concentration was reported for June 24. During 2005, a chromium concentration of 1.41 µg/L was reported for the sample with an elevated TDS (August 20). The remainder of the samples ranged from 0.15 to 1.26 µg/L, with an average of 0.43 µg/L (inclusive of the result for August 20 the average was 0.59 µg/L). The results suggest that the chromium concentrations in 2005 were higher than in 2004.

During 2006, a concentration of 0.77 µg/L was detected in the June 18 sample; the remainder of the analyses were relatively constant with an average concentration of about 0.32 µg/L. This is somewhat lower than observed during 2005 but similar to that observed in 2004.

Selenium. The total selenium concentration in Doris Lake outflow during 2004 ranged from 0.18 µg/L to 0.90 µg/L, with an average of 0.51 µg/L. During 2005, selenium concentrations ranged from 0.46 µg/L to 1.26 µg/L, with an average of 0.73 µg/L (inclusive of the August 20 sample). It is noted that the maximum concentration in 2005 exceeded the CCME guideline for the protection of freshwater aquatic life. The results suggest that concentrations during 2005 were elevated above those recorded in 2004. During 2006, the selenium concentration ranged from about 0.76 µg/L to about 1.69 µg/L, with an average concentration of 1.22 µg/L. These results are slightly higher than the results for 2005. While the selenium concentrations exceeded CCME guidelines for a number of sampling events, it should be noted that the predicted concentrations in Tail Lake are expected to be below CCME guidelines and discharge of Tail Lake water is not likely to change the existing selenium concentrations.

Cadmium. With the improved detection limit of 0.002 µg/L for cadmium, only one sample was above the detection limit in 2004 (0.003 µg/L, July 22), and two samples were above detection in 2005 (0.002 and 0.005 µg/L on August 5 and 20 respectively). During 2006 the cadmium concentration ranged from less than 0.002 µg/L to about 0.011 µg/L. However, the average cadmium concentration of 0.004 µg/L remained well below the CCME guideline for the protection of freshwater aquatic life.

Total Suspended Solids. Total suspended solids (TSS) ranged from 3 mg/L to 8 mg/L with an average of 5 mg/L in 2004. In 2005, barring the single sample that had a TSS of 25 mg/L, the TSS ranged from 2 mg/L to 4 mg/L. In 2006 total suspended solids concentrations ranged from 2 to 4 mg/L, with an average of about 3 mg/L.

The results for Tail Lake outflow can be summarised as follows:

Copper. During 2004, the total copper concentration ranged from 0.66 to 1 µg/L, with an average of 0.78 µg/L. The results reported for 2005 ranged from 0.51 to 0.92 µg/L, with an average of 0.76 µg/L, indicating essentially no change from 2004. During 2006, copper concentrations ranged from 0.52 to 1.13 µg/L, with an average of 0.75 µg/L, showing good correlation with the results from previous years.

Chromium. The chromium concentration in Tail Lake outflow ranged from 0.09 to 0.86 µg/L during 2004, with an average of 0.36 µg/L. The results reported for 2005 ranged from < 0.03 µg/L to 0.34 µg/L with an average of 0.26 µg/L, indicating lower concentrations during 2005. During 2006, a maximum concentration 0.645 µg/L was recorded for the June 18 sample; the remainder of the results were all below 0.29 µg/L. The average chromium concentration (inclusive of the June 18 result) was 0.24 µg/L.

Aluminium. The results reported for 2004 indicated aluminium concentrations ranging from 9 to 46 µg/L, with an average of 18 µg/L. The 2005 results were similar, with concentrations ranging from 9.5 to 45 µg/L and returned an average concentration of 16 µg/L. During 2006, aluminium ranged from about 12 µg/L to about 65 µg/L, with an average of about 22 µg/L.

Selenium. The results for 2004 indicated that the total selenium concentration in Tail Lake outflow ranged from <0.1 µg/L to 0.4 µg/L, with an average of < 0.3 µg/L. Concentrations reported for 2005 ranged from 0.23 µg/L to 0.52 µg/L, with an average of 0.36 µg/L, indicating little change from the 2004 results. Similar to the results for Doris Creek, Tail Lake outflow was elevated in selenium during August and September. The results for 2006 ranged from 0.36 µg/L to a maximum of 2.23; however, the average was marginally higher at about 0.96 µg/L.

Cadmium. The improved detection limit indicates that cadmium concentrations in Tail Lake outflow is at or below the detection limit of 0.002 µg/L. During 2006 the cadmium concentrations ranged from below the detection limit of 0.002 to 0.0095 µg/L, with an average concentration of about 0.0045 µg/L.

Total Suspended Solids. During 2004 the total suspended solids concentrations were below the detection limit of 3 mg/L, and below the detection limit of 1 mg/L during 2005. The 2006 results for total suspended solids were at or below 3 mg/L, with the exception of the August 11 sample which was at 5 mg/L.

A direct comparison of the current results with historical (i.e. pre 2003) results is not advisable due to changes in analytical methods (mainly resulting in improved detection limits) and uncertainties associated with quality control. Nonetheless, in consideration of these constraints, a comparison with the historical results indicates similar results for the parameters of significance, and that the more current results (in particular the 2004 data set) provide a more reliable database for background site water quality.

Selection of Background Water Quality Concentrations

The water and load balance model is based on a monthly time-step. It is therefore necessary to adopt monthly input background concentrations. The assumed background water quality input concentrations for Doris Creek and the actual monitoring results are discussed below.

The initial water quality modelling was undertaken with background water quality derived from the 2004 monitoring period. At that time, because of the limited database, the maximum concentration detected in each month was selected as input to the water quality model. Those inputs are compared to monthly average copper concentrations for the 2004 to 2006 monitoring seasons in Table 3.1. As shown, the assumed input concentration for June, very closely approximates the average concentration for 2004 to 2006. The background concentration of 1.53 µg/L assumed for July however appears to be conservative when compared to the 2004 to 2006 average of 1.29 µg/L. The assumed input concentration for August is marginally below and that for September is marginally above the corresponding average concentrations. However, since most of the flow in Doris Creek occurs in June and July, and hence most of the discharge would occur during those months, it is anticipated that the assumed inputs will result in conservative estimates of allowable discharge rates.

Table 3.1: Summary of monthly average copper concentrations in Doris Lake outflow

Month	Measured Copper Concentrations (µg/L)			Average for 2004 to 2006	Assumed Inputs to Water Quality Model
	2004	2005	2006		
June	1.13	-	1.29	1.21	1.20
July	1.34	1.18	1.35	1.29	1.53
August	1.20	1.26	1.47	1.31	1.26
September	-	1.47	1.40	1.43	1.50

Further comparison is provided in Figure 3.2. As shown, the total copper concentration in Doris Lake outflow (Doris Creek) adopted for the month of July was 1.53 µg/L, which is conservative. Since the model determines the discharge flow rates proportional to the flow hydrograph, the copper concentration for July in effect determines the maximum discharge rate. As is shown in the modelling results (e.g. Appendices H and I), in all managed discharge cases, copper concentrations in Doris Creek approach the CCME concentration only in the month of July and all other months fall below the CCME value. Therefore, while the assumed concentration for June does not reflect the maximum concentration for that month, the difference becomes irrelevant and the modelling results remain conservative.

Similar comparisons are provided for aluminium and chromium in Figures 3.3 and 3.4. As noted before, while selenium concentrations exceed CCME guidelines in Doris Creek intermittently, the predicted concentration in Tail Lake is at or below CCME and discharge water will likely lower the concentrations in Doris Creek downstream of the waterfall. The background water quality estimates, as used in the water quality model, are provided in Appendix B.

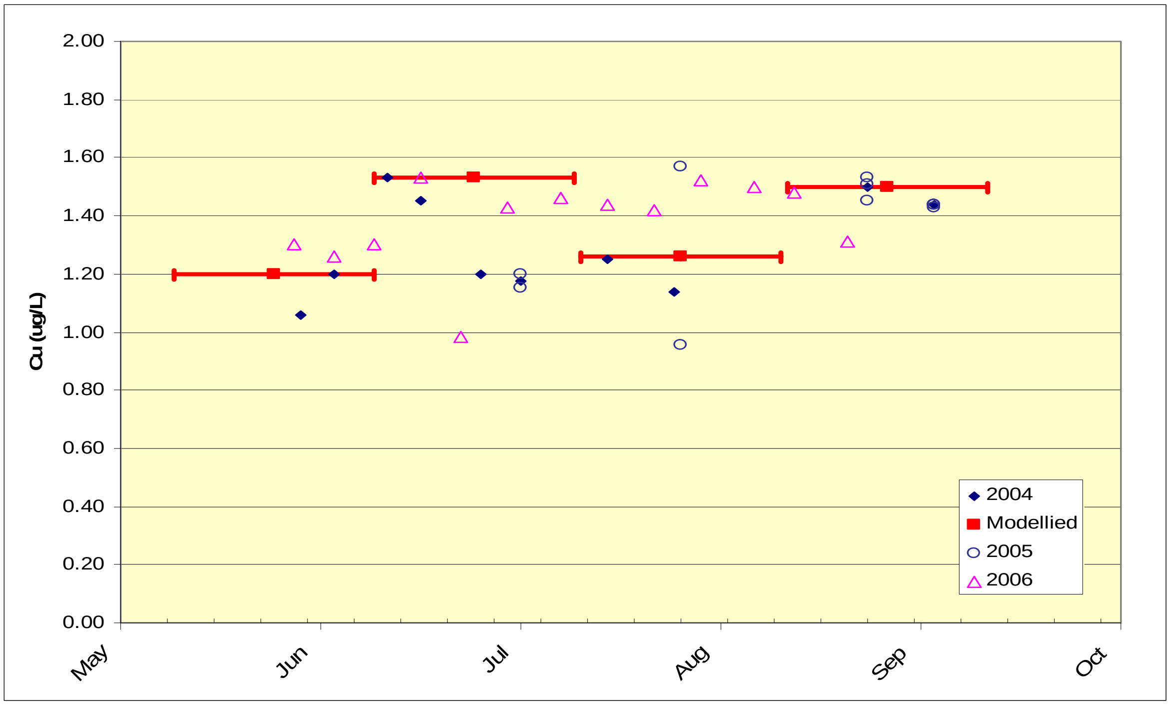

Figure 3.2: Comparison between actual and model inputs for background total copper concentrations in Doris Creek

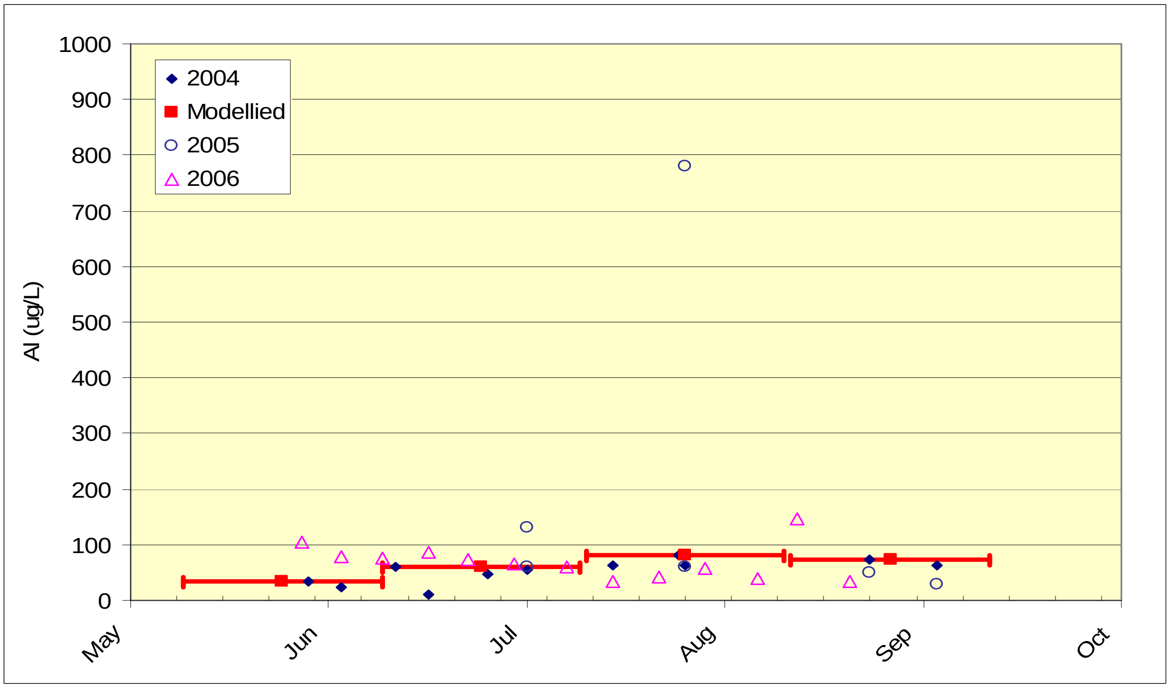

Figure 3.3: Comparison between actual and model inputs for background total aluminium concentrations in Doris Creek

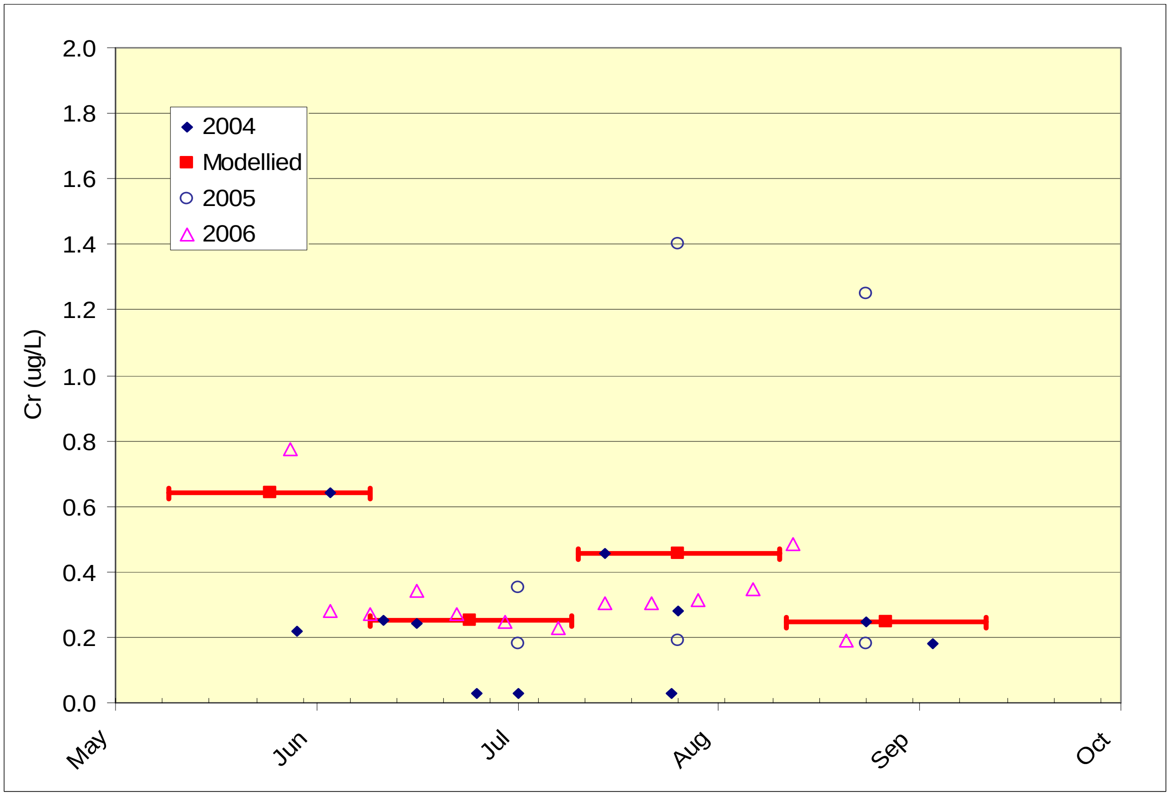

Figure 3.4: Comparison between actual and model inputs for background total chromium concentrations in Doris Creek

3.3.3 Nitrogen Release from Blast Residues

In general, the estimates of ammonia-N, nitrate-N and nitrite-N were derived following the methods described in Ferguson and Leask (1988), with the exception of increasing the blast residue factor as described below.

Mine production rates and estimated explosives usage rates provided by MHBL indicated a powder factor of about 1.14 kg per tonne of rock mined. This is marginally higher than a typical powder factor for underground drifting of about 0.9 kg per tonne as reported by McIntosh Redpath Engineering (2003).

Ferguson and Leask (1988) suggest that about 1% of the total mass of ANFO used during mining will remain as blast residues within the mined rock, accounting for missed fires, spillage and incomplete detonation. However, for the purpose of this assessment a conservative blast residue content of ten times that recommended by Ferguson and Leask (1988), or about 10%, was adopted for the base case evaluation.

Subsequent to mining, the proportion of blast residues that will be released from the mined rock will depend on a number of factors, including rate of infiltration, water – rock contact ratio and duration of exposure. Therefore, the steps to calculate the release of ammonia and nitrate from the mined rock were as follows:

1. An estimate of the amount of ANFO used in the blasting of each of the waste rock and ore materials was calculated by multiplying the amount of each material by the powder factor.
2. The residual mass of ANFO was then estimated by multiplying the total mass of ANFO used to produce the rock and ore with the overall residue factor (i.e. 10%).
3. The amount of nitrogen in the ANFO was calculated assuming that the ANFO comprises 94% NH_4NO_3, and 6% fuel oil. The mass weight equivalent of the N in ammonium nitrate is 35%, therefore the total N content of the ANFO is 33%.
4. The amount of nitrogen released from the waste rock in storage was calculated assuming that about 20% of the residual nitrogen will be flushed from the waste rock over a three year period, i.e. about 6.7% of the residual nitrogen would be flushed annually. The release was assumed to occur over a 5 month period, prorated to the site hydrograph. The same approach was adopted to calculate the release from the construction fill.
5. Although the ore will reside on the stockpile for about 2 weeks on average, the ore stockpile is expected to respond similar to the waste rock storage pile, and the calculations described above in Step 4 were applied to the ore stockpile as well.
6. The nitrogen release to the tailings slurry was calculated assuming that all of the remaining blast residues will be flushed from the ore and released to the tailings water due to the high solubility of ammonia and nitrate compounds.
7. A proportion of the waste rock will be directly backfilled to the underground workings. That rock will be less exposed to flushing, since the mine is expected to be dry. Nonetheless, the calculations for waste rock stored on surface were also applied to the waste rock backfill, with the exception that the blast residues would be released year round to mine water.
8. The speciation of the nitrogen in the blast residues was assumed to be 28% ammonia, 70% nitrate, and 2% nitrite. In contrast to the recommendations in Ferguson and Leask (1988), this conservatively assumes a higher portion of the nitrogen will be present as ammonia.

The overall calculation to estimate annual nitrogen release from the fill and waste rock therefore was as follows:

$$N_T = (PF * W_r) * R_f * 0.33 * A_r$$

Where: N_T = annual release of total nitrogen (kg/year),
PF = powder factor (1.14 kg ANFO per tonne of rock),
W_r = mass of rock produced/placed (tonnes),
R_f = residual nitrogen remaining (assumed to be 10%),
A_r = fraction released annually (0.067), and
0.33 = total nitrogen content of blast residues (fraction).

The total nitrogen was then apportioned to ammonia, nitrate and nitrite as in Step 8. The calculations do not consider any effects from natural nutrient degradation or attenuation within the waste rock and fill.

The estimated weights of construction fill and waste rock that would contribute to nutrient release from blast residues are summarised in Table 3.2. Note that the table makes provision for four cases where fill may be used for shoreline erosion protection at Tail Lake. All these scenarios do not allow for bedrock correction of 40% and are therefore very conservative. The table also include mass estimates for the construction of fish habitat in Doris Lake and in Roberts Bay. Since the quarry rock will be placed fresh and remain fully submerged, only nutrient release is expected from this rock. The estimated nutrient release expected to occur from these activities are presented in Appendix C. The estimated nutrient release that may occur from the construction of the jetty is also included in the appendix.

In addition to the estimates provided in Table 3.2, approximately 244,000 tonne of milled ore would annually contribute blast residue to Tail Lake.

Table 3.2: Summary of estimated construction fill and waste rock production

		Estimated Quantity		Footprint Surface^1 Area (m^2)	Distribution		Quantity		
Infrastructure Component	**General Detail**	**ECM (m^3)**	**Dry Tonnes**		**Doris Lake**	**Tail Lake**	**Doris Lake**	**Tail Lake**	**Comment**
Tank farm at mill (7.5 million litre)	71m x 71m surface area; 1.2:1 side slopes; 0.5m thick; 0.8m high berm	5,200	10,800	5,000	100.00%	0.00%	10,800	-	
Tailings discharge decant road	5.1m wide traffic surface; 1.2:1 side slopes; 2.0m thick; 378m length	5,700	11,900	2,400	100.00%	0.00%	11,900	-	
Tailings discharge pump house pad	20m x 20m surface area; 1.2:1 side slopes; 2.0m thick	700	1,500	400	100.00%	0.00%	1,500	-	
All-weather road (barge site to mill)	6m wide traffic surface; 1.2:1 side slopes; 2.0m thick; 4.8km length	80,700	167,800	51,900	10.42%	0.00%	17,500	-	
All-weather road (tailings service road)	5.1m wide traffic surface; 1.2:1 side slopes; 2.0m thick; 5.9km length	88,500	184,100	59,000	32.20%	67.80%	59,300	124,800	
Caribou crossings (8)	10m long; 5:1 approach slopes; 2.0m thick	2,500	5,200	2,500	37.50%	25.00%	2,000	1,300	
Road turnouts (8) & turnaround (tailings service road)	10m wide; 30m long; 1.2:1 side slopes; 2.0m thick & 10m x 10m turnaround	5,000	10,500	3,100	22.22%	77.78%	2,300	8,200	
Float plane & boat dock service road	6m wide traffic surface; 1.2:1 side slopes; 2.0m thick; 300m length	8,500	17,600	3,300	100.00%	0.00%	17,600	-	
Landfill access road	6m wide traffic surface; 1.2:1 side slopes; 2.0m thick; 150m length	2,600	5,300	1,600	100.00%	0.00%	5,300	-	
Bridge crossing and abutments (2)	10m wide traffic surface; 1.2:1 side slopes; 2.5m thick; 27m length	1,900	3,800	900	100.00%	0.00%	3,800	-	
Mill and camp area	Mill, Crusher, Ore Stockpile, workshop, fuel tank farm, mill reagents storage, laydown area, power supply, camp / dry, mine office, sewage treatment, water treatment plant, waste rock pile pad and berm, waste rock pond,	55,100	114,600	62,600	0.00%	100.00%	-	114,600	Collect and pump to Tail Lake
Float plane & dock	10m x 30m surface area; 1.2:1 side slopes; 3.0m thick	900	1,900	1,000	100.00%	0.00%	1,900	-	
Tailings emergency dump catch basins (4)	25.2m x 25.2m surface area; 2:1 side slopes; 2.0m average base thickness; 1m high berm	5,100	10,600	4,400	25.00%	75.00%	2,700	8,000	
Doris Lake fish habitat	5 areas each with 25m x 25m surface area; 1.5m thickness; and 1 area with 30m x 30m surface area; 1.5m thickness (Golder 2005)	6,000	12,500	4,000	0.00%	0.00%	-	-	Only nutrients release
All surface road maintenance	Allowance for all surface road maintenance @ 5cm new surfacing grade every year for 8 years	36,500	75,900	n/a	24.12%	32.15%	18,300	24,400	
Landfill interim cover	100m x 50m surface area; 1.2:1 side slopes; 0.3m thick added on top of waste every year for 8 years	12,000	25,000	n/a	100.00%	0.00%	25,000	-	
Shoreline erosion (contingency)	20% of 12.9 ha surface area (up to elev. 29.4m); 0.5m thickness (SRK 2005c)	12,900	26,800	25,800	0.00%	100.00%	-	26,800	
Landfill closure	100m x 100m surface area; 1.2:1 side slopes; 1m thick for ultimate cover	10,000	20,800	n/a	100.00%	0.00%	20,800	-	
Subtotal							200,700	308,100	
Shoreline protection contingency									
Base Case	No protection						-	-	
	TOTAL						200,700	308,100	
Case 1	Provide rip-rap on 20 % of the area affected to an elevation of 29.4 m						-	26,800	
	TOTAL						200,700	334,900	
Case 2	Provide rip-rap on 60 % of the area affected to an elevation of 29.4 m						-	80,400	
	TOTAL						200,700	388,500	
Case 3	Provide rip-rap on 100 % of the area affected to an elevation of 29.4 m						-	134,000	
	TOTAL						200,700	442,100	
Case 4	Provide rip-rap on 100 % of the area affected to the Full Supply Level						-	515,700	
	TOTAL						200,700	823,800	

3.3.4 Solute Release from Mine Waste Rock and Ore

A portion of the waste rock that will be produced during the development stages of the underground mine workings will need to be stored on surface until it can be backfilled in the mined out stopes. The backfilling operations will be scheduled so that the waste rock can be backfilled as soon as practical. The estimated mass of waste rock that will be in storage on the storage pad was derived from the mining and backfilling schedule illustrated in Figure 3.6.

Figure 3.5: Schedule of ‘on surface’ waste rock storage

As shown in the figure, the waste rock storage will peak at about 137,000 tonnes at about month 13, and the pad will remain active for a period of about 32 months. In the water and load balance calculations it was conservatively assumed that the maximum waste rock mass in storage (i.e. 137,000 tonnes) will be present from day 1, and will remain in storage for a period of 36 months. This approach is clearly very conservative.

The rates of solute release for the waste rock were extrapolated from the humidity cell test results completed by Rescan Consultants, as reported in the Rescan December 2001 report entitled "Acid Rock Drainage Characterization - Boston and Doris Lake Properties" – Rescan (2001). The tests were completed on four samples described as i) mafic volcanic, ii) gabbro, iii) mafic volcanic with possible veining, and, iv) quartz (>1% pyrite). The samples were obtained from the Doris Lake Property during a diamond drilling program undertaken in 2001. Of the four samples tested, three come from diamond drill holes into the Doris Connector zone under Doris Lake. These three samples are the gabbro, mafic volcanic with possible veining, and the quartz (> 1% pyrite) samples. The fourth sample tested in the humidity cell is from a shallow sample, the mafic volcanic sample, located at the extreme south of the Doris Hinge Zone.

The samples selected for these humidity cells all fall well above the average total sulphur and sulphide sulphur contents of the waste rock samples tested for acid base account (ABA) (AMEC 2003a). The sulphide sulphur concentrations for these four samples were as follows:

i) Mafic Volcanic 1.68% (wt) total sulphur and 1.68% (wt) sulphide sulphur;
ii) Gabbro 1.85% (wt) total sulphur and 1.85% (wt) sulphide sulphur;
iii) Mafic Volcanic Possible Veining 6.57% (wt) total sulphur and 6.54% (wt) sulphide sulphur; and
iv) Quartz 1.87% (wt) total sulphur and 1.87% (wt) sulphide sulphur.

As part of the waste rock characterization program, 166 samples were tested for ABA. The total sulphur concentrations for these samples ranged from 0.01% (wt) to 6.57% (wt) with an average of 0.79% (wt). Furthermore, out of the 166 samples only 21 samples had sulphide sulphur concentrations in excess of 1.50% (wt), and comprised ten samples of mafic volcanic, nine samples of quartz, and two samples of gabbro. It is apparent therefore that all four samples used in the humidity cell tests tend to over represent the sulphide mineralization in the waste rock.

The distribution of the rock type that will likely be brought to surface for temporary storage will comprise:

i) 75.3% Fe tholeiites, consisting primarily of mafic volcanic and mafic volcanic with quartz veining;
ii) 0.5% Mg tholeiites, consisting primarily of Gabbro and altered wall rock (altered basalts); and
iii) 24.2% diabase dike material.

While there are no representative humidity cell test data for the diabase dike material, it is noted that none of this material had a sulphur content in excess of 0.5 %.

The Fe tholeiites are probably best represented by the three humidity cells completed on the mafic volcanic, mafic volcanic with possible veining and the quartz samples. The Mg tholeiites is likely best represented by the humidity cell test completed on the gabbro sample. However, in both cases, the sulphide mineral content is to be over represented.

The investigation showed that the majority of the waste rock would not be net acid generating. For the minor proportion of the waste rock that might be acid generating, the humidity cell tests generally indicated that there would be a lag of many years before acid generating conditions would occur. Therefore, the waste rock would not generate acid within the three year period while stored on surface.

The contaminant release that may occur from the waste rock was calculated as follows:

1. The average solute release rates, in units of mg/kg/week, were calculated from the final cycles of the humidity cell tests for each of the rock types to provide estimates of 'steady state' solute production rates. Where the concentrations of parameters were consistently below the detection limit (reported in Appendix H of the Rescan kinetic testing report, December 2001), solute concentrations were assumed to be at 50 % of the detection limit and were used to estimate solute release rates. An average production rate was then estimated for each solute. For simplicity, the average was obtained for all the rock types on an equal weight basis. Because of the similarity in release rates, and the over representation of sulphide minerals in the samples tested, averaging across the samples on an equal weight basis remains conservative. The results are summarised in Table 3.3. The average rate was then used to calculate overall solute releases from the bulk of the waste rock as described below.

2. The average solute release rates were multiplied by the total mass of waste rock to yield a total generation rate.

3. The humidity cell tests were performed on rock samples crushed to 80% less than 6 mm. The actual fines content (< 6 mm) of the waste rock will be significantly lower, depending on the friability of the rock, and the fraction of fines is expected to range from 0.1 to 0.4 mm. Since the specific surface area (surface area per unit mass) increases inversely with particle size, and thus the area of available reactive surfaces, the lower proportion of fines in the waste rock compared to the samples tested will result in reduced rates of solute release. A correction factor of 0.3 was adopted. Therefore, the total solute release rates from Step 2 were multiplied by a factor of 0.3 to correct for surface area exposure.

4. The humidity cell tests were operated under conditions of high and frequent flushing which promotes the release of solutes generated from oxidation. In the humidity cell tests, 1 kg of rock was flushed weekly with 500 mL of water, which equates to an infiltration rate of about 28 mm/week. At the site, infiltration to the waste rock is expected to occur only 4 to 5 months per year. The infiltration to the waste rock is expected to be less than 50% of the mean annual precipitation, or about 104 mm per year, which equates to be 5 to 6 mm/week. The lower infiltration rate in the field is expected to lead to the formation of selective flowpaths and thus, compared to the humidity cell tests, a lower proportion of the waste rock will be contacted by infiltrating water which will further limit solute release. Experience elsewhere indicated that only about 10% to 40% of the soluble loads that are generated are released to seepage. For the purpose of this calculation, conservatively a factor of 40% was adopted.

5. The annual solute release was prorated on a monthly basis over the summer months according to the site runoff hydrograph.

In summary, the overall calculation to determine the average monthly load was as follows:

$$M_i = L_{HC})_i * W_R *20* 0.3 * 0.4 /1000$$

Where M_i = loading of solute *i* in kg/year,
$L_{HC})_i$ = solute *i* production rate in the humidity cell (mg/kg/wk),
W_R = tonnes of waste rock in storage,
0.4 and 0.3 are correction factors as discussed above in points 3 and 4,
20 is the assumed number of weeks per year (5 months) for which the waste rock is not frozen, and
1000 is a unit conversion factor to obtain kg.

The same calculations were applied to the ore stockpile even though the ore is expected to remain on the stockpile for a very short period only.

In general, the samples tested in the humidity cells showed little solute release during the initial flush, and concentrations in the leachate remained low and generally below detection throughout testing. It is important to note in particular:

- Chromium concentrations were below the detection limit of 0.005 mg/L (five times the CCME guideline) and although 50% of the detection limit was adopted in the calculations this still represents 2.5 times the CCME guideline, and chromium loadings are likely to be overestimated.
- Selenium concentrations were below the detection limit of 0.01 mg/L (ten times the CCME guideline) and again although 50% of the detection limit was adopted in the calculation (five times the CCME guideline) it is considered that the selenium loadings are likely overestimated in the calculations.

Table 3.3: Summary of average solute release rates from waste rock samples tested in the humidity cells

Parameter	Units	Description				Overall Average
		Mafic Volcanic	Gabbro	Mafic with Veining	Quartz	
Sulphate	mg/kg/week	1.55	6.43	5.68	79	23
Total Metals						
Aluminium Al	mg/kg/week	0.026	0.010	0.0093	0.0043	0.013
Antimony Sb	mg/kg/week	0.022	0.020	0.023	0.022	0.022
Arsenic As	mg/kg/week	0.00044	0.00040	0.00046	0.00065	0.00049
Barium Ba	mg/kg/week	0.0011	0.0010	0.0012	0.0011	0.0011
Beryllium Be	mg/kg/week	0.00055	0.00050	0.00058	0.00054	0.00054
Bismuth Bi	mg/kg/week	0.022	0.020	0.023	0.022	0.022
Boron B	mg/kg/week	0.011	0.010	0.012	0.011	0.011
Cadmium Cd	mg/kg/week	2.2×10^{-7}	2.0×10^{-7}	2.3×10^{-7}	2.2×10^{-7}	2.2×10^{-7}
Calcium Ca	mg/kg/week	3.9	4.8	5.8	4.5	4.7
Chromium Cr	mg/kg/week	0.0011	0.0010	0.0012	0.0011	0.0011
Cobalt Co	mg/kg/week	0.0011	0.0010	0.0012	0.0011	0.0011
Copper Cu	mg/kg/week	0.00044	0.00040	0.00046	0.00043	0.00043
Iron Fe	mg/kg/week	0.0033	0.0030	0.0035	0.0032	0.0033
Lead Pb	mg/kg/week	0.00022	0.00020	0.00023	0.00022	0.00022
Lithium Li	mg/kg/week	0.0011	0.0010	0.0012	0.0011	0.0011
Magnesium Mg	mg/kg/week	2.2	2.5	2.4	1.6	2.2
Manganese Mn	mg/kg/week	0.0015	0.0051	0.0040	0.0008	0.0029
Mercury Hg	mg/kg/week	4.4×10^{-7}	4.0×10^{-7}	4.6×10^{-7}	4.3×10^{-7}	4.3×10^{-7}
Molybdenum Mo	mg/kg/week	0.00022	0.00020	0.00023	0.00022	0.00022
Nickel Ni	mg/kg/week	0.0022	0.0020	0.0023	0.0022	0.0022
Phosphorus P	mg/kg/week	0.033	0.030	0.035	0.032	0.033
Potassium K	mg/kg/week	0.22	1.15	0.23	0.22	0.45
Selenium Se	mg/kg/week	2.2×10^{-6}	2.0×10^{-6}	2.3×10^{-6}	2.2×10^{-6}	2.2×10^{-6}
Silicon Si	mg/kg/week	0.17	0.25	0.14	0.14	0.18
Silver Ag	mg/kg/week	4.4×10^{-5}	4.0×10^{-5}	4.6×10^{-5}	4.3×10^{-5}	4.3×10^{-5}
Sodium Na	mg/kg/week	0.22	0.20	0.23	0.22	0.22
Strontium Sr	mg/kg/week	0.002	0.0122	0.005	0.004	0.006
Thallium Tl	mg/kg/week	4.4×10^{-7}	4.0×10^{-7}	4.6×10^{-7}	4.3×10^{-7}	4.3×10^{-7}
Tin Sn	mg/kg/week	0.0033	0.0030	0.0035	0.0032	0.0033
Titanium Ti	mg/kg/week	0.0011	0.0010	0.0012	0.0011	0.0011
Vanadium V	mg/kg/week	0.0033	0.0030	0.0035	0.0032	0.0033
Zinc Zn	mg/kg/week	0.0022	0.0026	0.0028	0.0073	0.0037

3.3.5 Solute Release from Quarried Rock

Sources of quarried rock that were tested by AMEC (AMEC 2003a) included the Doris North mine portal adit, rock from the proposed new barge loading area (Quarry #1), the quarry west of the proposed camp (Quarry #2) and the area east of Tail Lake (Quarry #3). Acid base account test results completed on samples from these sources indicated that the quarry rock will be non acid forming and that the sulphide content of the proposed fill rock is very low (< 0.04%).

Three humidity cell tests were completed on quarry rock samples, designated as Quarry #Q1, #Q2 and #Q3 (AMEC 2003a). Using the results from the humidity cell tests, solute release calculations were completed as described above for the waste rock samples. Briefly, the average solute release rates, in units of mg/kg/week, were calculated from the final 'steady state' cycles of the humidity cell tests. Where the concentrations of parameters were consistently below the detection limit, solute concentrations were assumed to be at 50 % of the detection limit and were used to estimate solute release rates. An average production rate was then estimated for each solute by obtaining an equal weight average for the three samples. The results are summarised in Table 3.4. The average rate was then used to calculate overall solute releases from the bulk of the construction rock as described below. The average solute release rates were multiplied by the total mass of waste rock, as shown in Table 3.4, to yield a total generation rate within each of the designated catchments.

The release rates were multiplied by the number of weeks for which the rock will not be frozen to estimate the overall annual solute generation. As before, to estimate the net release, a surface area correction factor of 0.3 and a release factor of 40% were adopted. The annual loading was then prorated on a monthly basis according to the site hydrograph.

In summary, the overall calculation to determine the average monthly load was as follows:

$$M_i = L_{HC})_i * W_R *20* 0.3 * 0.4 /1000)$$

Where M_i = loading of solute *i* in kg/year,
$L_{HC})_i$ = solute *i* production rate in the humidity cell (mg/kg/wk),
W_R = tonnes of waste rock in storage,
0.4 and 0.3 are correction factors as discussed above in points 3 and 4,
20 is the assumed number of weeks (5 months per year) for which the construction rock is not frozen, and
1000 is a unit conversion factor to obtain kg.

It should be noted that the entire loading generated by the fill is modelled to contribute to contaminant concentrations from time of placement, and it is assumed that transport of the leachate to each of Doris Lake and Tail Lake occurs instantaneously. In many cases this will lead to conservative estimates of solute concentrations in each of the lakes, because the actual transport of solutes to the lakes will depend on the:

- Distance from the lake that the fill is placed; and
- Potential sorption reactions that may occur as water flows over and through the tundra soil that will remove and attenuate solutes, thus increasing the time before the solutes will enter the respective lakes.

Furthermore, it was assumed that all of the site fill will generate solutes. In reality, a significant proportion of the fill will be covered by buildings and concrete pads and the actual loadings will be proportionately lower. The approach therefore is conservative.

Table 3.4: Summary of average solute release rates from quarry rock sample humidity cell testing

Parameter	Units	Sample Description			Overall Average
		Quarry # Q1	Quarry # Q2	Quarry # Q3	
Sulphate	mg/kg/week	0.82	0.86	0.89	0.85666667
Total Metals					
Aluminium Al	mg/kg/week	0.026	0.024	0.025	0.025
Antimony Sb	mg/kg/week	0.00012	0.00012	0.00012	0.00012
Arsenic As	mg/kg/week	0.00099	0.00062	0.00012	0.00058
Barium Ba	mg/kg/week	0.000060	0.000055	0.000115	0.000077
Beryllium Be	mg/kg/week	0.00012	0.00012	0.00012	0.00012
Bismuth Bi	mg/kg/week	0.00012	0.00012	0.00012	0.00012
Boron B	mg/kg/week	0.0060	0.0055	0.0060	0.0058
Cadmium Cd	mg/kg/week	0.000029	0.000032	0.000026	0.000029
Calcium Ca	mg/kg/week	1.5	1.5	1.4	1.5
Chromium Cr	mg/kg/week	0.00012	0.00012	0.00012	0.00012
Cobalt Co	mg/kg/week	0.00012	0.00012	0.00012	0.00012
Copper Cu	mg/kg/week	0.00023	0.00012	0.00012	0.00015
Iron Fe	mg/kg/week	0.0060	0.0055	0.0060	0.0058
Lead Pb	mg/kg/week	0.00012	0.00012	0.00012	0.00012
Lithium Li	mg/kg/week	0.00012	0.00012	0.00012	0.00012
Magnesium Mg	mg/kg/week	0.14	0.25	0.05	0.15
Manganese Mn	mg/kg/week	0.00018	0.00012	0.00012	0.00014
Mercury Hg	mg/kg/week	0.0000024	0.0000023	0.0000023	0.0000023
Molybdenum Mo	mg/kg/week	0.000000060	0.000000055	0.000000060	0.000000058
Nickel Ni	mg/kg/week	0.00015	0.00012	0.00012	0.00013
Phosphorus P	mg/kg/week	0.018	0.017	0.018	0.017
Potassium K	mg/kg/week	0.053	0.029	0.029	0.037
Selenium Se	mg/kg/week	0.00012	0.00012	0.00012	0.00012
Silicon Si	mg/kg/week	0.30	0.29	0.24	0.28
Silver Ag	mg/kg/week	0.000030	0.000029	0.000058	0.000039
Sodium Na	mg/kg/week	0.052	0.036	0.02	0.036
Strontium Sr	mg/kg/week	0.00094	0.00086	0.00053	0.00078
Thallium Tl	mg/kg/week	0.000012	0.000012	0.000012	0.000012
Tin Sn	mg/kg/week	0.00012	0.00012	0.00012	0.00012
Titanium Ti	mg/kg/week	0.00012	0.00012	0.00012	0.00012
Vanadium V	mg/kg/week	0.00047	0.00012	0.00012	0.00023
Zinc Zn	mg/kg/week	0.00060	0.00055	0.00060	0.00058

3.3.6 Sewage Effluent

Water quality performance estimates were obtained from a manufacturer of package sewage treatment plants (information provided by PJ Equipment Sales Corp). Expected average solute concentrations and annual loadings for a 175 person camp are summarised in Table 3.5. It was assumed that these loadings would report to Tail Lake continuously throughout the mill operational period, and for one year thereafter.

It should be noted that the phosphorus speciation is not known. In an attempt to quantify orthophosphate concentrations, the phosphorus for this source was input to the model as both total phosphate and orthophosphate. In reality, the orthophosphate estimates provided in the model run outputs should be treated as total phosphate rather than orthophosphate.

Table 3.5: Summary of estimated treated sewage water quality and loadings

Parameter	Average Concentration (mg/L)	Average Loading (kg/year)
Total Ammonia	10	250
Nitrate	1.0	25
Nitrite	30	751
Aluminium	0.052	1.3
Arsenic	0.0002	0.004
Cadmium	0.0001	0.0013
Chromium	0.0025	0.063
Copper	0.0020	0.050
Iron	0.025	0.63
Lead	0.0001	0.0013
Molybdenum	0.0001	0.0013
Nickel	0.0005	0.013
Phosphorus	1.0	25
Uranium	0.0002	0.005
Zinc	0.002	0.05

3.3.7 Process Tailings

Mineral processing of the gold bearing ore will comprise free gold recovery by gravity separation, followed by concentration of the sulphide minerals by conventional flotation technology. The flotation concentrate will then be cyanide leached for gold recovery. The cyanide leached tailings will be detoxified to reduce total and free cyanide concentrations, using Caro's Acid. Cyanide and its metal complexes are oxidized to cyanate (CNO^-) in this process. The detoxified cyanide leach effluent would be combined with the flotation tailings and pumped to Tail Lake.

Bench scale pilot testing of the proposed process was carried out by AMMTEC as reported by AMEC (MHBL 2005). Results from the testing program are summarised in Table 3.6. The summary table shows two sets of results; the first was reported by AMMTEC who completed the testing, and the second set represents a repeat analysis by Vizon Scientific (formerly B.C. Research Laboratories (BCR)) at lower detection limits. The increase in the cyanate concentration corresponded well with the theoretical stoichiometry expected for the oxidation of the total cyanide in solution. However, it is noted that some hydrolysis to ammonia, and ammonia oxidation to nitrite, had also occurred during the treatment steps. These nutrient degradation reactions are discussed further in Section 3.5.

Table 3.6: Cyanide leach and cyanide detoxified solution assays

Parameter	Units	Cyanide Leach Solution		Cyanide Detoxified Solution	
		AMMTEC	BCR*	AMMTEC	BCR*
pH	-	10.63	10.17	7.86	7.70
Free CN	mg/L	120	153	<5	0.009
Total CN	mg/L	210	220	2.5	1.82
WAD CN	mg/L	180	153	0.25	0.18
CNO	mg/L	360	312	400	282
SCN	mg/L	37	38	0.2	0.82
Ammonia-N	mg/L	3.0	2.2	17	22
Nitrate-N	mg/L	-	1.3	-	2.5
Nitrite-N	mg/L	-	0.052	-	0.39

Note: *Repeat analysis by B.C. Research Laboratories

The detoxified leach slurry was combined with the flotation tailings in the laboratory tests at the ratio expected during operations. The analytical results for the blended effluent stream are summarised in Table 3.7. The 'freshly' blended effluent was analysed immediately after it was produced, and again after it was aged for 1 month. Complete results are provided in Appendix D.

The laboratory tests were not conducted as 'locked cycle' tests (i.e. the effluent was not recycled until steady state concentrations were achieved), and therefore, the net increase in solute concentrations in the effluent represents the net solute loading that would be expected from the tailings.

These concentrations were therefore used to estimate the solute release per unit mass tailings produced, as follows:

$$L_i = (C_i /1000)^* (100/SG - 1)$$

Where L_i = release of solute i in kg/tonne tailings,
C_i = concentration of solute i, and
SG = % (wt) solids content of the tailings slurry.

Conservatively, only the maximum total concentration of each solute from the two blended effluent analyses was used in the above calculation. In general, solute concentrations in the aged samples were below the maximum concentration in the blended effluent analyses, with the exception of ammonia, sulphate and iron. The ammonia however is derived from the degradation of cyanate, which is significantly higher in the blended effluent samples, and is accounted for in the degradation reactions described later on. Sulphate concentrations were slightly higher in the aged samples and could have resulted from ongoing oxidation reactions, depending on how the samples were stored, which, as discussed below, are not expected to occur once the tailings have been deposited in Tail Lake. The iron analysis in both the BCR samples was below detection whereas iron was detected in the AMMTEC analyses. However, considering the pH of the effluent, the results reported by AMMTEC appear to be anomalous since iron would be expected to be precipitated from solution to very low concentrations. Nonetheless, the iron concentration reported by AMMTEC for the blended effluent was used in the calculations.

Where both the AMMTEC and the BCR reported values were below detection, the concentration was assumed to be equal to the lower of the two detection limits.

Table 3.7: Summary of blended and aged mill effluent

Parameter	Units	Blended Effluent		Aged Blended Effluent	
		AMMTEC	BCR*	AMMTEC	BCR*
pH	-	8.18	7.63	7.95	7.87
Free CN	mg/L	<5	0.03	<5	0.01
Total CN	mg/L	0.29	0.24	0.20	0.15
WAD CN	mg/L	0.04	0.036	0.01	0.014
CNO	mg/L	32	33	9.1	8.3
SCN	mg/L	<0.1	0.45	0.3	<0.2
Sulphate	mg/L	349	355	438	446
Ammonia-N	mg/L	1.0	1.1	4.4	5.3
Nitrate	mg/L	2.0	0.74	0.80	0.33
Nitrite	mg/L	1.0	0.12	0.90	<0.002
Alkalinity	mg/L	170	189	150	161
Total Metals					
Aluminium Al	mg/L	0.10	0.01	0.073	0.015
Antimony Sb	mg/L	-	0.003		0.003
Arsenic As	mg/L	0.008	0.01	0.002	0.007
Barium Ba	mg/L	0.04	0.041	0.04	0.032
Beryllium Be	mg/L	-	< 0.001	-	< 0.001
Bismuth Bi	mg/L	-	< 0.001	-	< 0.001
Boron B	mg/L	0.05	0.06	0.34	0.08
Cadmium Cd	mg/L	<0.005	< 0.0002	<0.005	< 0.0002
Calcium Ca	mg/L	106	93.5	68.5	65.3
Chromium Cr	mg/L	0.026	0.021	0.020	0.004
Cobalt Co	mg/L	0.040	0.044	0.032	0.04
Copper Cu	mg/L	0.039	0.039	0.024	0.02
Iron Fe	mg/L	0.120	< 0.05	0.220	< 0.05
Lead Pb	mg/L	<0.05	< 0.001	<0.05	< 0.001
Lithium Li	mg/L	-	0.011	-	0.009
Magnesium Mg	mg/L	22.8	26.2	28.2	28.8
Manganese Mn	mg/L	0.12	0.11	0.10	0.084
Mercury Hg	mg/L	<0.0005	< 0.00002	<0.0005	0.00007
Molybdenum Mo	mg/L	0.04	0.031	0.04	0.036
Nickel Ni	mg/L	0.03	0.031	0.01	0.007
Phosphorus P	mg/L	-	0.28	-	0.13
Potassium K	mg/L	182	182	168	175
Selenium Se	mg/L	-	< 0.001	-	< 0.001
Silicon SiO2	mg/L	-	14.9	-	8.27
Silver Ag	mg/L	-	< 0.0001	-	0.001
Sodium Na	mg/L	160	173	162	165
Strontium Sr	mg/L	-	0.33	-	0.28
Thallium Tl	mg/L	-	< 0.0001	-	< 0.0001
Tin Sn	mg/L	-	< 0.001	-	< 0.001
Titanium Ti	mg/L	-	0.001	-	< 0.001
Vanadium V	mg/L	0.005	< 0.001	<0.005	< 0.001
Zinc Zn	mg/L	0.090	0.009	0.092	0.007

Note: * Repeat analysis by B.C. Research Laboratories

The unit release rate was then multiplied by the monthly rate of tailings production to provide a total monthly loading as follows:

$$M_i = L_i * TP$$

Where M_i = loading of solute i in kg/month, and
TP = monthly tailings production in tonnes.

This 'conservation of mass' approach is conservative since some contaminants could reach concentrations at equilibrium with secondary mineral phases after which the concentration could stabilize or even decrease. The estimated loadings were assumed to remain constant throughout operations.

Once extracted from the underground workings, the ore is exposed to atmospheric conditions and the sulphide minerals are exposed to oxidizing conditions. The estimate solute release from the tailings, as described above, represent oxidation reactions that occur during the handling and processing of the ore. In addition, any readily available water soluble solutes associated with the ore rock will also be dissolved during processing and report to the tailings water.

Subsequent to deposition, the tailings will at all times be covered by a water depth in excess of 4 m. The water cover will prevent any oxygen entry to the tailings and therefore, the sulphide minerals contained in the tailings will be prevented from oxidizing. Consequently no additional solute release from the tailings will occur after the tailings have been deposited in Tail Lake. It should further be noted that since the tailings will be fully submerged and water will be decanted from the surface of the lake, no hydraulic gradients will develop that could cause the pore water to be displaced from the tailings. It is therefore expected that the tailings porewater will be 'locked' interstitially in the tailings indefinitely.

The water and load balance calculations consequently do not consider any additional solute release from the tailings once they have been deposited in Tail Lake.

3.3.8 Sources of Salinity

Drilling Fluids

Drilling fluids were assumed to be present in all mine and quarry products, i.e. construction fill, waste rock and ore.

For the mine water recovered from the underground workings, it was assumed that:

- On average a circulating flow of 191 litres per minute (40 gpm) of saline solution, containing 18% (by weight) calcium chloride, will be maintained during underground mining; and
- About 5% of the solution would be lost and report to mine water, which would be pumped directly to Tail Lake.

In addition, saline fluid losses to the construction fill, ore and waste rock are expected to occur. To estimate these loadings, it was assumed that:

- Saline drilling fluids will contribute a 3% increase in moisture content of the quarried construction fill, waste rock and ore.

The total saline fluid content of the rock and fill was determined from the weight distributions given in Table 3.2. Salinity releases were calculated assuming 40% of the waste rock or fill would be flushed annually. The annual loadings were prorated to monthly release rates based on the Doris Lake outflow hydrograph.

Porewater Release from Permafrost Thaw

Salinity released due to thawing of permafrost surrounding Tail Lake was included in the load balance calculations. It is anticipated that the permafrost thaw will occur as the water level in Tail Lake rises. Because of the outward hydraulic gradients that will be generated by the rising water level in the lake, little porewater release to the lake water will occur during the time that the water level continues to rise. However, as soon as the water level is lowered to the final water elevation, hydraulic gradients will be reversed toward the lake, and there will be a release of porewater from the thawed areas. The volume of porewater that could be released from the thawed areas was estimated as follows.

A shoreline survey indicated that approximately 5,100 m of Tail Lake shore may contain permafrost that could be thawed by a rise in the water elevation. Thermal modeling suggests that the permafrost could be thawed to a depth of about 3 m, over a shore width of about 50 m. Assuming an average slope of about 6% for the shore, an initial moisture content of 50%, and a drained field moisture content of 35% for the soils, it can be shown that a volume of about 57,000 m^3 of saline water could be released. It was assumed that the permafrost thaw water would approximate seawater quality, i.e. it would contain about 17.1 g/L chloride, 1 g/L sulphate, 9.3 g/L sodium and about 1.7 g/L calcium.

Conservatively, it was assumed that the entire volume of thawed porewater that could be released would be released to Tail Lake within a period of one year, following the lowering of the water level in Tail Lake to its final spill elevation, or when the rise in water level is reversed.

Porewater Release from Permafrost Soil Erosion

Subsequent to lowering the water level in Tail Lake, erosion of the thawed soils may continue to contribute salinity to Tail Lake. As discussed in the next section, ongoing salinity release from this source is calculated inclusive of the sediment release calculations.

3.3.9 Shoreline Erosion

As a result of the expected rise in water level in Tail Lake during tailings deposition, permafrost soils around the perimeter of Tail Lake are expected to thaw. The thawed soils may become susceptible to re-suspension due to wave action while submerged.

After tailings deposition ceases, as part of the water management strategy, the water level in Tail Lake will be lowered to its original elevation. At that time, the soils above the waterline that have thawed will be subject to physical erosion caused by overland runoff and wave action impacting on the shoreline. This erosion may lead to sloughing and slumping of thawed soils at steep gradients, which may further exacerbate particulate transport to Tail Lake.

The combined effects of physical erosion and re-suspension by wave action may increase the suspended solids concentration in Tail Lake. Calculations have been completed that estimated potential total sediment loadings from three possible erosion mechanisms as follows:

- *Re-suspension of tailings by wave action.* The calculations considered the depth of the water cover, the tailings solids size distribution, and the prevailing wind fetch and speed (SRK 2006b).
- *Physical shoreline erosion from overland runoff and wave action.* Calculations completed to estimate the potential sediment transport due to shoreline erosion processes considered only the mass transport that occurs as a result of the physical process of erosion (Appendix E).
- *Shoreline material re-suspension by wave action.* These calculations address soil that had been eroded from the shoreline and has accumulated on the bed of Tail Lake and the shallow fringes near the lake shore (Appendix F).

Due to the depth of the water cover that will exist over the tailings, the effect of wave action on re-suspension of tailings will be negligible (SRK 2006b).

The estimated potential sediment loadings to Tail Lake generated from shoreline erosion and through re-suspension, before any correction for particles settling from the water column, derived from these calculations are summarized in Table 3.8.

Table 3.8: Summary of estimated solids loadings to Tail Lake at elevation 28.3 m

Case	Loading by Physical Shoreline Erosion (kg/year)	Loading Resulting from Re-Suspension of Eroded Material (kg/year)	Estimated Total Annual Loading (kg/year)
Base Case	2,846,891	206,066	3,052,957
Upper Limit	7,354,467	281,115	7,635,582
Lower Limit	948,964	122,261	1,071,225

Settling tests were carried out to assess the residual total suspended solids concentration that may result from these sediment loadings. The test procedures and results for the settling tests are provided in Appendix G. As part of that investigation, the properties of the suspended solids as well as total solute release from the sediments were assessed. The results can briefly be summarized as follows:

- While X-ray diffraction testing indicated the presence of pyrite in the sediments, analytical results indicate that the actual sulphide mineral content is very low, and, that the sediments are not net acid generating.

- Illite and mica are the dominant clay minerals present in the sediments.
- Irrespective of the initial clay content (with particle sizes ranging from 15 % to 40 % less than 2 µm), the settling tests indicated that the solids settled from the water column fairly rapidly, with total suspended solids decreasing to below a detection limit of 1 mg/L within a 72 hour period.

The settling tests were conducted to reflect the estimated potential upper limit sediment loadings (see Table 3.8) to Tail Lake, corrected for low flow conditions (yield of 111 mm/year) at steady state (i.e. the worst case conditions). The results from the settling tests were therefore corrected to reflect both low (111 mm/year) and high (180 mm/year) yield conditions, and for the estimated base case and lower limit conditions. The correction method is discussed in Appendix G. The resulting estimated suspended solids and total solute concentrations that may result from the erosion effects are summarized in Table 3.9 and represent incremental loadings to Tail Lake in the absence of erosion control measures.

It is however important to note the following:

- These concentrations could occur only if: i) sediment loadings reach the estimated maximum rates, and, ii) they persist at those rates indefinitely. In the absence of any physical interventions, effects such as natural revegetation and re-establishment of permafrost are likely to reduce overall sediment loadings in time.
- The solute loading estimates include salinity release (elevated chloride, sodium and potassium concentrations), which somewhat double accounts for the salinity release calculations described previously.

Table 3.9: Estimated steady state total solute concentrations in Tail Lake

Description	**Units**	**CCME**	**Test Average**	**Low Yield (111 mm/year)**			**High Yield (180 mm/year)**		
Flow	**m^3/year**		**-**	**500,000**			**812,000**		
Case			**-**	**Lower Limit**	**Base case**	**Upper Limit**	**Lower Limit**	**Base case**	**Upper Limit**
Total Sediment Load	g/L		14.5	2.14	6.11	15.27	1.32	3.76	9.40
TSS (measured)	mg/L		1.0	0.1	0.4	1.1	0.1	0.3	0.6
TSS (calc.)	mg/L		7.2	1.1	3.0	7.6	0.7	1.9	4.7
Chloride	mg/L		195	29	82	205	18	50	126
Total Metals									
Aluminium Al	µg/L	100	623	92	*262*	*656*	57	*162*	*404*
Antimony Sb	µg/L		0.17	0.025	0.070	0.176	0.015	0.043	0.108
Arsenic As	µg/L	5	1.0	0.15	0.44	1.1	0.09	0.27	0.67
Bismuth Bi	µg/L		0.025	0.004	0.011	0.026	0.002	0.006	0.016
Boron B	µg/L		78	11	33	82	7	20	50
Cadmium Cd	µg/L	0.038	0.025	0.004	0.011	0.026	0.002	0.006	0.016
Calcium Ca	µg/L		5,906	8,73	2,488	6,223	538	1,532	3,832
Chromium Cr	µg/L	1	1.2	0.18	0.52	*1.29*	0.11	0.32	0.80
Cobalt Co	µg/L		0.31	0.046	0.13	0.33	0.028	0.080	0.20
Copper Cu	µg/L	2	1.97	0.29	0.83	2.0	0.18	0.51	1.3
Iron Fe	µg/L	300	605	89	255	*638*	55	157	*393*
Lead Pb	µg/L	2	0.12	0.017	0.049	0.12	0.011	0.030	0.076
Lithium Li	µg/L		5.7	0.85	2.4	6.0	0.52	1.5	3.7
Magnesium Mg	µg/L		8,264	1,222	3,481	8,707	752	2,144	5,361
Manganese Mn	µg/L		14	2.1	6.1	15	1.3	3.7	9.4
Mercury Hg	µg/L	0.1	0.050	0.007	0.021	0.053	0.005	0.013	0.032
Molybdenum Mo	µg/L	73	0.80	0.12	0.34	0.84	0.073	0.21	0.52
Nickel Ni	µg/L	25	0.63	0.094	0.27	0.67	0.058	0.16	0.41
Phosphorus P	µg/L		47	7	20	49	4	12	30
Potassium K	µg/L		6,485	959	2,732	6,833	590	1,682	4,208
Selenium Se	µg/L	1	2.5	0.37	1.0	*2.6*	0.23	0.66	*1.6*
Silicon Si	µg/L		1,518	224	640	1,600	138	394	985
Silver Ag	µg/L		0.025	0.004	0.011	0.026	0.002	0.006	0.016
Sodium Na	µg/L		115,565	17,083	48,685	121,764	10,519	29,979	74,978
Strontium Sr	µg/L		41	6	17	43	4	11	26
Thallium Tl	µg/L	0.8	0.005	0.001	0.002	0.005	0.0001	0.001	0.003
Tin Sn	µg/L		0.095	0.014	0.040	0.100	0.009	0.025	0.062
Titanium Ti	µg/L		35	5.2	15	37	3.2	9.2	22
Vanadium V	µg/L		5.20	0.77	2.2	5.5	0.47	1.4	3.4
Zinc Zn	µg/L	30	3.40	0.50	1.4	3.6	0.31	0.88	2.2

Note: Values in bold italics exceed CCME guidelines

3.4 Overall Tail Lake Mass Balance Calculations

The contaminant load and water quality calculations for Tail Lake were set up in an Excel spreadsheet to calculate solute loadings and concentrations on a monthly basis as follows:

- The calculations for Tail Lake tracked the inventory of contaminants in the lake with time through the operational period and beyond;
- The total contaminant inventory was used to calculate the water quality at the beginning of each time step, which was then used to track contaminant concentration changes through dilution, nutrient degradation reactions and/or operational decant for that time step; and
- At the end of the time step, the lake inventory was updated to accommodate the total **gain (loading)** and/or **loss (removal)** of solute from the system. **Loadings** of solutes included all flows to Tail Lake from all the sources (mill, mine water, sewage and background) and products generated from nutrient degradation reactions and **losses** included pore water lock-up, decant or discharges, and removals by nutrient degradation reactions.

As discussed later, the rise in water level in Tail Lake will be minimised, and the lake will remain relatively shallow. Because the lake will remain shallow and based on the wind conditions at the site, the likelihood of a stable thermocline to develop for the duration of summer is expected to be small. Therefore, in simple terms, Tail Lake was regarded as a completely mixed system. The overall Tail Lake mass balance calculation for each solute, at each time step was as follows:

$$TM_t = MC + MI - MO - MR + MG$$

Where TM_t = mass contained at the end of the time step t (kg),
MC = mass contained at the beginning of the time step (kg),
MI = mass in all **inflows** to Tail Lake over the entire time step (kg),
MO = mass in all **outflows** from Tail Lake over the entire time step (kg),
MR = mass **removed** by nutrient degradation or conversion reactions (kg), and
MG = mass **generated** by nutrient degradation or conversion reactions (kg).

The loadings in the inflows included all the sources discussed in the preceding sections. Background loadings to Tail Lake were included using the estimated surface runoff flows and concentrations, and background solute concentrations measured in Tail Lake outflow.

The solute concentration at the end of the time step was then calculated as follows:

$$SC = TM_t / V_t / 1000$$

Where SC = solute concentration at the end of time step t (mg/L),
TM_t = mass contained at the end of time step t (kg),
V_t = volume of free water contained in Tail Lake at the end of time step t (m^3), and
1000 = conversion factor from kg/m^3 to mg/L.

The solute loading to Tail Lake included degradable cyanide and its derivative compounds (predominantly cyanate) and ammonia-N. A number of nutrient degradation reactions are expected to occur within Tail Lake. These are presented and discussed briefly in the following sections.

3.5 Nutrient Degradation Reactions

3.5.1 Cyanide and Cyanate

Residual cyanide present in the tailings water will oxidize to produce cyanate according to the following reaction:

$$CN^- + ½\, O_2 => CNO^-$$

As shown by the results from the aging test (see Table 3.7), cyanate hydrolyses relatively rapidly to ammonia. The reaction stoichiometry for cyanate conversion (hydrolysis) to ammonia is as follows:

$$CNO^- + H_2O + H^+ => NH_3 + CO_2$$

Using the stoichiometry from this equation, the production of ammonia can be calculated. The approximate rate of hydrolysis was estimated from the aging test results.

3.5.2 Natural Ammonia-N Degradation Processes

Ammonia nitrogen in open water systems may behave in one or more of the following three ways:

1. It may serve as a prime nutrient to support phytoplankton and rooted aquatic growths. Ammonia is assimilated directly by phytoplankton. The growth of phytoplankton requires that appropriate conditions exist, which includes sufficient nutrients and sunlight.

2. Some proportion will be lost to the atmosphere as gaseous NH_3, when its partial pressure in the water is greater than that in the atmosphere. The degree of loss is a function of pH which controls the ionization of ammonia as follows:

   $$NH_4^+ \Leftrightarrow NH_3 + H^+$$

   At a pH of 9 to 9.5 about 40 to 50% of the ammonia nitrogen is present as ammonia and will be volatilised. However, at pH of about 7, almost all of the ammonia nitrogen is ionized and little loss will occur.

3. Biological nitrification occurs naturally in lakes and water bodies. Biological nitrification occurs when ammonia-nitrogen is first oxidized to nitrite (NO_2^-) and then to nitrate (NO_3^-) by nitrifying bacteria. The rate of reaction is directly proportional to the bacterial population, availability of oxygen and the temperature of the water column, and therefore generally occurs in the epilimnion or upper aerated part of a water body. The growth rate of nitrifying bacteria typically is rapid when appropriate conditions exist, which includes sufficient nutrients and a

sufficiently elevated temperature. At temperatures above 15°C biological activity is usually sufficiently rapid to achieve effective removal rates. When temperatures drop below 10°C, rates become very slow. This also means that the biological processes will be most effective during summer and will "shut-down" when the water body freezes over.

Since the pH of the lake water is expected to vary between 7 and 8, volatilization of ammonia is not expected to significantly reduce ammonia-N concentrations. Therefore, mechanisms 1 and 3 are expected to cause ammonia-N removal from Tail Lake.

As noted before, the rate of biological removal depends on the availability of nutrients and sunlight. In natural environments, phosphorus most commonly is the rate limiting nutrient that controls biological activity. Phosphorus concentrations typically are low in mine effluent waters, which would restrict bacterial and algal growth. Under the proposed mine operating plan, treated sewage water would be discharged to Tail Lake. This flow would contain some residual phosphorus, which will likely stimulate natural removal. It is furthermore possible to enhance natural removal by phosphorus addition to Tail Lake. For example, at the Colomac Mine Site, NT, phosphorus was added with great success to cyanide contaminated tailings water to enhance the growth of natural populations of algae and bacteria. At that site, elevated concentrations of cyanide, thiocyanate, ammonia and nitrate have effectively been removed from the TCA as a result. The potential removals that may occur within Tail Lake are evaluated in the following sections in the context of the removal that was observed at the Colomac Site (Chapman *et al*. 2003).

Assessment of Natural Removal of Ammonia-N

In the following evaluation, the potential for natural removal of ammonia-N from Tail Lake is estimated from the rates of removal observed at the Colomac Mine Site (Chapman *et al*. 2003) and relies on a comparison of conditions between the two sites.

Briefly, at the Colomac Site, natural removal of cyanide compounds has led to the formation of very high concentrations of ammonia-N in the TCA (Tailings Lake), containing up to 48 mg/L ammonia-N, and, in the adjacent Zone 2 Pit (Pit Lake) containing up to 24 mg/L ammonia-N. In addition, Fuscum Lake, a lake adjacent to the Tailings Lake, was contaminated with water from Tailings Lake resulting in an ammonia-N concentration of about 15 mg/L.

In Fuscum Lake, ammonia-N was removed to less than 0.2 mg/L without any enhancement by phosphorus addition. The removals observed in this lake provide estimates of baseline removals that may be expected.

In the TCA and the contaminated pit lake, natural removal of ammonia-N was enhanced by the addition of phosphorous (as mono-ammonium phosphate). Typically, phosphorus additions are targeted to achieve an N:P ratio of about 7 to 8:1.

A summary of the rates of removal observed for the three contaminated lakes is provided in Table 3.10. The table also provides the phosphorus and ammonia-N concentrations. The Fuscum

Lake data represent the initial and final water quality data. The Pit Lake and Tailings Lake data represent the results obtained in the epilimnion over a period of 70 days. (Both Tailings Lake and the Pit Lake exhibit a typical thermal stratification during the summer months, with the thermocline reaching a maximum depth of between 5 m and 6 m. It is within the warmer upper layer or epilimnion that all the ammonia-N removal occurs.) The rate of removal calculated for Fuscum Lake represents the average over the entire summer period. The Tailings Lake and Pit Lake rates pertain to a single season removal only. These rates therefore are directly comparable.

Table 3.10: Summary of natural and enhanced ammonia-N removal rates at Colomac (after Chapman *et al.* 2003)

Location	Conditions	Phosphorus		Ammonia-N		Ammonia-N Removal (mg/m^2/day)
		Initial (mg/L)	End of Season (mg/L)	Initial (mg/L)	End of Season (mg/L)	
Fuscum Lake	Natural	0.018	-	14	0.19	148
Pit Lake	Enhanced	0.8	0.6	22	6 (ongoing)	1400
Tailings Lake	Enhanced	0.9	0.2	48	9 (ongoing)	2000

To enhance natural removal rates, phosphorus was added to Tailings Lake and to the Pit Lake during the spring thaw to achieve initial concentrations of about 1 mg/L of total phosphorus. Over the course of one summer season (June to August), the ammonia-N concentration decreased from about 45 mg/L to about 9 mg/L in the upper (heated) layer of Tailings Lake. The Pit Lake is more sheltered to sunlight by high walls, and the ammonia concentration decreased from about 24 mg/L to less than 6 mg/L over a similar period. As shown in the table, the natural rate of ammonia-N removal was enhanced by about an order of magnitude by adding excess phosphate to the water.

Based on the natural ammonia-N removal observed in Fuscum Lake, and enhanced removal rates observed in the Pit Lake and in Tailings Lake, it is concluded that natural or enhanced removal are viable processes for ammonia-N removal in Tail Lake. To estimate the effectiveness of these processes in Tail Lake, it is necessary to consider the differences in conditions between the two sites.

Nutrients

As noted above, growth of phytoplankton requires that sufficient nutrients are present. The sewage treatment plant discharge, which will be pumped to Tail Lake, is expected to contain approximately 1 mg/L of phosphorus. On average, assuming that phosphorus will annually be removed from solution, as is observed elsewhere, the phosphorus concentration would be expected to fluctuate to between < 0.07 mg/L to a maximum of about 0.12 mg/L. These concentrations are in the same range as the concentrations detected in Fuscum Lake, and therefore would be supportive of natural removal of ammonia-N in Tail Lake.

Sunlight

Table 3.11 below compares the average sunshine hours for nearby meteorological stations, and the exposure profiles are shown in Figure 3.7. Tail Lake is located at a latitude of about 67^{o}N, and the

Colomac Site is located at a latitude of 64°N. As shown in the table, Kuglutuk is located at about 67°N and on average experiences about 1,629 hours of sunshine. The sunshine exposure for Colomac is expected to be similar to that of Baker Lake, i.e. 1,843 hours. The Tail Lake (represented by Kuglutuk) and Colomac (Baker Lake) sunshine profiles are very similar, as shown in Figure 3.7. These comparisons are supportive of natural removal of ammonia-N from Tail Lake. However, due to the lower sunshine exposure at Tail Lake site, the ammonia-N removal is expected to be somewhat lower than that observed at the Colomac Site (i.e. about 85%).

Table 3.11: Total annual bright Sunshine hours

Station	Latitude	Longitude	Annual
Baker Lake	64° 18' N	96° 05' W	1,843
Kugluktuk (Coppermine A)	67° 50' N	115° 7' W	1,629
Norman Wells A	65° 17' N	126° 48' W	1,854
Yellowknife A	62° 28' N	114° 27' W	2,277

(Source: Environment Canada 1951-1980 Climate Normals)

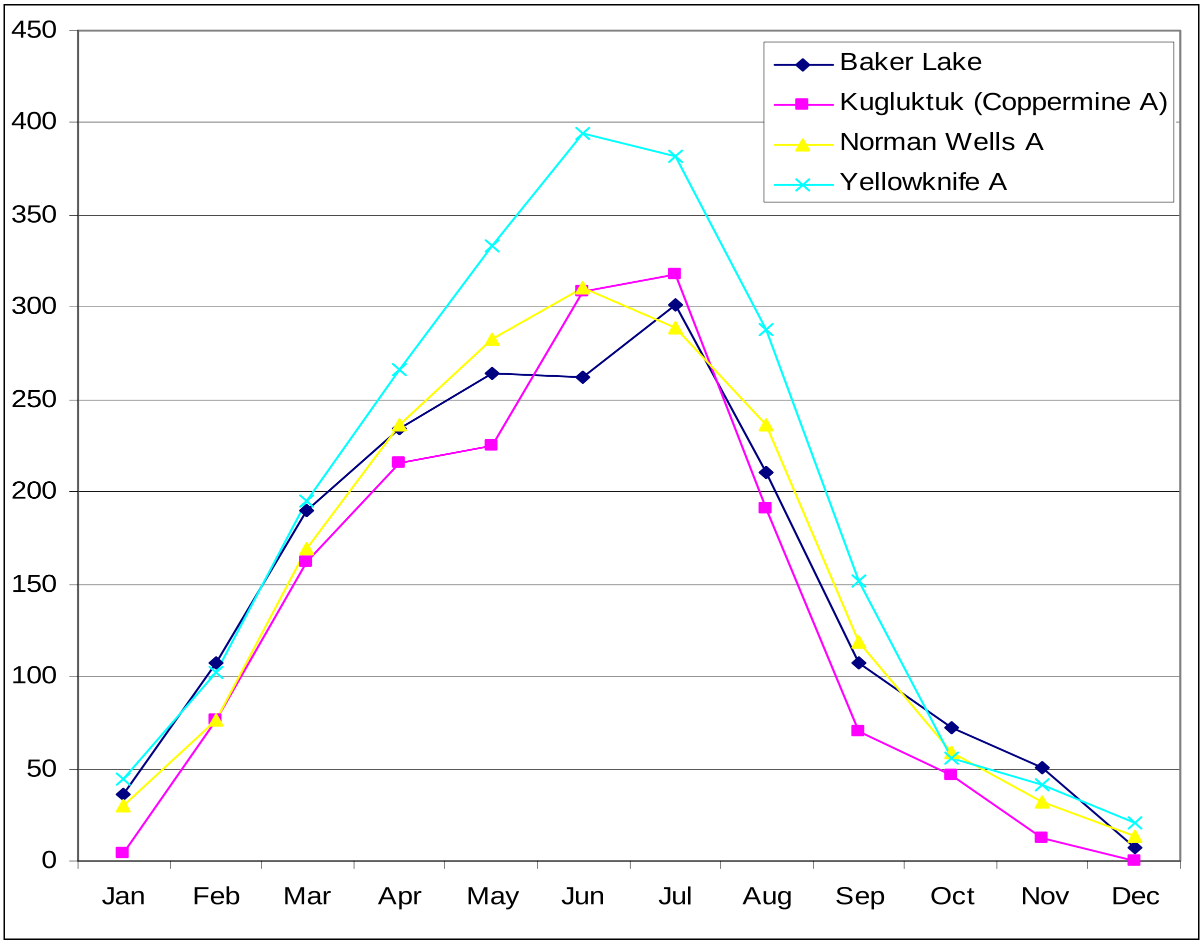

Figure 3.6: Average monthly sunshine profiles

Thermal Profile/Stratification

The maximum operating depth of Tail Lake is about 5 m to 6 m. Therefore, the entire water body is expected to be at a uniform temperature, and ammonia removal would be expected to occur throughout. These conditions are similar to those in Fuscum Lake (average depth of 4 m) and in the epilimnion of the Pit Lake and Tailings Lake.

Net Removal Capacity at Tail Lake

To estimate the potential ammonia-N removal that may occur in Tail Lake, the removal rates given in the last column of Table 3.10 were corrected by multiplying them with a factor of 0.85 for the reduced sunshine exposure. These corrected rates were then used to estimate potential natural and enhanced removal rates for Tail Lake as follows:

1. The Tail Lake pond surface area was calculated from the pond level.

2. The adjusted removal rate was then multiplied by the surface area to obtain the total removal capacity.

3. Removal was assumed to occur only from June through September.

As noted previously, the removal would occur by one of two mechanisms. In the first mechanism, ammonia is taken up directly as a nutrient in cell growth. The biomass that is generated would sink to the bottom of the lake and accumulate as lake sediment. Some proportion of the nitrogen could be recycled to the water column as the biomass decays. In the second mechanism, ammonia is oxidized to nitrate in a process called nitrification as discussed in the next section.

3.5.3 Nitrification

Nitrification, or ammonium oxidation, is a two-step respiratory process occurring in sediment (benthic nitrification) or the water column (pelagic nitrification) (Grady and Lim 1980). In the first step, mediated by *Nitrosomonas* micro-organisms, ammonia is oxidized to nitrite as follows:

$$NH_4^+ + 1.5O_2 = NO_2^- + H_2O + 2H^+$$

In the second step, is mediated by *Nitrobacter* micro-organisms, nitrite is oxidized to nitrate as follows:

$$NO_2^- + 0.5O_2 = NO_3^-$$

Both reactions are energy yielding and therefore occur independently of each other. Oxygen serves as the electron acceptor, and therefore an aerobic environment is required for these reactions to occur. Indeed, oxygen is the only electron acceptor that can be utilized by *Nitrosomonas* and *Nitrobacter* micro-organisms. Therefore, partial or incomplete oxidation of nitrite to nitrate would occur only if the oxygen demand by ammonia oxidation exceeds available oxygen in the water column. (The potential for oxygen limiting conditions is assessed in Section 4. In the interim, it can be shown that the complete oxidation of 1.5 mg/L ammonia to nitrate requires about 6.3 mg/L O_2. Since the solubility of oxygen in water at the expected temperature in Tail Lake is well above this oxygen demand (i.e. in the range of 10 mg/L for static conditions), it is unlikely that the system will become oxygen deficient. It should be noted that oxygen diffusion and surface mixing induced by wind will further enhance the availability of oxygen. At similar concentrations, ammonia is therefore expected to be fully oxidized to nitrate.)

Excluding oxygen limitations, the growth limiting substrate for *Nitrosomonas* (ammonia oxidation step) usually is ammonia; the growth limiting substrate for *Nitrobacter* (nitrite oxidation step) usually is nitrite. The growth rate of *Nitrobacter* is much greater than the growth rate of *Nitrosomonas* for a wide range of conditions (Water Pollution Control Federation 1983; Grady and Lim 1980). Therefore, because the nitrification process is sequential (i.e. ammonia => nitrite => nitrate), little or no nitrite will result from the oxidation of ammonia. Furthermore, because the growth rate of *Nitrobacter* is much greater than the growth rate of *Nitrosomonas*, the *Nitrobacter* will utilize the excess nitrite from the explosives and the sewage treatment plant discharge, and it too will be depleted from the water column.

Further evidence for the depletion of nitrite from the water column can be found in the reported oxidation rates. Nitrite oxidation rates ranging from 0.7 to 4.2×10^{-4} mg NO_2-N/L/h for low temperature conditions are reported by Bianchi *et al*. (1999). For example, using the lower end of the range, it can be shown that during the open water season (approximately 180 days) in excess of 1.8 mg/L of nitrite may be oxidized in Tail Lake water.

3.5.4 Denitrification

The final step in the biological processes contributing to the degradation of ammonia is de-nitrification wherein nitrate is reduced to nitrogen gas. This is an anaerobic process and occurs at depth below the aerated zone. Because of lower temperatures at depth, de-nitrification is likely to proceed at a slower rate than nitrification. In-situ measurements of denitrification rates for a reservoir in a cold climate ranged from 25 to 450 µmol N_2 m^{-2} h^{-1} (mean 291 µmol N_2 m^{-2} h^{-1}) (Tomaszek and Czerwieniec 2002). Similar rates of denitrification were also observed at the Colomac Site, where denitrification was observed to continue under ice throughout winter.

3.5.5 Summary

Removal calculations for cyanide and ammonia were included in the spreadsheet model. A simple empirical approach was adopted for these calculations and all calculations were applied only for open water conditions. The calculations include the intermediate step of ammonia oxidation to nitrite, followed by oxidation to nitrate. The reaction rate constants were estimated from available information for the tailings, those observed at the Colomac Site and additional data published for natural systems. The estimated removal rates for each parameter were as shown in Table 3.12. The table shows removal rates for a 'base case' which generally correspond to removal rates observed for natural systems, and an 'enhanced case' which reflect rates estimated from the Colomac site rates corrected for site specific conditions.

Table 3.12: Summary of assumed conversion rates

Parameter	Base Case (kg/m^2/month)	Enhanced (kg/m^2/month)
Free Cyanide to Ammonia-N	0.000036	0.00029
Total Cyanide to Ammonia-N	0.00013	0.0011
WAD CN to ammonia	0.000036	0.00029
Cyanate (CNO) to Ammonia-N	0.034	0.28
Ammonia-N oxidation to NO_2-N	0.0044	0.036
NO_2-N oxidation to NO_3-N	0.00023	0.0012
Denitrification (NO_3-N to N_2)	0.0012	0.0023

It should furthermore be noted that phosphorus will also be removed from solution through biological activity. Because of the comparatively low overall concentration of phosphorus, its removal was not included in the calculations.

3.6 Summary of Conservative Assumptions

In conclusion, a brief summary of some of the conservative assumptions that have been adopted is presented in Table 3.13.

Table 3.13: Summary of selected conservative assumptions adopted

Item	Component/Source	Conservative Assumption	Reason
1	Waste Rock Storage	137,000 tonnes in storage from day one for 36 months	Actual schedule indicates a maximum storage of 137,000 by month 13, with complete removal in 32 months
2	Waste Rock and Fill Solute Release	Solute occurs from day one, and is instantaneously transported to Tail Lake Outflow/ Doris Lake Outflow	Wetting of the fill/rock may take several seasons before solute release can occur; frozen zones will further affect solute release; solute attenuation will occur by sorption reactions which will further delay the transport of the solutes
3	Site Fill	All of the fill will produce solutes at an equal rate	Buildings and concrete slabs will cover a significant proportion of the mill site which will reduce the solute release proportionately
4	Tailings	Adopted maximum solute concentrations from the blended effluent in the calculations	Aging tests generally showed a reduction in solute concentrations with time
5	Salinity Release	Calculations include salinity release from porewater and from sediment erosion	Double accounting salinity release since the settling tests were completed on 'whole' samples, i.e. with porewater in tact
6	Underground Workings	Assumed solutes and blast residues released from waste rock backfill in underground workings commences from day one	Underground workings are expected to frozen and dry and solute release from backfill is unlikely

4 Conceptual Discharge Scenarios

4.1 Introduction

In this chapter a series of water management strategies or scenarios for Tail Lake are identified and briefly described. These scenarios are then evaluated by assessing effects on water accumulation in Tail Lake, water quality in Tail Lake, and, effects of discharge on receiving water quality in Doris Creek under the following assumptions:

- The first premise is that MMER criteria would be met before any discharge could be permitted.
- The second premise is that the discharge can be regulated to meet CCME guidelines for the protection of freshwater aquatic life downstream of the mixing zone, i.e. downstream of the waterfall in Doris Creek.

4.2 Modeling Approach

In general, the modelling approach was as follows. For each scenario where Tail Lake discharge would be managed (prior to reaching the FSL), it was assumed that the monthly discharge rate would be controlled to be proportional to Doris Creeks' hydrograph. To estimate the maximum allowable discharge volume, the discharge to Doris Creek was increased until a parameter in Doris Creek was at its CCME guideline. Only total metals were considered and, where observed, potential nutrient exceedances were recorded. The reason this approach was adopted is that the nutrients are degradable and degradation rates can be enhanced with little additional effort.

In most cases, total copper concentration was the controlling parameter, and discharge flows were limited to meet the CCME guideline for this parameter in Doris Creek. However, chromium and selenium concentrations were also predicted to be at their respective CCME guidelines in Doris Creek for certain scenarios.

The potential scenarios have been selected to represent a wide range of possible operating conditions. The following assumptions were adopted:

- Except where specified otherwise, average flow conditions represent a mean annual precipitation of 207 mm, a mean annual site runoff of 180 mm and a mean annual evaporation rate of 220 mm;
- No precautionary steps are assumed to have been taken to control or limit sediment release from the shoreline of Tail Lake and base case sediment release rates are adopted (see Table 3.9);
- Waste rock storage will occur for 36 months from start of operations at the maximum scheduled storage of 137,000 tonnes;
- Blast residues were assumed to be 10% of explosive usage; and

- Nutrient degradation rates proceed at base case rates (see Table 3.12).

Sensitivity analyses to assess effects of deviations from these assumptions on water quality in Tail Lake, Doris Creek and the water management strategy are presented in a later section.

4.3 Assessment of Discharge Scenarios

4.3.1 Scenario Descriptions

Scenario 1 – ‘No Intervention’

In the ‘No Intervention’ case, conditions were adopted to first assess the overall effect of contaminant accumulation in Tail Lake, and, then to assess the potential effects on receiving water quality when it becomes necessary to release water, i.e. when the FSL of Tail Lake is reached. The scenario was assessed for average flow conditions.

As a worst case it was assumed that there is no conversion of cyanide compounds and no degradation of nutrients. This is very conservative since the laboratory tests and observations elsewhere clearly showed that nutrient degradation will occur.

Scenario 2 – ‘No Intervention’ with Nutrient Degradation

This scenario was designed to demonstrate the effects of nutrient degradation on overall water quality. Therefore, the conditions and assumptions were the same as those adopted for Scenario 1, except that nutrients were allowed to degrade at the base case rates.

Scenario 3 – Minimise Management Period

The purpose of this scenario was to establish the minimum time period for which active discharge would occur. Therefore, the discharge rate was maximised from year 1, while still meeting CCME guidelines for copper in Doris Creek downstream of the waterfall. The scenario was completed for average flow conditions.

Scenario 4 – No Discharge in Year 1 and Minimise Management Period

Consideration may be given to not discharge within the first year of operation in order to verify the predicted water quality. Water quality measurements in Tail Lake during the first year of operation can be used to verify the modelled water quality and would provide confidence in a subsequent discharge strategy. Therefore, this scenario is designed to assess the potential impact of not discharging during the first year on the overall strategy of ‘minimum operational period’.

The scenario therefore assumes that there would be no discharge in year 1, but that in subsequent years the discharge rate would be maximized to maintain the copper concentration below 2 µg/L in Doris Creek.

Average flow conditions with base case nutrient degradation rates were evaluated.

Scenario 5 – 'Balanced' Discharge Strategy

All the discharge scenarios above determined the annual discharge to meet CCME guidelines in Doris Creek, i.e. the flow is maximised to not exceed a copper concentration of 2 µg/L in Doris Creek. However, if the discharge from Tail Lake is reduced, the copper concentration in Doris Creek will decrease during the active discharge period. If the discharge flow is reduced to the point where the discharge is lower than the average annual inflow to Tail Lake, water will be accumulated in Tail Lake and ultimately it will reach the FSL. At that time, there will be a step increase in the discharge rate from the controlled rate to the net inflow rate. This step increase will lead to a concurrent increase in concentrations in Doris Creek. Initially, the copper concentration will be elevated whereas when the step increase in flows occur the copper concentration will be substantially lower. This scenario examines the discharge rate that would result in a copper concentration during the early stages that would be balanced with the increase that would occur when the discharge rate increases once the FSL is reached. Hence the initial effects would be 'balanced' with the later effects.

Scenario 6 – Intermediate Flow Discharge Strategy

The purpose of this scenario is to assess effects of a flow condition that is halfway between the maximum flow rate that would be associated with the minimum discharge management time (Scenario 3), and that of the 'balanced' discharge strategy (Scenario 5).

Scenario 7 – Effect of High Flow on 'No Intervention' Scenario

This scenario is the same as Scenario 1, but with a 1 in 500 year wet year in the first year of operation followed by average flow conditions. The following assumptions were adopted:

- Average flow conditions represent a mean annual precipitation of 207 mm, a mean annual site runoff of 180 mm and a mean annual evaporation rate of 220 mm.
- A 1:500 wet year event represents a runoff of 335 mm.

Other assumptions remained as before.

Scenario 8 - Effects of High Flow on Minimised Management Period

This scenario is the same as Scenario 3, but with a 1 in 500 year wet year in the first year of operation followed by average flow conditions. The following assumptions were adopted:

- Average flow conditions represent a mean annual precipitation of 207 mm, a mean annual site runoff of 180 mm and a mean annual evaporation rate of 220 mm.
- A 1:500 wet year event represents a runoff of 335 mm.

Other assumptions remained as before.

Scenario 9 – Effects of High Flow on Intermediate Flow Discharge Strategy

This scenario is the same as Scenario 6, but with a 1 in 500 year wet year in the first year of operation followed by average flow conditions. The following assumptions were adopted:

- Average flow conditions represent a mean annual precipitation of 207 mm, a mean annual site runoff of 180 mm and a mean annual evaporation rate of 220 mm.
- A 1:500 wet year event represents a runoff of 335 mm.

Other assumptions remained as before.

The water quality modeling results are presented and discussed below.

4.3.2 Results and Discussion

The results from the scenarios modelled are provided in Appendix H. The results for each scenario are presented as follows. First, a schematic is presented illustrating the copper loadings at year 2 at the end of operations, when peak concentrations are predicted in Doris Creek and immediately after the spillway is lowered (i.e. post closure conditions). Second, a series of plots are shown for key parameters within Tail Lake, and within Doris Creek downstream of the mixing zone. Third, a summary table is included that show the estimated maximum concentrations for each of Tail Lake, Doris Creek and Little Roberts Lake outflow. This is followed by a table showing concentrations for years 1 to 10, and finally a table showing total loadings at each of these loadings for the first 10 years.

The results are summarised in Table 4.1 and Table 4.2 for Tail Lake and Doris Creek respectively. These tables provide i) the year and maximum concentration reached in Tail Lake for each parameter (except for TDS and associated parameters), and ii) the year and maximum concentration reached in Doris Creek when discharge first commences (again except for TDS and associated parameters).

As reported by AMEC, the tailings water generated from the metallurgical program passed toxicity benchmark tests. The tailings water discharged to Tail Lake will be diluted by water already in Tail Lake and freshwater runoff that will enter the lake subsequent to deposition. It is therefore expected that the water in Tail Lake too will pass toxicity criteria at all times. Modeling results further indicate that the water in Tail Lake should meet MMER criteria at all times. There should therefore be no constraint on discharging water from Tail Lake. However, as discussed later in Section 5, before any discharge commences, Tail Lake water would be submitted for toxicity testing and chemical analysis to ensure that MMER criteria are met.

As shown in Table 4.2, the ‘un managed’ scenarios (Scenarios 1, 2 and 7), where Tail Lake is allowed to reach FSL and then spill naturally, all parameters are likely to meet CCME guidelines in Doris Creek except for nitrite. Nitrite exceedance could occur only in the very unlikely case that there is no oxidation of nitrite, and, even then would only marginally exceed the CCME guideline (maximum concentration of 0.027 mg/L compared to the CCME guideline of 0.018 mg/L).

Considering that the water could be retained in Tail Lake for five or more years before any water would need to be discharged, nitrite is not considered to represent a concern. Furthermore, as discussed before, nitrite is chemically oxidized by oxygen and there is ample evidence that nitrite will oxidize rapidly within the Doris Creek.

The model results presented in Table 4.2 for the managed discharge scenarios also suggest that nitrite concentrations could be problematic (i.e. Scenarios 3 and 4) under the conservative assumptions adopted for these calculations. The predicted maximum nitrite concentrations in Doris Creek for these scenarios range from 0.026 to 0.032 mg/L compared to the CCME guideline of 0.018 mg/L. It should be noted that if these concentrations arise, they would occur only occur for the initial 1 to 2 years of discharge. It is furthermore important to note that no allowance was made for additional nitrite oxidation within the mixing zone in Doris Creek. The waterfall will oxygenate the water resulting in the oxidation of nitrite. (The oxygen demand for such low concentrations of nitrite will be minimal and will not affect dissolved oxygen concentrations in Doris Creek). Generally nitrite is not observed to persist in an aerated natural system, such as in Doris Creek, and the low concentrations would readily be oxidized to nitrate. Therefore, the inferred 'nitrite exceedances' are considered unlikely to occur.

The strategy of not discharging in year 1 of operations (Scenario 4) has the added advantage that the water quality can be characterized for a full year and short term changes can be evaluated well in advance of releasing any water from Tail Lake.

Discharge strategies not only affect the maximum water level that will be reached in Tail Lake, but also the period for which active management will be required. These effects, together with key observations, are summarised in Table 4.3. Key observations include:

- Provided that nitrite does not pose a problem, the shortest time that stable ('walk away') conditions (i.e. requiring no additional water management) can be reached is projected to be about five years, inclusive of the operational period (Scenario 3). In this scenario the water level in Tail Lake will reach a maximum elevation of 29.4 m, in Year 3 and will then decrease until the original lake elevation of 28.3 m is reached in Year 5. The North Dam can then be breached since, to maintain the original water elevation in Tail Lake, the discharge rate would be reduced to the net inflow into Tail Lake. Consequently the breach can be undertaken without any risk to the receiving environment. The copper concentration in Tail Lake is projected to decrease below the CCME guideline by Year 8.
- Not discharging in year 1 (Scenario 4) eliminates the initial potential risk associated with nitrite releases and a stable 'walk away' condition can be reached in a similar timeframe to Scenario 3. However, the maximum water level in Tail Lake increases by about 1 m from 29.4 to 30.4 m.
- The 'balanced effects' discharge strategy (Scenario 5) will minimise concentrations below CCME guidelines in Doris Creek throughout operations and the active water management period. However, the Tail Lake discharge system would have to be operated for up to 12 years when the FSL is reached. Thereafter, the site would need to be monitored annually until about

Year 34, when the copper concentration in Tail Lake is expected to decrease below CCME guidelines. At that time, the North Dam can be breached for final closure.

- The intermediate flow case (Scenario 6), would meet CCME guidelines in Doris Creek at all times. If operated continuously, the FSL of Tail Lake would be reached at about Year 35. However, the copper concentration in Tail Lake should decrease to below the CCME guidelines by about Year 20, and it will be possible to breach the North Dam at that time. Consequently the FSL would not be reached and the maximum elevation would be about 31.9 m.
- Very wet conditions at the beginning of operations (Year 1) generally result in improved water quality in Tail Lake but marginally extend the active water management period as indicated by the results for Scenarios 8 and 9.

4.4 Conclusions and Recommendations

4.4.1 Summary of Results and Conclusions

In summary, the water quality modelling results and discharge scenario evaluations indicate that:

- Water management strategies are available that will not cause exceedance of CCME guidelines in Doris Creek;
- Alternative strategies are also available that may cause marginal exceedances of CCME guidelines in Doris Creek; however, such exceedances would be of short duration and will significantly reduce the requirements (time and management) for active operation; and,
- The range of discharge conditions that remain protective of the receiving environment indicate that there is significant flexibility available to manage Tail Lake water to still meet CCME guidelines in Doris Creek.

The results indicate that adaptive management of the water in Tail Lake is possible. This means that while one strategy might be selected as a preferred strategy, it is not the only strategy that will be protective of the receiving environment. More importantly, if conditions or actual water quality in Tail Lake deviate from those predicted in the water quality modeling, then it will be possible to switch to an alternate strategy that would remain protective of the receiving environment without compromising the tailings deposition and overall water management for the site.

Table 4.1: Summary of estimated maximum concentrations in Tail Lake for average flow conditions (180 mm/year yield)

Parameter	Units	MMER Criteria	CCME Guidelines	Scenario / Maximum Concentration in Tail Lake								
				1	2	3	4	5	6	7	8	9
Year of Occurrence				**Year 2**	**Year 2**	**Year 2**	**Year 2**	**Year 2**	**Year 2**	**Year 2**	**Year 2**	**Year 2**
pH			**6 to 9**	**7 to 8**	**7 to 8**	**7 to 8**	**7 to 8**	**7 to 8**	**7 to 8**	**7 to 8**	**7 to 8**	**7 to 8**
TDS	mg/L			652	652	1583	1377	584	732	646	1296	694
TSS	mg/L	15		4.8	4.8	3.7	3.8	4.4	4.6	5.0	4.7	4.7
Free CN	mg/L		0.0050	0.0060	0.0025	0.0036	0.0025	0.0027	0.0030	0.0052	0.0028	0.0024
Total CN	mg/L	1		0.059	0.025	0.035	0.025	0.026	0.029	0.051	0.027	0.023
WAD CN	mg/L			0.0080	0.0034	0.0048	0.0034	0.0036	0.0040	0.0069	0.0037	0.0032
CNO	mg/L			6.6	2.8	4.0	2.8	3.0	3.3	5.7	3.1	2.6
SCN	mg/L			0.090	0.090	0.118	0.099	0.094	0.101	0.078	0.098	0.086
Sulphate	mg/L			83	83	109	92	87	93	72	90	79
Chloride	mg/L			422	422	1051	947	418	456	419	863	432
Total Ammonia	mg/L		0.97	0.99	1.01	1.31	0.94	1.06	1.15	0.86	1.04	0.93
Nitrate	mg/L		2.9	5.4	5.2	6.8	5.7	5.3	5.8	4.7	5.6	4.9
Nitrite	mg/L		0.02	0.73	0.39	0.53	0.39	0.42	0.45	0.64	0.42	0.37
Alkalinity	mg/L			52	52	64	56	53	56	48	56	51
Phosphate-P	mg/L			0.1537	0.1537	0.2183	0.1953	0.1616	0.1766	0.1361	0.1847	0.1542
Org. Carbon	mg/L			6.4	6.4	4.8	4.7	6.4	6.2	6.6	6.1	6.3
Hardness CaCO3	mg/L			100	100	127	109	104	111	90	109	98
Total Metals												
Aluminium Al	mg/L		0.10	0.15	0.15	0.14	0.13	0.12	0.15	0.16	0.17	0.15
Antimony Sb	mg/L			0.0138	0.0138	0.0194	0.0171	0.0145	0.0158	0.0122	0.0164	0.0138
Arsenic As	mg/L	0.5	0.005	0.054	0.054	0.072	0.063	0.056	0.061	0.047	0.062	0.053
Barium Ba	mg/L			0.0097	0.0097	0.0125	0.0106	0.0101	0.0108	0.0085	0.0106	0.0093
Cadmium Cd	mg/L		0.000038	0.000051	0.000051	0.000066	0.000056	0.000053	0.000057	0.000044	0.000055	0.000048
Calcium Ca	mg/L			225	225	295	248	234	252	194	245	215
Chromium Cr	mg/L		0.0010	0.0060	0.0060	0.0078	0.0066	0.0062	0.0067	0.0052	0.0065	0.0057
Cobalt Co	mg/L			0.0094	0.0094	0.0123	0.0103	0.0098	0.0105	0.0081	0.0102	0.0089
Copper Cu	mg/L	0.3	0.0020	0.009	0.009	0.011	0.009	0.009	0.010	0.007	0.009	0.008
Iron Fe	mg/L		0.30	0.17	0.17	0.15	0.14	0.15	0.18	0.18	0.19	0.18
Lead Pb	mg/L	0.2	0.0020	0.00038	0.00038	0.00047	0.00041	0.00039	0.00040	0.00033	0.00040	0.00036
Lithium Li	mg/L			0.0054	0.0054	0.0055	0.0054	0.0050	0.0049	0.0056	0.0051	0.0049
Magnesium Mg	mg/L			8.8	8.8	10.6	9.3	8.9	9.4	8.1	9.3	8.4
Manganese Mn	mg/L			0.026	0.026	0.034	0.028	0.027	0.029	0.022	0.028	0.025
Mercury Hg	mg/L		0.00010	0.0000116	0.0000116	0.0000107	0.0000107	0.0000095	0.0000117	0.0000124	0.0000132	0.0000116
Molybdenum Mo	mg/L		0.073	0.0081	0.0081	0.0107	0.0090	0.0085	0.0091	0.0070	0.0089	0.0078
Nickel Ni	mg/L	0.5	0.025	0.008	0.008	0.010	0.008	0.008	0.008	0.007	0.008	0.007
Potassium K	mg/L			37	37	49	41	39	42	32	41	36
Selenium Se	mg/L		0.0010	0.00096	0.00096	0.00081	0.00081	0.00084	0.00095	0.00101	0.00102	0.00095
Silver Ag	mg/L		0.00010	0.00011	0.00011	0.00013	0.00012	0.00011	0.00012	0.00011	0.00012	0.00011
Sodium Na	mg/L			117	117	386	293	112	178	116	297	164
Thallium Tl	mg/L		0.00080	0.000041	0.000041	0.000048	0.000042	0.000042	0.000043	0.000040	0.000043	0.000040
Tin Sn	mg/L			0.00209	0.00209	0.00296	0.00262	0.00220	0.00241	0.00186	0.00252	0.00211
Zinc Zn	mg/L	0.5	0.030	0.021	0.021	0.027	0.023	0.022	0.023	0.018	0.023	0.020

Note: Shaded values exceed CCME guidelines for the protection of Freshwater Aquatic Life

Table 4.2: Summary of estimated maximum concentrations in Doris Creek for average flow conditions (180 mm/year yield)

Parameter	Units	MMER	CCME	Scenario / Maximum Concentration in Doris Creek								
		Criteria	Guidelines	1	2	3	4	5	6	7	8	9
Year of Occurrence				Year 9	Year 9	Year 3	Year 3	Year 12	Year 3	Year 8	Year 3	Year 3
pH			6 to 9	7 to 8	7 to 8	7 to 8	7 to 8	7 to 8	7 to 8	7 to 8	7 to 8	7 to 8
TDS	mg/L			172	172	216	227	161	160	172	203	159
TSS	mg/L			7.0	7.0	6.8	7.0	7.0	6.9	7.0	6.9	6.9
Free CN	mg/L		0.0050	0.0002	< DL	0.0002	0.0002	< DL	0.0001	0.0002	0.0002	0.0001
Total CN	mg/L	1		0.004	0.002	0.004	0.004	0.002	0.003	0.004	0.003	0.003
WAD CN	mg/L			0.0002	< DL	0.0003	0.0002	< DL	0.0001	0.0002	0.0002	0.0001
CNO	mg/L			0.19	< DL	0.22	0.20	0.04	0.09	0.19	0.17	0.08
SCN	mg/L			0.003	0.003	0.006	0.007	0.001	0.003	0.003	0.005	0.002
Sulphate	mg/L			5	5	9	9	4	5	5	8	5
Chloride	mg/L			82	82	113	123	75	72	82	104	72
Total Ammonia	mg/L		0.97	0.05	0.02	0.08	0.08	0.02	0.04	0.05	0.07	0.04
Nitrate	mg/L		2.9	0.2	0.1	0.4	0.4	0.1	0.2	0.2	0.3	0.2
Nitrite	mg/L		0.018	0.027	0.003	0.032	0.031	0.007	0.016	0.027	0.026	0.013
Alkalinity	mg/L			28	28	29	29	28	28	28	29	28
Phosphate-P	mg/L			0.0273	0.0273	0.0315	0.0325	0.0255	0.0277	0.0273	0.0309	0.0273
Org. Carbon	mg/L			7.5	7.5	7.3	7.5	7.5	7.5	7.5	7.5	7.5
Hardness CaCO3	mg/L			47	47	50	50	46	47	47	49	47
Total Metals												
Aluminium Al	mg/L		0.10	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Antimony Sb	mg/L			0.0031	0.0031	0.0035	0.0035	0.0030	0.0032	0.0031	0.0034	0.0031
Arsenic As	mg/L	0.5	0.005	0.0022	0.0022	0.0041	0.0043	0.0015	0.0020	0.0022	0.0036	0.0018
Barium Ba	mg/L			0.0033	0.0033	0.0035	0.0035	0.0032	0.0033	0.0033	0.0035	0.0033
Cadmium Cd	mg/L		0.000038	0.000004	0.000004	0.000007	0.000007	0.000004	0.000005	0.000004	0.000006	0.000005
Calcium Ca	mg/L			14	14	24	25	13	15	14	21	14
Chromium Cr	mg/L		0.0010	0.0008	0.0008	0.0010	0.00106	0.0007	0.0008	0.0008	0.0010	0.0008
Cobalt Co	mg/L			0.0011	0.0011	0.0013	0.0014	0.0010	0.0011	0.0011	0.0013	0.0011
Copper Cu	mg/L	0.3	0.0020	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Iron Fe	mg/L		0.30	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Lead Pb	mg/L	0.2	0.0020	0.00007	0.00007	0.00008	0.00008	0.00007	0.00007	0.00007	0.00008	0.00007
Lithium Li	mg/L			0.0029	0.0029	0.0029	0.0030	0.0029	0.0029	0.0030	0.0029	0.0029
Magnesium Mg	mg/L			7.3	7.3	7.5	7.4	7.3	7.4	7.3	7.4	7.3
Manganese Mn	mg/L			0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021
Mercury Hg	mg/L		0.00010	0.0000012	0.0000012	0.0000012	0.0000014	0.0000010	0.0000009	0.0000012	0.0000013	0.0000009
Molybdenum Mo	mg/L		0.073	0.0004	0.0004	0.0007	0.0008	0.0003	0.0004	0.0004	0.0006	0.0004
Nickel Ni	mg/L	0.5	0.025	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Potassium K	mg/L			4	4	5	5	3	4	4	5	4
Selenium Se	mg/L		0.001	0.00090	0.00090	0.00089	0.00090	0.00090	0.00090	0.00090	0.00090	0.00090
Silver Ag	mg/L		0.0001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
Sodium Na	mg/L			43	43	58	57	42	43	43	53	43
Thallium Tl	mg/L		0.00080	0.000031	0.000031	0.000031	0.000031	0.000030	0.000031	0.000031	0.000031	0.000031
Tin Sn	mg/L			0.00046	0.00046	0.00054	0.00056	0.00043	0.00046	0.00045	0.00052	0.00045
Zinc Zn	mg/L	0.5	0.030	0.004	0.004	0.004	0.004	0.003	0.004	0.004	0.004	0.004

Note: Shaded values exceed CCME guidelines for the protection of Freshwater Aquatic Life

Table 4.3: Summary of modelled scenarios to assess average flow conditions

Scenario	Description	Nutrient Degradation	Flow Conditions	Active Discharge Rate	Maximum Water Level	Year at Maximum Elevation	Year of Thaw	Year Cu<CCME in Tail Lake	Year Spillway Lowered	Doris Creek
1	No Intervention	No	Average	-	33.5 m (FSL)	8	8	35	35	May exceed CCME for NO_2 for Year 8 and 9
2	No Intervention with nutrient degradation	Base Case	Average	-	33.5 m (FSL)	8	8	35	35	Meets CCME at all times
3	Minimize Management Period	Base Case	Average	1,000,000 from Year 1	29.3	3	4	8	5	May exceed CCME for NO_2 in years 2 and 3; may be at CCME for Cr*
4	No discharge in Year 1 then minimize management period	Base Case	Average	1,300,000 from Year 2	30.4	2	3	7	5	May Exceed CCME for NO_2 in Year 2 only; may marginally exceed CCME for Cr*
5	Balance initial discharge and spill effects	Base Case	Average	200,000 from Year 1	33.5 m (FSL)	12	12	34	34	Meets CCME at all times
6	Discharge at 50 % of Scenario 3	Base Case	Average	500,000 from year 1	31.9	20	10	20	20	Meets CCME at all times
7	Effect of wet year on Scenario 1	No	Year 1 at 1:500 year wet	-	33.5 m (FSL)	7	7	34	34	May exceed CCME for NO_2 in years 7 and 8
8	Effect of wet year on Scenario 3	Base Case	Year 1 at 1:500 year wet	1,000,000 from Year 1	30.1	3	4	9	7	May exceed CCME for NO_2 in years 2 and 3
9	Effect of wet year on Scenario 6	Base Case	Year 1 at 1:500 year wet	500,000 from year 1	32.3	21	10	21	21	Meets CCME at all times

Note: * May be an artefact of high detection limits used in testing program

4.4.2 Recommendations

As noted, various water management strategies are available that would result in minimal changes of water quality in the receiving environment. For example, all water could be contained in Tail Lake until the FSL is reached. While this strategy would provide ample time to monitor the development of water quality in Tail Lake to verify the predictive modelling results, it would necessitate an extended period of site management. A more appropriate strategy however would be to minimise the onsite presence and operation discharge requirements by maximising discharge volumes. Other benefits for this strategy would include the fact that the FSL of Tail Lake would not be reached, and, as a result the potential effects of permafrost thaw and associated sediment release would be minimised.

It is therefore recommended that a strategy that will minimise the maximum water elevation in Tail Lake and yet be protective of the receiving environment, by meeting CCME guidelines, be adopted. Scenario 3 most closely approximates such a strategy.

The recommended alternative strategy would be to not discharge in Year 1 and then minimise the period of active discharge management by maximising discharge rates. This strategy would provide ample water quality and flow monitoring results in both Tail Lake and in Doris Creek to evaluate rates of changes in water quality over the short-term. These results can then be used to verify the maximum annual discharge rate and to develop battery limits on response times required to changes in flow conditions in Doris Creek to manage discharge rates. Scenario 4 most closely approximates this strategy. As noted before, one of the disadvantages of this strategy is a substantial increase in the maximum operating water level in Tail Lake. This strategy also has an inherently higher risk associated with it. For example, if a ‘wet’ year is experienced in the first year, followed by drought conditions in subsequent years, the lower flow conditions in the following years would severely hamper the discharge strategy. In contrast, the preferred strategy (Scenario 3) would be ‘in step’ with climatic conditions from the start.

The next section presents a series of sensitivity runs that assess potential impacts on the preferred strategy.

4.5 Sensitivity Analysis

Sensitivity runs were completed to assess the effects of a number of conditions and assumptions including:

- Background copper concentrations in Doris Creek
- Low flow conditions
- Nutrient degradation rates
- Sediment loading estimates, and
- Sediment loading control measures (i.e. shoreline erosion protection).

The assumptions adopted for each of the sensitivity runs are summarized in Table 4.4 below. In all cases the sensitivity runs were completed relative to the recommended base case water management strategy (Scenario 3). The results from the sensitivity analyses are provided in Appendix I. In addition to the sensitivity runs shown, the effects of mill upset conditions, as they relate to cyanide treatment, and oxygen demand in Tail Lake water were assessed.

Table 4.4: Summary assumptions adopted for sensitivity runs

Run ID	Description	Assumptions / Conditions			Nutrient Degradation
		Sediment Load	Erosion Control	Runoff Yield	
	Background Copper Concentration				
CuBG1	Copper Conc. Increased by 5 %	Base case	no	180 mm	Base Case
CuBG2	Copper Conc. Increased by 10 %	Base case	no	180 mm	Base Case
CuBG3	Copper Conc. Increased by 20 %	Base case	no	180 mm	Base Case
	Low Runoff Conditions				
LowFlow1	Scenario 1 - No Control	Base Case	no	111 mm	zero
LowFlow2	Scenario 2 - No Control	Base Case	no	111 mm	Base Case
LowFlow3	Scenario 3	Base Case	no	111 mm	Base Case
	Nutrient Degradation Rates				
Degrad1	Scenario 3	Base case	no	180 mm	None
Degrad2	Scenario 3	Base case	no	180 mm	Enhanced
	Sediment Loadings				
SedLoad1	Scenario 3	Upper Limit	no	180 mm	Base Case
SedLoad2	Scenario 3 - Low Flow	Upper Limit	no	111 mm	Base Case
	Sediment Control				
SedCont1	Cover 20 % of Area to 29.4 m (50 %)	Upper Limit	20%-29.4	180 mm	Base Case
SedCont2	Cover 60 % of Area to 29.4 m (80 %)	Upper Limit	60%-29.4	180 mm	Base Case
SedCont3	Cover 100 % of Area to 29.4 m (90 %)	Upper Limit	100%-29.4	180 mm	Base Case
SedCont4	Cover 100 % of Area to 33.5 m (FSL) (90%)	Upper Limit	100 % FSL	180 mm	Base Case

4.5.1 Background Copper Concentrations in Doris Creek

To assess the effects of changes of copper concentrations in the background water quality (in Doris Creek) on the discharge scenarios, it is necessary to first understand how the discharge volumes estimates were derived. Therefore, in this section, the use of the background water quality and runoff hydrograph to estimate the monthly discharge rates is discussed first. The effects of changes in background water quality are then examined.

As previously discussed in Section 3.3.2, the maximum background copper concentration observed in any month is used as input to the model. It is furthermore important to note that the calculations to determine the maximum possible discharge for any given scenario distributes the discharge flow at a fixed ratio according to the hydrograph in Doris Creek. That is to say, because the maximum background copper concentration is detected in July, the flow determined in that month limits the discharge rates in all the other months. This is more readily explained by example as shown in Table 4.5. The table shows the monthly flows, the flow distribution and the measured background water quality in Doris Creek. For simplicity, in this example the copper concentration in Tail Lake was fixed at 10 µg/L. (In the model the copper concentration varies from month to month due to changes in inflows and discharges.)

The maximum possible discharge for each month is determined by calculating the volume of water that could be released to increase the copper concentration in Doris Creek, for the combined creek and discharge flow, to 2 µg/L. The monthly estimated maximum discharge is then compared to the flow in Doris Creek. The lowest ratio represents the maximum allowable monthly ratio that is then adopted and the discharge rates are recalculated to correspond to this value. In the example given in the table, the lowest ratio (5.9%) occurs for July. The column next to the discharge ratio shows the monthly discharge flows corrected to the Doris Creek hydrograph, i.e. the corrected discharge flows all are equal to 5.9% of the flow in Doris Creek for the corresponding month. As shown, the corrected discharge for the year of about 986,000 m^3 that results from this approach is substantially less than the total maximum possible discharge of about 1,307,000 m^3.

The last column in the table shows the estimated copper profile downstream of the discharge. As shown, copper concentration would equal the CCME guideline only for the month of July. Concentrations in September and October may also approach the CCME guideline. The net result of this approach is that the period of peak effects in Doris Creek is further constrained; conversely, the total annual discharge volume is underestimated by about 30%.

Table 4.5: Example calculation to illustrate maximum discharge volume estimations

Month	Doris Creek Flow m^3/month	Doris Creek Distrib.	Doris Creek Cu µg/L	Tail Lake Cu Conc. µg/L	Maximum* Discharge possible m^3/month	Discharge to Doris Ck Flow Ratio (%)	Discharge Corrected to Doris Ck m^3/month	Copper Conc. in Doris Ck µg/L
June	7,200,000	43%	1.20	10	720,000	10.0%	423,000	1.63
July	4,464,000	27%	1.53	10	262,000	5.9%	262,000	2.00
August	1,891,000	11%	1.26	10	174,000	9.2%	111,000	1.69
September	2,400,000	14%	1.50	10	151,000	6.3%	141,000	1.96
October	837,000	5%	1.50	10	53,000	6.3%	49,000	1.96
Total	16,792,000	100%	-	-	1,307,000	-	986,000	-

Note: *Maximum discharge would result in a steady copper concentration of 2 µg/L for each month

On average, as shown by the example, the effect of the discharge calculation is that the maximum increase in total copper concentration in Doris Creek will be 0.47 µg/L, and more often would be less than this value. On this basis, the effects of increased background levels on the maximum copper concentrations in the Doris Creek can be demonstrated for maintaining the discharge rates determined for Scenario 3 (Minimum Management Period, Average Flows) as shown in Table 4.6.

The results indicate that a 20 percent increase in the background copper concentration will result in a peak copper concentration in Doris Creek of about 2.23 µg/L. It should be noted that the copper concentration would exceed the CCME guideline in July, September and October, but not in June and August, given the current background water quality profile. Also, the exceedances would occur only over a period of about 3 years as shown in Figure 4.1.

Table 4.6: Effect of background increases on copper concentrations in Doris Creek

Increase in Background Copper Concentration (%)	Maximum Copper Concentration in Background (μg/L)	Maximum Copper Concentration in Doris Creek (μg/L)
Base Case	1.53	2.00
5	1.61	2.02
10	1.68	2.09
20	1.84	2.23

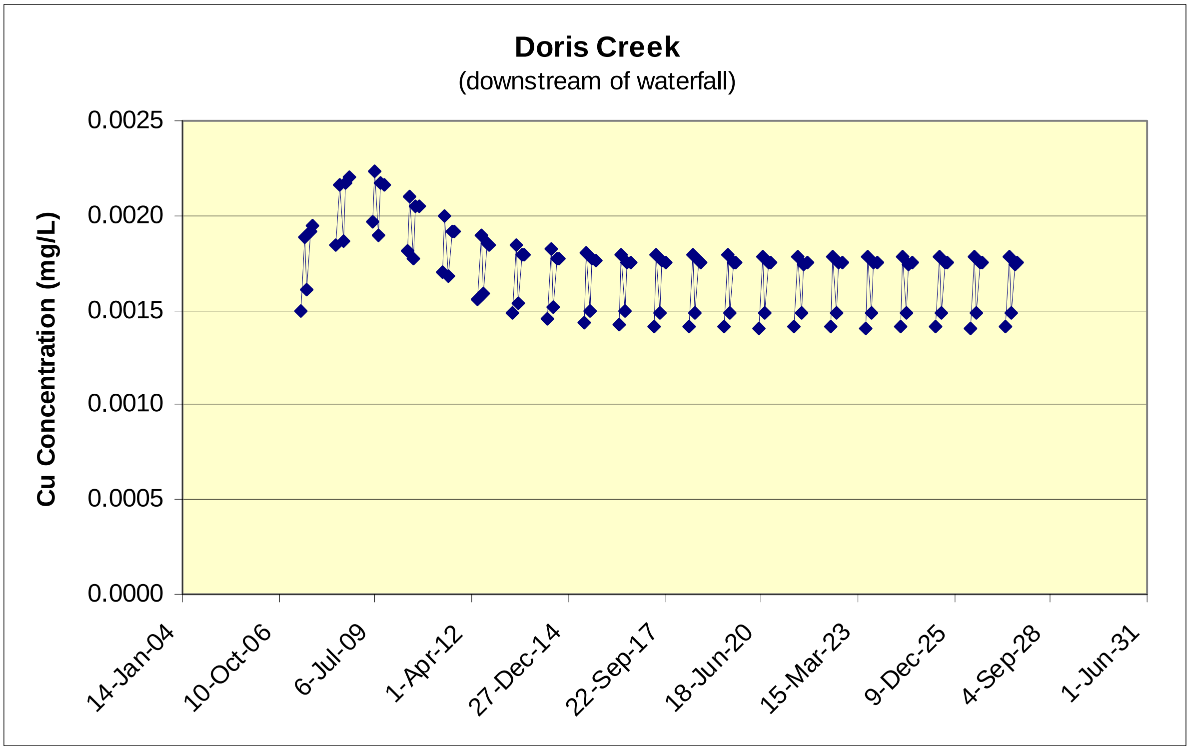

Figure 4.1: Effect of a 20 % increase in background concentrations on copper concentrations in Doris Creek downstream of the discharge point (discharge at 1,000,000 m^3/year as for Scenario 3 – average flow conditions)

Conversely, the effect of background copper concentration increases on the allowable discharge rate has been determined and are summarised in Table 4.7. The table also shows the resultant maximum water level in Tail Lake should the increase in background water quality stay in effect indefinitely. The results indicate a decrease in the maximum allowable discharge proportional to the increase in the background copper concentrations in Doris Creek. For example a 10 percent increase in the background copper concentration in Doris Creek would require a reduction of the annual discharge volume from 1,000,000 m^3 to about 750,000 m^3 to maintain copper concentrations in Doris Creek at or below the CCME guideline. This would cause an increase in the maximum water level by about 0.6 m to about 29.9 m. However, as discussed before, the calculation method underestimates the actual allowable discharge volume by about 30%, and it may be possible to still maintain discharge rates at close to the target annual volume. For a 10% increase in the background concentration the operational discharge period could be extended to about 12 years with the given discharge rate of 750,000 m^3 per year.

Table 4.7: Effect of background copper increases on maximum discharge rates to CCME in Doris Creek

Increase in Background Copper Concentration (%)	Maximum Copper Concentration in Background (µg/L)	Maximum Discharge Rate to meet CCME for Cu in Doris Creek (m^3/year)	Max. Elevation in Tail Lake (m)	Year of Maximum Water Level	Year when Cu < CCME in Tail Lake	Year when Spillway can be lowered to Original Lake Elevation
Base Case	1.53	1,000,000	29.3	3	8	5
5	1.61	900,000	29.5	3	9	6
10	1.68	750,000	29.9	3	13	12
20	1.84	400,000	33.5	25	25	25

4.5.2 Low Flow Conditions

The results from the sensitivity runs completed to assess effects of low flows on the potential discharge strategies are provided in Appendix I and are summarised in Table 4.8 and Table 4.9. As before, these tables summarise the maximum concentrations predicted respectively in Tail Lake and Doris Creek. Table 4.10 provides a summary of all the low flow scenarios modelled.

As would be expected, the time to discharge is significantly longer for the scenarios where Tail Lake is allowed to fill to the FSL. The time to discharge would increase from about 8 years to about 13 years.

The results further indicate that low flow conditions (111 mm yield) would result in a marginal increase in the estimated maximum concentrations for all solutes in Tail Lake for Scenarios 1 and 2. However, since the dilution within Tail Lake does not change between the low and base flow conditions, the outcome after Tail Lake overflows is the same irrespective of the flow conditions.

For Scenario 3, however, the lower flows in Doris Creek, at the low yield, prevent discharging at the elevated discharge rate possible for the base case. Rather, the maximum possible discharge is only 550,000 m^3 per year. At this lower discharge rate, adjusted to suit the low flow conditions, it is possible to continue to meet CCME guidelines in Doris Creek. As for the base flow conditions, the volume in Tail Lake will be drawn down to the original lake level before the FSL is reached. The period of active discharge, however, would be extended by about 1 year.

It is apparent from these results that the discharge strategies can be tailored to actual site conditions to still meet CCME guidelines in Doris Creek.

Table 4.8: Summary of estimated maximum concentrations in Tail Lake for low flow conditions (111 mm/year yield)

Tail Lake	Units	MMER	CCME	Base Case (180 mm)			Low Flow Conditions (111 mm)		
Parameter		Criteria	Guidelines	1	2	3	1a	2a	3a
Year of Occurrence				Year 2	Year 2	Year 2	Year 2	Year 2	Year 2
pH			6 to 9	7 to 8	7 to 8	7 to 8	7 to 8	7 to 8	7 to 8
TDS	mg/L			652	652	1583	736	736	1427
TSS	mg/L	15		4.8	4.8	3.7	4.7	4.7	5.1
Free CN	mg/L		0.0050	0.0060	0.0025	0.0036	0.0067	0.0028	0.0033
Total CN	mg/L	1		0.059	0.025	0.035	0.066	0.027	0.032
WAD CN	mg/L			0.0080	0.0034	0.0048	0.0090	0.0037	0.0044
CNO	mg/L			6.6	2.8	4.0	7.4	3.0	3.7
SCN	mg/L			0.090	0.090	0.118	0.101	0.101	0.119
Sulphate	mg/L			83	83	109	93	93	109
Chloride	mg/L			422	422	1051	484	484	968
Total Ammonia	mg/L		0.97	0.99	1.01	1.31	1.12	1.09	1.26
Nitrate	mg/L		2.9	5.4	5.2	6.8	6.1	6.0	7.0
Nitrite	mg/L		0.02	0.73	0.39	0.53	0.85	0.42	0.49
Alkalinity	mg/L			52	52	64	55	55	62
Phosphate-P	mg/L			0.15	0.15	0.22	0.18	0.18	0.22
Org. Carbon	mg/L			6.4	6.4	4.8	5.7	5.7	5.4
Hardness CaCO3	mg/L			100	100	127	108	108	124
Total Metals									
Aluminium Al	mg/L		0.10	0.15	0.15	0.14	0.16	0.16	0.22
Antimony Sb	mg/L			0.0138	0.0138	0.0194	0.0160	0.0160	0.0197
Arsenic As	mg/L	0.5	0.005	0.054	0.054	0.072	0.063	0.063	0.073
Barium Ba	mg/L			0.0097	0.0097	0.0125	0.0107	0.0107	0.0124
Cadmium Cd	mg/L		0.000038	0.000051	0.000051	0.000066	0.000057	0.000057	0.000066
Calcium Ca	mg/L			225	225	295	252	252	296
Chromium Cr	mg/L		0.0010	0.0060	0.0060	0.0078	0.0067	0.0067	0.0078
Cobalt Co	mg/L			0.0094	0.0094	0.0123	0.0106	0.0106	0.0124
Copper Cu	mg/L	0.3	0.0020	0.009	0.009	0.011	0.010	0.010	0.011
Iron Fe	mg/L		0.30	0.17	0.17	0.15	0.18	0.18	0.24
Lead Pb	mg/L	0.2	0.0020	0.00038	0.00038	0.00047	0.00042	0.00042	0.00049
Lithium Li	mg/L			0.0054	0.0054	0.0055	0.0056	0.0056	0.0059
Magnesium Mg	mg/L			8.8	8.8	10.6	9.2	9.2	10.3
Manganese Mn	mg/L			0.026	0.026	0.034	0.029	0.029	0.034
Mercury Hg	mg/L		0.00010	0.0000116	0.0000116	0.0000107	0.0000133	0.0000133	0.0000178
Molybdenum Mo	mg/L		0.073	0.0081	0.0081	0.0107	0.0092	0.0092	0.0107
Nickel Ni	mg/L	0.5	0.025	0.008	0.008	0.010	0.008	0.008	0.010
Potassium K	mg/L			37	37	49	42	42	49
Selenium Se	mg/L		0.0010	0.00096	0.00096	0.00081	0.0010	0.0010	0.0012
Silver Ag	mg/L		0.00010	0.00011	0.00011	0.00013	0.00012	0.00012	0.00013
Sodium Na	mg/L			117	117	386	132	132	301
Thallium Tl	mg/L		0.00080	0.000041	0.000041	0.000048	0.000042	0.000042	0.000046
Tin Sn	mg/L			0.00209	0.00209	0.00296	0.00241	0.00241	0.00297
Zinc Zn	mg/L	0.5	0.030	0.021	0.021	0.027	0.023	0.023	0.027

Note: Shaded values above CCME guidelines

Table 4.9: Summary of estimated maximum concentrations in Doris Creek for low flow conditions (111 mm/year yield)

Doris Creek	Units	MMER	CCME	Base Case			Low Flow Conditions		
Parameter		**Criteria**	**Guidelines**	**1**	**2**	**3**	**1a**	**2a**	**3a**
Year of Occurrence				**Year 9**	**Year 9**	**Year 2**	**Year 15**	**Year 15**	**Year 3**
pH			**6 to 9**	**7 to 8**	**7 to 8**	**7 to 8**	**7 to 8**	**7 to 8**	**7 to 8**
TDS	mg/L			172	172	216	183	183	203
TSS	mg/L			7.0	7.0	6.8	7.0	7.0	6.9
Free CN	mg/L		0.0050	0.0002	0.0000	0.0002	0.0002	0.0000	0.0002
Total CN	mg/L	1		0.004	0.002	0.004	0.004	0.002	0.004
WAD CN	mg/L			0.0002	< DL	0.0003	0.0003	< DL	0.0002
CNO	mg/L			0.19	0.00	0.22	0.27	0.00	0.19
SCN	mg/L			0.003	0.003	0.006	0.004	0.004	0.006
Sulphate	mg/L			5	5	9	6	6	8
Chloride	mg/L			82	82	113	91	91	105
Total Ammonia	mg/L		0.97	0.05	0.02	0.08	0.06	0.02	0.08
Nitrate	mg/L		2.9	0.2	0.1	0.4	0.3	0.1	0.4
Nitrite	mg/L		0.018	0.027	0.003	0.032	0.038	0.003	0.028
Alkalinity	mg/L			28	28	29	28	28	29
Phosphate-P	mg/L			0.0273	0.0273	0.0315	0.0260	0.0260	0.0324
Org. Carbon	mg/L			7.5	7.5	7.3	7.5	7.5	7.4
Hardness CaCO3	mg/L			47	47	50	47	47	49
Total Metals									
Aluminium Al	mg/L		0.10	0.08	0.08	0.08	0.08	0.08	0.09
Antimony Sb	mg/L			0.0031	0.0031	0.0035	0.0029	0.0029	0.0036
Arsenic As	mg/L	0.5	0.005	0.0022	0.0022	0.0024	0.0022	0.0022	0.0024
Barium Ba	mg/L			0.0033	0.0033	0.0035	0.0033	0.0033	0.0036
Cadmium Cd	mg/L		0.000038	0.000004	0.000004	0.000007	0.000005	0.000005	0.000007
Calcium Ca	mg/L			14	14	24	17	17	23
Chromium Cr	mg/L		0.0010	0.0008	0.0008	0.0010	0.00078	0.0008	0.0010
Cobalt Co	mg/L			0.0011	0.0011	0.0013	0.0009	0.0009	0.0014
Copper Cu	mg/L	0.3	0.0020	0.002	0.002	0.002	0.002	0.002	0.002
Iron Fe	mg/L		0.30	0.13	0.13	0.13	0.13	0.13	0.13
Lead Pb	mg/L	0.2	0.0020	0.00007	0.00007	0.00008	0.00007	0.00007	0.00009
Lithium Li	mg/L			0.0029	0.0029	0.0029	0.0030	0.0030	0.0030
Magnesium Mg	mg/L			7.3	7.3	7.5	7.4	7.4	7.4
Manganese Mn	mg/L			0.021	0.021	0.021	0.021	0.021	0.021
Mercury Hg	mg/L		0.00010	0.0000012	0.0000012	0.0000012	0.0000016	0.0000016	0.0000015
Molybdenum Mo	mg/L		0.073	0.0004	0.0004	0.0007	0.0005	0.0005	0.0007
Nickel Ni	mg/L	0.5	0.025	0.001	0.001	0.001	0.001	0.001	0.001
Potassium K	mg/L			4	4	5	4	4	5
Selenium Se	mg/L		0.001	0.00090	0.00090	0.00089	0.00090	0.00090	0.00091
Silver Ag	mg/L		0.0001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
Sodium Na	mg/L			43	43	58	43	43	52
Thallium Tl	mg/L		0.00080	0.000031	0.000031	0.000031	0.000031	0.000031	0.000031
Tin Sn	mg/L			0.00046	0.00046	0.00054	0.00048	0.00048	0.00053
Zinc Zn	mg/L	0.5	0.030	0.004	0.004	0.004	0.004	0.004	0.004

Note: Shaded values above CCME guidelines

Table 4.10: Summary of modelled scenarios for low flow conditions

Scenario	Description	Nutrient Degradation	Flow Conditions	Active Discharge Rate	Maximum Water Level	Year at Maximum Elevation	Year of Thaw	Year Cu < CCME in Tail Lake	Year Spill Way Lowered	Doris Creek
1	No Intervention	None	180	-	33.5 m (FSL)	8	8	35	35	May exceed CCME for NO_2 for Year 8 and 9 (unlikely)
2	No Intervention with nutrient degradation	Base Case	180	-	33.5 m (FSL)	8	8	35	35	Meets CCME at all times
3	Minimize Management Period	Base Case	180	1,000,000 from Year 1	29.3	3	4	8	5	May exceed CCME for NO_2 in years 2 and 3
1a	No Intervention	None	111	-	33.5 (FSL)	13	10	41	41	May exceed CCME for NO_2 for Year 13 and 14 (highly unlikely)
2a	No Intervention with nutrient degradation	Base Case	111	-	33.5 (FSL)	13	10	41	41	Meets CCME at all times
3a	Minimize Management Period	Base Case	111	550,000 from year 1	29.8	3	4	14	9	May exceed CCME for NO_2 in years 2 and 3

4.5.3 Nutrient Degradation Rates

The effect of cyanide compound and nutrient degradation rates on nutrient concentrations in Tail Lake and in Doris Creek were assessed for the preferred discharge strategy (Scenario 3), at base case conditions, to assess the effects of no degradation and enhanced degradation rates. The results for Tail Lake are illustrated in Figure 4.2. The corresponding results for Doris Creek are shown in Figure 4.3. Table 4.11 provides a summary of the estimated maximum concentrations.

The results for Tail Lake indicate that degradation rates mainly affect the cyanate and nitrate concentrations. The highest cyanate concentrations would result in the absence of any degradation, whereas the base case estimates result in the highest nitrate concentration. Maximum ammonia-N concentration estimates are similar irrespective of the degradation rate.

The results further indicate that degradation rates have little effect on nutrient concentrations in Doris Creek. In all cases, CCME guidelines would be met except for nitrite. As discussed before, rate of nitrite oxidation in Doris Creek has not been included in the calculations.

Table 4.11: Summary of estimated effects of degradation rates on nutrient concentrations (maximum concentrations)

Parameter	Units	MMER	CCME	Tail Lake			Doris Creek		
				Base Case	None	Enhanced	Base Case	None	Enhanced
				Year 2	Year 2	Year 2	Year 3	Year 3	Year 3
Free CN	mg/L		0.005	0.0036	0.0079	0.0036	0.00020	0.00043	0.00020
Total CN	mg/L	1.0		0.035	0.077	0.035	0.0038	0.0061	0.0038
WAD CN	mg/L			0.0048	0.0105	0.0048	0.0003	0.0006	0.0003
CNO	mg/L			4.0	8.7	4.0	0.22	0.47	0.22
SCN	mg/L			0.118	0.118	0.118	0.006	0.006	0.006
Total Ammonia	mg/L		0.97	1.31	1.27	1.31	0.084	0.078	0.084
Nitrate	mg/L		2.9	6.8	7.0	3.6	0.39	0.41	0.20
Nitrite	mg/L		0.018	0.53	0.95	0.40	0.032	0.055	0.025

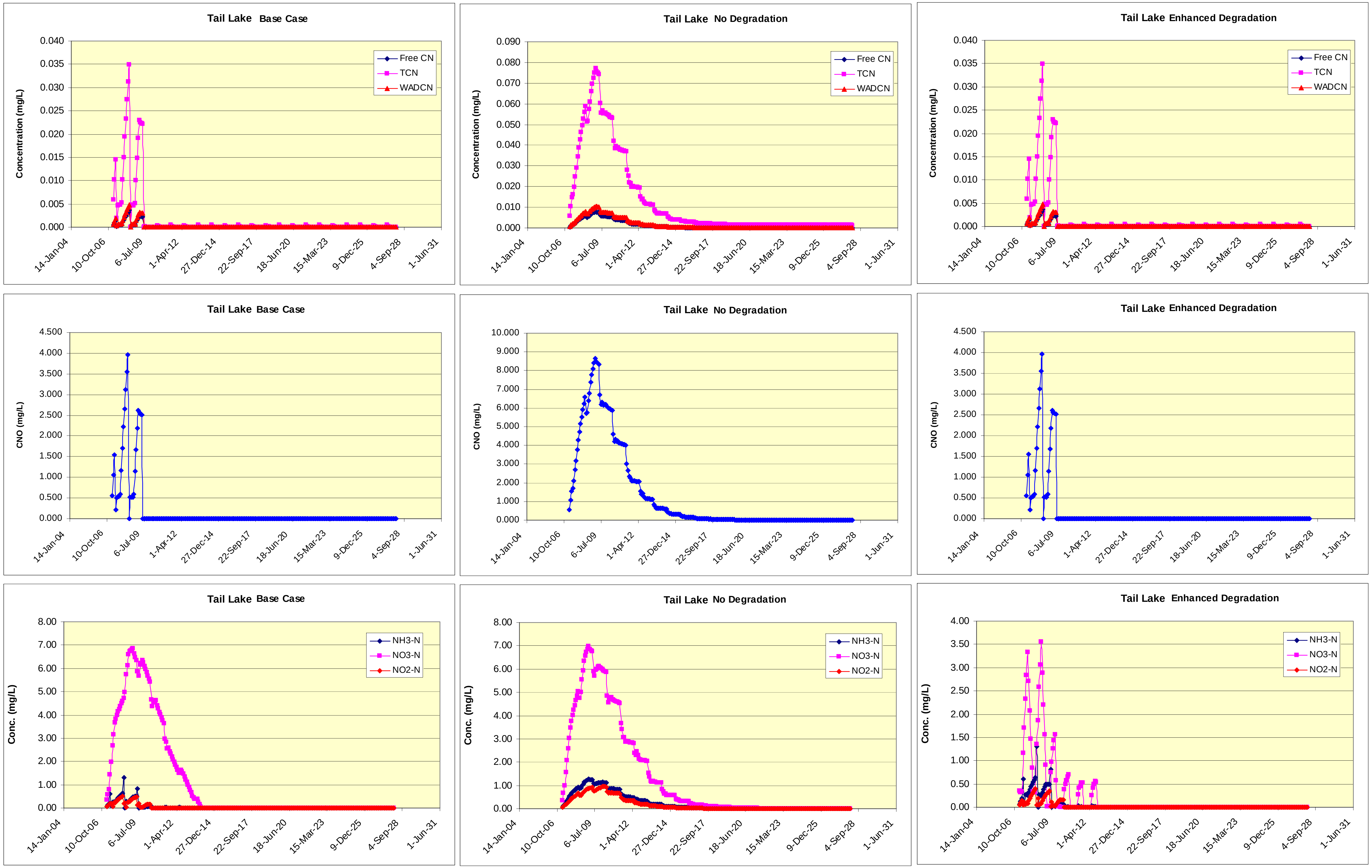

Figure 4.2: Effect of degradation rates on nutrient concentrations in Tail Lake

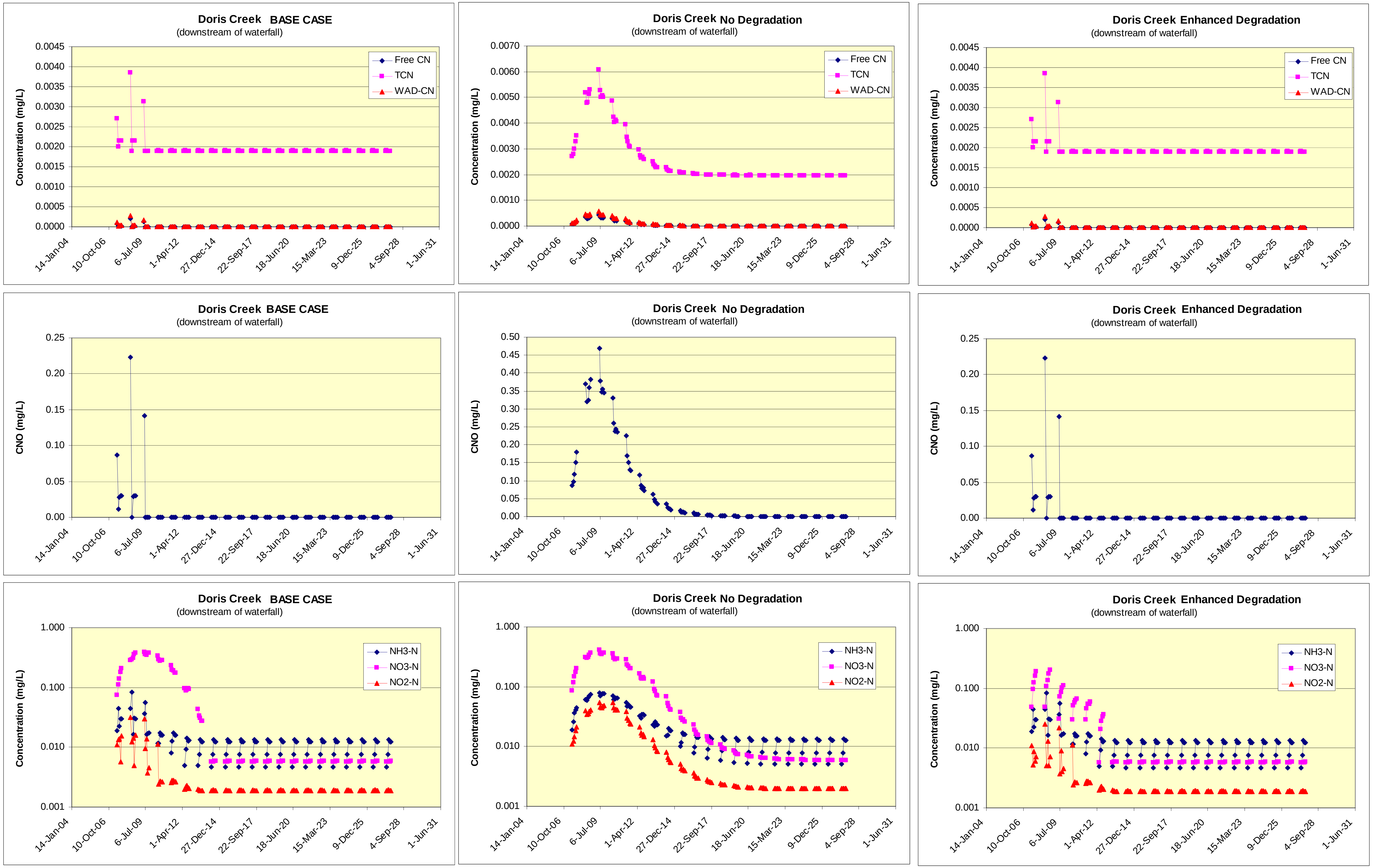

Figure 4.3: Effect of degradation rates on nutrient concentrations in Doris Creek

4.5.4 Sediment Loadings

The effects of sediment loadings that may result from erosion and re-suspension, without any control measures, are summarised in Table 4.12. Time series plots for select parameters are provided in Appendix I as before.

As shown in the table, total suspended concentrations in Tail Lake are predicted to increase to about 5.8 mg/L for the base case at the upper limit of solids loadings, and to about 8.5 mg/L for low flow conditions. These peak concentrations are predicted to occur in about 9 to 10 years from commencement of operations, or about 5 years from when the erosion first begins. The calculations assume that the sediment loadings will remain constant indefinitely after inception.

In addition to total suspended solids concentrations, the increased sediment loadings most significantly contribute to aluminium, iron, mercury and selenium concentrations in Tail Lake. It is important to note that the sediment loadings do not contribute significantly to the cadmium, chromium, copper and silver concentrations in Tail Lake, and that the peak concentrations relate to the short term operational conditions only. (Time series plots are provided for key parameters in Appendix I.)

Assuming that sediment loadings persist at the estimated upper limit indefinitely, then CCME guidelines for aluminium, iron and selenium would be exceeded in Tail Lake in the longer term. (In the base case (Scenario 3) only aluminium could exceed CCME guidelines.) However, for the base case flow conditions (i.e. yield of 180 mm) none of these parameters would exceed CCME in Doris Creek downstream of the waterfall. For the low flow conditions (i.e. yield of 111 mm) only aluminium is predicted to marginally (by about 2 %) exceed CCME guidelines in Doris Creek sporadically. Chromium would be at about its CCME guideline; however, as noted before, elevated detection limits used in the testing program likely are causing overestimation of chromium concentrations. The increased sediment loadings have negligible effect on the estimated chromium concentrations.

It should be noted that the annual sediment loading in Tail Lake ranges between 1,071,255 and 7,601,115 kg/year (Table 3.7). Assuming this load spreads out and settles evenly over the entire surface area of Tail Lake at the steady state flow-though elevation of 28.3 m (i.e. 76.6 ha), this would result in a sediment build-up of between 0.5 and 3.8 mm/year (assuming soil dry density of 2,600 kg/m^3). If the assumption is made that the sediments will only settle out on the tailings surface (i.e. a surface area of 19.1 ha based on the final tailings elevation of 24.3 m), the annual build-up of sediments is between 2.2 and 15.3 mm/year. These numbers are small enough that any sediment-build-up does not need to be accounted for in the model.

The results suggest that while the water quality in Tail Lake may deteriorate from sediment loadings at the estimated upper limit, water quality in Doris Creek is likely to be maintained within CCME guidelines by the proposed water management strategy, without the need for additional erosion control measures. Erosion control measures may however improve the water quality in Tail Lake. The effect of erosion controls on water quality in Tail Lake is examined in the next section.

4.5.5 Sediment Loading Control Measures

The results for the sensitivity runs completed on the erosion control measures are summarised in Table 4.13 for Tail Lake, and in Table 4.14 for Doris Creek. All of the sensitivity runs were completed for the upper limit sediment load estimates. As noted earlier in Table 4.4, four cases were evaluated, ranging from covering 20 % of the area identified as potentially susceptible to erosion, to 100 % coverage to the FSL.

Table 4.12: Summary of upper limit sediment loading effects on Tail Lake and Doris Creek water quality

Parameter	Units	MMER	CCME	Tail Lake			Doris Creek		
		Criteria	Guidelines	Scenario 3	SedLoad1	SedLoad2	Scenario 3	SedLoad1	SedLoad2
Sediment Load				**Base case**	**Upper Limit**	**Upper Limit**	**Base case**	**Upper Limit**	**Upper Limit**
Flow Yield	mm			180	180	111	180	180	111
Discharge	m3/year			1,000,000	1,000,000	550,000	1,000,000	1,000,000	550,000
Year of Peak				Year 2 / 9*	Year 2 / 9*	Year 2 / 10*	Year 2 / 9*	Year 2 / 9*	Year 2 / 10*
pH			6 to 9	7 to 8	7 to 8	7 to 8	7 to 8	7 to 8	7 to 8
TDS	mg/L			1583	1583	1427	216	216	203
TSS	mg/L	15		3.7	5.8	8.5	6.8	6.9	7.1
Sulphate	mg/L			109	109	109	9	9	8
Chloride	mg/L			1051	1075	987	113	114	106
Total Ammonia	mg/L		0.97	1.31	1.31	1.26	0.08	0.08	0.08
Nitrate	mg/L		2.9	6.8	6.8	7.0	0.4	0.4	0.4
Nitrite	mg/L		0.02	0.53	0.53	0.49	0.03	0.03	0.03
Alkalinity	mg/L			64	64	62	29	29	29
Phosphate-P	mg/L			0.22	0.22	0.22	0.03	0.03	0.03
Org. Carbon	mg/L			4.8	4.8	5.4	7.3	7.3	7.4
Hardness CaCO3	mg/L			127	127	124	50	50	49
Aluminium Al	mg/L		0.10	0.14	0.32	0.54	0.083	0.093	0.102
Antimony Sb	mg/L			0.0194	0.0194	0.0197	0.0035	0.0035	0.0036
Arsenic As	mg/L	0.5	0.005	0.0033	0.0033	0.0033	0.0006	0.0006	0.0006
Barium Ba	mg/L			0.0125	0.0125	0.0124	0.0035	0.0035	0.0036
Cadmium Cd	mg/L		0.000038	0.000066	0.000066	0.000066	0.000007	0.000007	0.000007
Calcium Ca	mg/L			295	295	296	24	24	23
Chromium Cr	mg/L		0.0010	0.0078	0.0078	0.0078	0.0010	0.0010	0.0010
Cobalt Co	mg/L			0.0123	0.0123	0.0124	0.0013	0.0013	0.0014
Copper Cu	mg/L	0.3	0.0020	0.011	0.011	0.011	0.002	0.002	0.002
Iron Fe	mg/L		0.30	0.15	0.33	0.54	0.13	0.14	0.14
Lead Pb	mg/L	0.2	0.0020	0.00047	0.00047	0.00049	0.00008	0.00008	0.00009
Lithium Li	mg/L			0.0055	0.0060	0.0084	0.0029	0.0030	0.0031
Magnesium Mg	mg/L			10.6	10.6	12.5	7.5	7.5	7.5
Manganese Mn	mg/L			0.034	0.034	0.034	0.021	0.021	0.021
Mercury Hg	mg/L		0.00010	0.000011	0.000025	0.000042	0.0000012	0.0000020	0.0000027
Molybdenum Mo	mg/L		0.073	0.0107	0.0107	0.0107	0.0007	0.0007	0.0007
Nickel Ni	mg/L	0.5	0.025	0.010	0.010	0.010	0.001	0.001	0.001
Potassium K	mg/L			49	49	49	5	5	5
Selenium Se	mg/L		0.0010	0.00081	0.0015	0.0024	0.00089	0.00092	0.00096
Silver Ag	mg/L		0.00010	0.00013	0.00013	0.00014	0.00001	0.00001	0.00001
Sodium Na	mg/L			386	401	312	58	58	53
Thallium Tl	mg/L		0.00080	0.000048	0.000048	0.000047	0.000031	0.000031	0.000031
Tin Sn	mg/L			0.00296	0.00296	0.00297	0.00054	0.00054	0.00053
Zinc Zn	mg/L	0.5	0.030	0.027	0.027	0.027	0.004	0.004	0.004

Note: *Operationally related parameters peak early whereas erosion related parameters peak later on.

Table 4.13: Summary of erosion control measures on water quality in Tail Lake

Parameter	Units	MMER	CCME	Base Case Scenarios		Sensitivity Runs			
		Criteria	Guidelines	Scenario 3	SedLoad1	SedCont1	SedCont2	SedCont3	SedCont4
Sediment Loading				**Base Case**	**Upper Limit**	**Upper Limit**	**Upper Limit**	**Upper Limit**	**Upper Limit**
Measure				**none**	**none**	**20 % to 29.4 m**	**60 % to 29.4 m**	**100 % to 29.4 m**	**100 % to FSL**
Efficiency	%			-	-	50	80	90	90
TDS	mg/L			1583	1583	1583	1583	1583	1583
TSS	mg/L	15		3.7	5.8	3.3	3.1	3.1	3.1
Sulphate	mg/L			109	109	109	109	109	110
Chloride	mg/L			1051	1075	1043	1038	1036	1036
Total Ammonia	mg/L		0.97	1.31	1.31	1.31	1.32	1.33	1.38
Nitrate	mg/L		2.9	6.8	6.8	6.9	7.2	7.4	9.3
Nitrite	mg/L		0.02	0.526	0.526	0.526	0.526	0.526	0.527
Alkalinity	mg/L			64	64	64	64	64	64
Phosphate-P	mg/L			0.22	0.22	0.22	0.22	0.22	0.22
Org. Carbon	mg/L			4.8	4.8	4.8	4.8	4.8	4.8
Hardness CaCO3	mg/L			127	127	127	127	127	127
Total Metals									
Aluminium Al	mg/L		0.10	0.14	0.32	0.086	0.064	0.063	0.088
Antimony Sb	mg/L			0.0194	0.0194	0.0194	0.0194	0.0194	0.0195
Arsenic As	mg/L	0.5	0.005	0.0033	0.0033	0.0033	0.0033	0.0034	0.0037
Barium Ba	mg/L			0.0125	0.0125	0.0125	0.0125	0.0125	0.0125
Cadmium Cd	mg/L		0.000038	0.000066	0.000066	0.000067	0.000069	0.000072	0.000087
Calcium Ca	mg/L			295	295	295	295	295	296
Chromium Cr	mg/L		0.0010	0.0078	0.0078	0.0078	0.0078	0.0078	0.0079
Cobalt Co	mg/L			0.0123	0.0123	0.0123	0.0123	0.0123	0.0124
Copper Cu	mg/L	0.3	0.0020	0.011	0.011	0.011	0.011	0.011	0.011
Iron Fe	mg/L		0.30	0.15	0.33	0.09	0.07	0.06	0.07
Lead Pb	mg/L	0.2	0.0020	0.00047	0.00047	0.00047	0.00048	0.00049	0.00057
Lithium Li	mg/L			0.0055	0.0060	0.0055	0.0055	0.0055	0.0055
Magnesium Mg	mg/L			10.6	10.6	10.6	10.7	10.7	10.7
Manganese Mn	mg/L			0.034	0.034	0.034	0.034	0.034	0.034
Mercury Hg	mg/L		0.00010	0.0000107	0.000025	0.0000069	0.0000070	0.0000072	0.0000085
Molybdenum Mo	mg/L		0.073	0.0107	0.0107	0.0107	0.0107	0.0107	0.0107
Nickel Ni	mg/L	0.5	0.025	0.010	0.010	0.010	0.010	0.010	0.010
Phosphorus P	mg/L			0.305	0.305	0.306	0.308	0.309	0.323
Potassium K	mg/L			49	49	49	49	49	49
Selenium Se	mg/L		0.0010	0.00081	0.0015	0.00062	0.00056	0.00055	0.00067
Silver Ag	mg/L		0.00010	0.00013	0.00013	0.00013	0.00013	0.00014	0.00017
Strontium Sr	mg/L			0.104	0.104	0.104	0.104	0.104	0.104
Thallium Tl	mg/L		0.00080	0.000048	0.000048	0.000048	0.000049	0.000050	0.000058
Tin Sn	mg/L			0.00296	0.00296	0.00297	0.00298	0.00299	0.00308
Zinc Zn	mg/L	0.5	0.030	0.027	0.027	0.027	0.027	0.027	0.028

Note: Shaded values above CCME guidelines for the protection of Freshwater Aquatic Life.

Table 4.14: Summary of erosion control measure effects on water quality in Doris Creek

Parameter	Units	MMER	CCME	Base Case Scenarios		Sensitivity Runs			
		Criteria	Guidelines	Scenario 3	SedLoad1	SedCont1	SedCont2	SedCont3	SedCont4
Sediment Loading				**Base Case**	**Upper Limit**	**Upper Limit**	**Upper Limit**	**Upper Limit**	**Upper Limit**
Measure				**none**	**none**	**20 % 29.4 m**	**60 % 29.4 m**	**100 % 29.4 m**	**100 % FSL**
Efficiency	%			-	-	50	80	90	90
TDS	mg/L			216	216	216	216	216	216
TSS	mg/L			6.8	6.9	6.8	6.8	6.8	6.8
Sulphate	mg/L			9	9	9	9	9	9
Chloride	mg/L			113	114	113	112	112	112
Total Ammonia	mg/L		0.97	0.08	0.08	0.08	0.09	0.09	0.09
Nitrate	mg/L		2.9	0.4	0.4	0.4	0.4	0.4	0.5
Nitrite	mg/L		0.018	0.032	0.032	0.032	0.032	0.032	0.032
Alkalinity	mg/L			29	29	29	29	29	29
Phosphate-P	mg/L			0.032	0.032	0.031	0.031	0.031	0.031
Org. Carbon	mg/L			7.3	7.3	7.3	7.3	7.3	7.3
Hardness CaCO3	mg/L			50	50	50	50	50	50
Total Metals									
Aluminium Al	mg/L		0.10	0.08	0.09	0.08	0.08	0.08	0.08
Antimony Sb	mg/L			0.0035	0.0035	0.0035	0.0035	0.0035	0.0035
Arsenic As	mg/L	0.5	0.005	0.0006	0.0006	0.0006	0.0006	0.0006	0.0007
Barium Ba	mg/L			0.0035	0.0035	0.0035	0.0035	0.0035	0.0035
Cadmium Cd	mg/L		0.000038	0.000007	0.000007	0.000007	0.000007	0.000007	0.000008
Calcium Ca	mg/L			24	24	24	24	24	24
Chromium Cr	mg/L		0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010
Cobalt Co	mg/L			0.0013	0.0013	0.0013	0.0014	0.0014	0.0014
Copper Cu	mg/L	0.3	0.0020	0.002	0.002	0.002	0.002	0.002	0.002
Iron Fe	mg/L		0.30	0.13	0.14	0.12	0.12	0.12	0.12
Lead Pb	mg/L	0.2	0.0020	0.00008	0.00008	0.00008	0.00008	0.00008	0.00009
Lithium Li	mg/L			0.0029	0.0030	0.0029	0.0029	0.0029	0.0029
Magnesium Mg	mg/L			7.5	7.5	7.5	7.5	7.5	7.5
Manganese Mn	mg/L			0.021	0.021	0.021	0.021	0.021	0.021
Mercury Hg	mg/L		0.00010	0.0000012	0.0000020	0.0000010	0.0000010	0.0000010	0.0000011
Molybdenum Mo	mg/L		0.073	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007
Nickel Ni	mg/L	0.5	0.025	0.001	0.001	0.001	0.001	0.001	0.001
Phosphorus P	mg/L			0.036	0.036	0.036	0.036	0.036	0.037
Potassium K	mg/L			5	5	5	5	5	5
Selenium Se	mg/L		0.001	0.00089	0.00092	0.00088	0.00088	0.00088	0.00089
Silver Ag	mg/L		0.0001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
Sodium Na	mg/L			58	58	57	57	57	57
Thallium Tl	mg/L		0.00080	0.000031	0.000031	0.000031	0.000031	0.000031	0.000032
Tin Sn	mg/L			0.00054	0.00054	0.00054	0.00055	0.00055	0.00055
Zinc Zn	mg/L	0.5	0.030	0.004	0.004	0.004	0.004	0.004	0.004

Note: Shaded values above CCME guidelines for the protection of Freshwater Aquatic Life.

In the first case, areas of highest risk would be identified and covered. For this case it assumed the sediment loadings could be reduced by 50%. This is not unreasonable since most erosion would occur in narrow gulleys and channels that would make up only a small proportion of the area. If these can be identified and controlled then the overall sediment loading would be substantially reduced. By the same reasoning, it was assumed that 60% coverage should provide 80% control. An efficiency of 90% was conservatively assigned to the 100% coverage options.

As shown, the sediment control measures will improve water quality in Tail Lake with respect to the key parameters, aluminium, selenium and iron, as identified in the preceding section. In particular, an efficiency of 50% would lower the aluminium concentration to below the CCME guideline in Tail Lake, and provide long term protection of water quality in Doris Creek.

The higher coverage options demand increasingly higher volumes of quarried rock, which also contribute to solute concentrations in Tail Lake. In particular, nutrient concentrations in Tail Lake are shown to increase, with nitrate increasing from about 6.8 mg/L for the base case to a maximum concentration of about 9.3 mg/L. Ammonia concentrations increase marginally from 1.31 mg/L to 1.38 mg/L. These releases however occur in the short term only and decrease in time as the blast residues are washed from the quarried rock.

Other parameters that will increase in the longer term (mainly for the 100% coverage to FSL case) include arsenic, cadmium, lead, silver and thallium; however, none of these increases significantly affect concentrations in Doris Creek, as shown in Table 4.14.

4.5.6 Tailings Treatment Upsets

Cyanide treatment systems generally are designed with sophisticated control and shutdown systems that will limit or prevent upset conditions. Rather than speculating on the possible range of upset conditions that may occur, modelling runs were completed to assess the range of upset conditions that could occur for the base case without significantly affecting water quality in the receiving environment. The calculations considered zero cyanide removal as the worst case upset condition that may occur. For these conditions, the free and total cyanide concentrations in the discharge were calculated from the flotation and untreated cyanide leachate volume ratio, and the respective concentrations. These were input to the model and the proportion of time determined for which these conditions could be tolerated without causing an exceedance in Doris Creek. The rate of cyanide degradation while the water is contained in Tail Lake will also impact on the resultant water quality. Therefore the calculations were completed for the no degradation and base case degradation rates.

The results are summarised in Table 4.15. As shown, to maintain the free cyanide concentration below the CCME guideline, the treatment plant needs to be 97.5 percent efficient. Conversely, the plant could fail for 9 days of the year while operating at 100 percent for the remainder of the time, and the free cyanide concentration should remain at or below the CCME guideline.

In consideration of degradation reactions in Tail Lake, the treatment efficiency can decreased to about 95 percent without causing a CCME guideline exceedance in Doris Creek. The proposed treatment system relies on well defined chemical reactions that can readily be manipulated through reagent control. Therefore, it is expected that these levels of efficiencies should readily be achievable.

Table 4.15: Summary of estimated cyanide treatment efficiency requirements

Degradation	Efficiency	Equivalent Days	Tail Lake		Doris Creek	
			CN(Free) (mg/L)	CN(T) (mg/L)	CN(Free) (mg/L)	CN(T) (mg/L)
Base Case	100%	0	0.0036	0.035	0.00020	0.004
None	97.5%	9.1	0.0925	0.163	0.00500	0.011
Base Case – Low Efficiency	94.5%	20.1	0.0889	0.156	0.00500	0.011

4.5.7 Oxygen Demand

The oxygen demand in Tail Lake will depend on the net accumulation of compounds that can be oxidized chemically. To estimate the maximum theoretical oxygen demand that may develop in Tail Lake, the water quality predictions were completed as for Scenario 1, i.e. nutrient degradation was not allowed within Tail Lake. For these conditions, solute concentrations in Tail Lake reach maximum values in Year 2, well before Tail Lake would reach FSL. These concentrations would therefore represent the maximum oxygen demand that could develop in Tail Lake. The estimated solute concentrations and corresponding calculated oxygen demands are summarised in Table 4.16. For these calculations it was conservatively assumed that the ammonia would be completely oxidized to nitrate. As shown, the maximum oxygen demand that may develop in Tail Lake is about 24.1 mg/L. The solubility of oxygen is temperature dependent and, at a temperature of about 10°C, it is approximately 11 mg/L.

Table 4.16: Summary of estimated maximum oxygen demand in Tail Lake water

Compound	Maximum Concentration		Oxygen Demand	Oxygen Demand
	mg/L	mmole/L	(stoichiometry)	(mg/L)
CNO*	6.6	0.15	2	4.8
Total Ammonia-N*	0.99	0.06	2	2.0
Nitrite-N*	0.73	0.05	0.5	0.4
Org. Carbon	5.1	0.53	2	16.9
Total				24.1

Note: *Assumes complete oxidation to nitrate.

Furthermore, the oxygen demand in Tail Lake will also be offset by oxygen generated from photosynthesis and oxygen transfer during the open water season from wave action and mixing. The oxygen generated by photosynthesis often lead to supersaturated conditions where the dissolved oxygen concentration actually exceeds the maximum theoretical solubility. This has been observed at many sites where phytoplankton growth has been stimulated (e.g. at the Colomac Site, Chapman *et al*. 2003). In fact, at the Colomac Site, dissolved oxygen concentrations consistently were measured at or above saturation levels even though the oxygen demand at that site far exceeded the oxygen demand expected in Tail Lake.

Even if the oxygen demand is not satisfied within Tail Lake, the net oxygen demand that would result in Doris Creek when discharging at a rate of 1,000,000 m^3 per year would amount to 1.4 mg/L. Clearly, this oxygen demand would readily be met in the creek by background concentrations, and would further be replenished as the water cascades over the waterfall.

It is therefore concluded that oxygen demand will have no discernable effects on the water in Doris Creek. Furthermore, considering the relatively low oxygen demand for the oxidation of nitrite, it concluded that nitrite would not persist within Doris Creek, but would rapidly be oxidized.

4.5.8 Assessment of Mill Processing Changes

As indicated previously, under the revised operating conditions, the volume of treated water discharged to Tail Lake will decrease relative to the total flow so that the discharge water quality will more closely reflect the flotation tailings water quality. While no analytical data are available for the blended tailings water at the revised volume ratio with treated clear filtrate from the flotation concentrate, in this section the estimated tailings water quality is revised based on the available results for the flotation tailings water quality and the treated water quality. Table 4.17 provides a summary of the water quality results for the flotation tailings and the treated concentrate solution respectively. These concentrations were used to estimate the mill discharge water quality for the revised milling process, calculated from the relative flows as shown in the table. The last column in the table represents the mill discharge water quality for the initial process configuration which was obtained from a mixing test. As shown, all but ammonia-N and nickel concentrations for the revised mill process will be equal or below the original estimate.

Maximum concentrations predicted in Tail Lake for the original and revised process configuration for similar conditions are shown in Table 4.18. As expected, predicted maximum concentrations are similar or marginally lower for the revised process configuration, with the exception of ammonia and nickel which are fractionally higher. It is noted that the predicted maximum copper concentration would be about 40 % lower, decreasing from 0.010 mg/L to about 0.006 mg/L. It is therefore concluded that the model simulations completed for the original process configuration based on actual test results remain valid and in general would be conservative.

Table 4.17: Estimated tailings discharge water quality for revised mill processing

Sample ID **Parameter**	**Units**	**Float Tails Solution**		**Cyanide Detoxified Solution**		**Revised Concentrations**	**Original Blended Concentrations**
		MMAR	**BCR**	**MMAR**	**BCR**		
		[HS9312]	**Sample 3**	**[MH3051]**	**Sample 2**		
Flow	m^3/h	2.8		46.5		49.3	49.3
pH		7.88	7.49	7.86	7.70	7.69	8.18
TDS	mg/L	250	220	7190	6953	623	832
Free CN	mg/L	<5	<0.005	<5	0.009	0.005	0.03
Total CN	mg/L	0.01	0.0109	2.5	1.82	0.13	0.29
WAD CN	mg/L	<0.01	<0.0005	0.25	0.181	0.013	0.04
CNO	mg/L	<5	<1	400	282	20	33
SCN	mg/L	0.2	0.45	0.2	0.82	0.336	0.45
Sulphate	mg/L	65	41	4043	4010	279	355
Total Ammonia	mg/L	<1	0.19	17	22	1.28	1.14
Nitrate	mg/L	2.0	1.14	8.0	2.54	1.8	2
Nitrite	mg/L	<1	0.021	23	0.386	0.68	1
Alkalinity	mg/L	115	116	435	441	134	189
Hardness CaCO3	mg/L	290	197	1470	1320	309	409
Total Metals							
Aluminium Al	mg/L	0.057	0.013	0.11	0.005	0.04	0.1
Arsenic As	mg/L	0.006	0.006	0.010	0.012	0.006	0.01
Cadmium Cd	mg/L	<0.005	<0.0002	<0.005	<0.0002	0.0002	0.0002
Chromium Cr	mg/L	0.002	<0.001	0.24	0.2	0.014	0.026
Copper Cu	mg/L	0.008	0.013	0.14	0.2	0.020	0.039
Iron Fe	mg/L	0.034	<0.05	0.17	0.18	0.05	0.12
Lead Pb	mg/L	<0.05	<0.001	<0.05	<0.001	0.001	0.001
Manganese Mn	mg/L	0.058	0.049	0.023	0.02	0.052	0.12
Mercury Hg	mg/L	<0.0005	<0.00002	<0.0005	0.00003	0.00002	0.00002
Molybdenum Mo	mg/L	0.03	0.021	0.08	0.068	0.028	0.04
Nickel Ni	mg/L	0.01	0.009	0.62	0.68	0.046	0.031
Selenium Se	mg/L	-	<0.001	-	0.01	0.001	0.001
Silver Ag	mg/L	-	<0.0001	-	<0.0001	0.0001	0.0001
Thallium Tl	mg/L	-	<0.0001	-	<0.0001	0.0001	0.0001
Zinc Zn	mg/L	0.025	<0.005	0.370	0.25	0.032	0.09

Table 4.18: Comparison of predicted maximum concentrations in Tail Lake for original process and revised process configuration for zero discharge conditions

Parameter	Units	MMER	CCME	Original Process Tail Lake	Revised Process Tail Lake
				Year 3	Year 3
pH			6 to 9	7 to 8	7 to 8
TDS	mg/L			725	689
Free CN	mg/L		0.005	0.0060	0.0010
Total CN	mg/L	1.0		0.058	0.027
WAD CN	mg/L			0.0080	0.0025
CNO	mg/L			6.6	4.1
SCN	mg/L			0.090	0.067
Sulphate	mg/L			73	57
Total Ammonia	mg/L		0.97	1.03	1.06
Nitrate	mg/L		2.9	5.7	5.7
Nitrite	mg/L		0.018	0.73	0.68
Alkalinity	mg/L			46	35
Hardness CaCO3	mg/L			92	73
Total Metals					
Aluminium Al	mg/L		0.1	0.10	0.09
Arsenic As	mg/L	0.5	0.005	0.054	0.053
Cadmium Cd	mg/L		0.000038	0.000054	0.000054
Chromium Cr	mg/L		0.001	0.0061	0.0037
Copper Cu	mg/L	0.3	0.002	0.010	0.006
Iron Fe	mg/L		0.3	0.11	0.10
Lead Pb	mg/L	0.2	0.002	0.00037	0.00037
Manganese Mn	mg/L			0.025	0.011
Mercury Hg	mg/L		0.0001	0.0000055	0.0000056
Molybdenum Mo	mg/L		0.073	0.0083	0.0060
Nickel Ni	mg/L	0.5	0.025	0.023	0.025
Selenium Se	mg/L		0.001	0.00045	0.00050
Silver Ag	mg/L		0.0001	0.00010	0.00010
Thallium Tl	mg/L		0.0008	0.000038	0.000038
Zinc Zn	mg/L	0.5	0.03	0.021	0.009

5 Tail Lake Water Management

5.1 Discussion of Potential Discharge Strategies

Two possible strategies for the management of the discharge system have been considered, as follows. In the first strategy, a fixed monthly flow rate, based on projected average monthly flow conditions and water quality in Doris Creek, and water quality in Tail Lake, distributed according to the Doris Lake outflow hydrograph would be adopted.

In the second strategy, discharge flows would actively be controlled according to current real time measured; i) flow conditions in Doris Creek, and, ii) current water quality in Tail Lake and Doris Creek. In this strategy it should however be realized that, while flow rates in Doris Creek could be measured on a real time basis, there would always be a delay in obtaining water quality results.

For either strategy, the effectiveness of the approach will depend on how rapidly water quality is likely to change within Doris Creek (background) and in Tail Lake.

Monitoring results to date suggest that significant changes in the background water quality in Doris Creek occur over periods of weeks rather than days. Similarly, when the discharge volume of water from the mill (about 36,000 m^3 per month) is compared to the Tail Lake reservoir (typically about 2,200,000 m^3) it is apparent that rate of change of water quality in Tail Lake too will not be rapid. It is therefore possible that reasonable performance can be achieved by either control strategy. Nonetheless, the latter strategy would significantly reduce the risk of discharging water in excess of the target rate.

The first strategy would be the most simple to manage. Conceptually, a chart would be developed that would show correlations between water quality in Tail Lake and flow rates in Doris Creek for each month of the active discharge period. The discharge flow rate would be fixed for periods of up to a week and adjusted as required based on the performance. Monitoring would be undertaken downstream of the mixing zone in Doris Creek to determine the performance against the flow charts, and, if required, these charts may be adjusted to improve the performance. It would however be accepted that marginal exceedances of the target concentrations in Doris Creek are likely to occur from time to time.

The second strategy would provide significantly better control on discharge rates and target concentrations (i.e. CCME guidelines) are likely to be achieved consistently throughout the open water season. It is therefore recommended that the latter strategy be adopted.

The key management and control components of the proposed discharge strategy will comprise:

- Real-time monitoring of flows in Doris Creek.
- Monitoring of water quality in Doris Creek and Tail Lake on a frequent basis.

- Managing the decant intake in Tail Lake to minimise suspended solids release.
- Use of the water quality results to determine allowable discharge rates.
- Controlling the discharge flow rate on a real-time basis.

The description and details of the water discharge management strategy is provided in the next section.

5.2 Water Management

5.2.1 Objectives

The primary objective of the Tail Lake water management strategy will be to meet CCME guidelines for parameters of concern to protect freshwater aquatic life in Doris Creek, downstream of the waterfall, with the possible exception of nitrite.

The following sections provide descriptions of the discharge system, sampling and analytical requirements, data management requirements, calculation of allowable discharge flowrates, and, operational and post operational water management activities.

5.2.2 Water Quality Monitoring and Locations

Approved water sampling protocols will be adopted. Water sampling and monitoring for the management of Tail lake water will be as follows.

Tail Lake

The intake to the discharge pipeline will be located on a floating barge system within the northern part of Tail Lake, about 1.5 m below the water surface. Three water samples will be obtained from the barge at depths of 1.0 m, 1.5 m and at 2.0 m to represent the intake water quality. The monitoring will initially be undertaken every second day, but may be reduced to weekly or less should the data indicate that the rate of change in water quality is small. Similarly, if the samples taken at different depths are shown to vary little, then sampling may be reduced to duplicate samples at the pipe intake depth.

End of Pipe Discharge

The frequency of sampling and analysis is specified in the MMER to be weekly, at least initially, for regulated parameters. However, there is provision to reduce the frequency of analysis for some parameters based on the results obtained. These results will be correlated with the intake water quality results for further confirmation that the intake monitoring results reasonably reflect actual discharge water quality.

Doris Creek Upstream of Weir

The upstream water quality samples for Doris Creek will be obtained upstream of the flow monitoring point, as dictated by site conditions. Sampling will initially be undertaken every second day to coincide with the intake monitoring samples. As for the intake sampling, the frequency may be reduced to weekly should the data indicate that the rate of change in water quality is small.

Doris Creek Downstream of Waterfall

Doris Creek downstream of the waterfall will be monitored only during periods of active discharge. The sample location will be established approximately 30 to 50 m downstream of the waterfall, as dictated by site conditions, to ensure that complete mixing of Tail Lake discharge and Doris Creek had occurred. Sampling will initially be undertaken every second day. As the discharge control strategy is refined and proven to meet discharge objectives, the frequency of sampling may be reduced.

Dam Seepage

If evident, toe seepage at the North and South Dams will be sampled and monitored on a weekly basis. If flows become significant, the seepage will be collected and pumped back to Tail Lake.

Mill Effluent

Mill tailings discharge water will be monitored at a location after all of the effluent streams have been combined into a single flow. Initially the water quality will be sampled daily and composited over a two day period. Depending on the variability in the tailings effluent water quality, the composite period may be increased and the frequency of analysis reduced.

5.2.3 Water Quality Analyses

Onsite Laboratory

A low level detection environmental laboratory will be established on site. For convenience the laboratory will be sited near the camp complex, but sufficiently removed from the mill site to prevent contamination. The laboratory will be established prior to commencement of any discharges from Tail Lake.

Suitably qualified personnel familiar with the operation and maintenance of a low level environmental laboratory will be retained to operate the laboratory. Documented standard operating procedures (SOPs) will be used.

The laboratory will be equipped with a low level inductively coupled plasma (ICP) mass spectrophotometer (MS) to enable low level detection analyses of metals. Details of the operation of the laboratory setup and technical information for the ICP-MS are provided in Appendix J.

MHBL will seek laboratory accreditation with the Canadian Association for Environmental Analytical Laboratories (CAEAL). The requirements include a well-documented quality assurance/quality control (QA/QC) program, as well as demonstrated proficiency in analysis of performance evaluation (PE) samples. The assessment and accreditation will be updated every two years.

A documented internal quality control program will be implemented which will include items such as calibration schedules, use of quality control samples, established control specifications with corrective actions if specifications are not met, data validation, equipment maintenance, and staff training and evaluation programs.

Quality control samples will include:

- blanks – analysis of de-ionized water to ensure that there is no contamination due to laboratory procedure;
- duplicates – a replicate analysis of a homogeneous sample to show method precision;
- spikes – a replicate sample spiked with a known amount of stock standard solution to show both method precision and accuracy and to check for any interferences; and
- reference materials – a National Institute of Standards and Technology (NIST) or other suitable certified reference material to show method accuracy.

All of the above laboratory QC samples will be run regularly. Results will be compared to Data Quality Objectives (DQOs) and be used to flag sample results where DQOs are not met. Control samples will be run at a minimum frequency of 10% of the samples for analysis. Quality records will be kept and will be available for inspection.

Water Quality Parameters

The parameters that will be monitored regularly, and intermittently, at the site are summarised in Table 5.1. Not all of the parameters will necessarily be measured on-site. Non-critical parameters such as dissolved and total organic carbon would be measured off-site on a less frequent basis.

Table 5.1: Parameters to be measured for effluent characterization and water quality monitoring

Deleterious substances and pH[1,2]	Required Effluent Characterization and Water Quality Monitoring Parameters[2,3]:	Required Additional Water Quality Monitoring Parameters	Site-Specific Parameters[6]
Arsenic	Aluminium	Dissolved oxygen[5]	Chromium
Copper	Cadmium	Temperature[5]	Manganese
Lead	Iron		Selenium
Nickel	Mercury[4]		Total phosphorus
Zinc	Molybdenum		Nitrite
Radium 226	Ammonia		Conductivity
Total cyanide	Nitrate		Calcium
Total suspended solids	Alkalinity		Chloride
pH	Total hardness		Magnesium
			Potassium
			Sodium
			Sulphate
			Dissolved organic carbon[5] Total organic carbon [5]

Notes:

1. List of parameters regulated (deleterious substances and pH) as per Schedule 3 of the MMER; concentration limits specified in the regulation (Schedule 4).
2. All concentrations are total values; dissolved concentrations may also be reported; effluent loading (Section 20 of MMER) will also be calculated and reported.
3. List of parameters required for effluent characterization and water quality monitoring as per Schedule 5 of the MMER Analysis of mercury may be discontinued if the concentration of total mercury in effluent is less than 0.10 µg/L in 12 consecutive samples of effluent.
4. In situ measured parameters only for water quality monitoring (in receiving waters).
5. These other parameters are potential contaminants or supporting parameters; analysis is optional and may be added based on site specific historical monitoring data or geochemistry data.

5.2.4 Third Party Verification

Upon the commencement of operations, MHBL will ensure that an independent, third party laboratory carry out monitoring of Tail Lake and Doris Creek water quality, above and below the waterfall, three times annually during active discharge to provide verification of MHBL's monitoring results. MHBL will provide the sampling and delivery of samples to the independent, third party laboratory, with copies of the results directly to the NWB and NIRB's Monitoring Officer.

5.2.5 Doris Creek Flow Monitoring

A pressure transducer will be installed at a suitable location within Doris Creek to facilitate real time monitoring of flow. The pressure transducer will be connected to a programmable logic controller (PLC) that would record flows in Doris Creek and be used to control the discharge flow rate. If initial monitoring suggests that greater accuracy is required, a flow monitoring weir may be constructed in Doris Creek at a location approximately 50 to 100 m upstream of the waterfall, as dictated by site conditions.

During periods of active discharge, the flow level in Doris Creek will be monitored visually on a daily basis and checked against the real time monitoring results. For this purpose, a staff gauge will be installed at the location where the pressure transducer is located. The area will also be inspected on a daily basis for ice and any debris, and cleared as required to ensure accurate monitoring of flows.

5.2.6 Data Management

Monitoring information that will be collected will include:

- The name of the person(s) who performed the sampling or took measurements;
- Date, time, and place of sampling or measurement;
- Date of analysis;
- Name of the person who performed the analysis;
- Analytical methods or techniques used; and
- Results of any analysis.

The results and records of any monitoring, data, or analysis shall be kept for a minimum of the life of the project including closure and post closure monitoring. This time period will be extended if requested by NIRB, DFO, EC or the NWB.

MHBL will set up and maintain a Laboratory Information Management System (LIMS) to record and manage all the water quality monitoring results. MHBL will consult with NIRB’s Monitoring Officer for guidance on presentation of monitoring results and records.

5.2.7 Determination of the Discharge Rate

The discharge rate will be determined in two steps. In the first step, the Allowable Discharge Volume Ratio (ADVR) is calculated as follows:

$$ADVR(Cu) = (CCME_{Cu} - [Cu]_{DC}) / ([Cu]_{TL} - CCME_{Cu})$$

Where $[Cu]_{DC}$ = copper concentration in Doris Creek (mg/L),
$[Cu]_{TL}$ = copper concentration in Tail Lake (mg/L), and
$CCME_{Cu}$ = CCME Freshwater Aquatic Guideline or site specific objective for copper (mg/L).

The ADVR for other key parameters would then be calculated on the same basis. The lowest ADVR ($ADVR_{MIN}$) is then selected as the controlling ADVR.

In the second step, the target discharge rate (TDR) is calculated as follows:

$$TDR = Q_{DC} * 0.8 * ADVR_{MIN}$$

Where TDR = target discharge rate (m^3/s), and
$ADVR_{MIN}$ = lowest allowable discharge ratio.

The factor 0.8 is a factor of safety that will ensure that the discharge contaminant loading remains at or below 80 percent of the CCME guideline in Doris Creek. This conservatism is applied to allow for potential upset conditions in flows or analytical results.

5.2.8 Discharge Control

The discharge system will comprise the installation of a discharge control system that will accurately control and measure the discharge flow rate over a flow range spanning 50 L/s to 275 L/s. A programmable logic controller (PLC) will be used to both control the discharge rate as well as log instantaneous flow rates and cumulative discharge volumes. The flow would be controlled with an actuated flow control valve, with excess flow recycled back to Tail Lake. The PLC will actuate the flow control valve to discharge Tail Lake water at a fixed ratio, equal to the TDR, relative to the flow in Doris Creek.

The pump intakes in Tail Lake (for the operational period) will be mounted on a floating barge system well away from the tailings discharge point to minimise suspended solids in the intake. Silt curtains will be installed around the pump intake to minimise intake of suspended solids.

The discharge to Doris Creek will be located sufficiently downstream from the flow monitoring location to ensure that the discharge will not interfere with flow measurements in Doris Creek, but sufficiently upstream of the waterfall to ensure complete mixing with Doris Creek water. The outlet would be placed such that the discharge flow would not lead to erosion or degradation of the creek bed. The approximate discharge location is shown in Dwg G-02 (SRK 2006a).

5.2.9 Operational Strategy

Starting in Year 1, the discharge strategy will be implemented as follows:

- Prior to commencement of milling, the laboratory will be set-up and analytical procedures developed, documented and verified. Sampling protocols will also be documented and verified.
- Two weeks prior to commencement of operations (assuming a spring start-up), water quality in Tail Lake and Doris Creek will be monitored every second day to establish baseline conditions.
- Real-time monitoring of the flows in Doris Creek will commence as soon as practical during the open water season. The pressure transducer would be connected to a programmable logic controller (PLC) that would record flows in Doris Creek and be used to control the discharge flow rate.
- Commencing with the start of tailings deposition, Tail Lake will be monitored for an additional two weeks every second day. As the dynamics of the system, i.e. rate of change in water quality, becomes better understood, the frequency of monitoring could be reduced.

- Before any discharge would commence, Tail Lake water would be submitted for toxicity testing and metals analysis. Only if the water meets MMER criteria will discharge from Tail Lake commence. The flow ratio would be calculated for each sampling event and adjusted as necessary. The discharge flow would be controlled by the automated flow control system which would use the real time flow monitoring in Doris Creek to control the discharge flow rate. Flow rates would automatically be logged by the flow control system.

In subsequent years, it is anticipated that at the start of the open water season the analytical turnaround time will likely prevent discharge for the first few days. The downstream together with the upstream and Tail Lake water quality monitoring results will be used to verify the performance of the discharge system at regular intervals and to make flow control adjustments as appropriate.

As part of the control strategy, the actual water quality in Tail Lake will regularly be compared with the predicted water quality to assess the accuracy of the model. If necessary, the model may be recalibrated to the actual water quality observed in Tail Lake. The model would then be rerun to assess potential implications on the discharge strategy and to determine future operational requirements.

5.3 Contingency Discharge Strategy

As demonstrated in Section 4 of this report, Tail Lake can be operated successfully at several lower than optimum discharge rates. In the event that maximum allowable discharge flow rates are lower than estimated herein, the proposed control system will automatically adjust to the lower flow rates.

In the unlikely event that no discharge is possible at, or after commencement of operations, water balance modelling has shown that Tail Lake has sufficient capacity to store water for several years after operations would cease. During this time it will be possible to monitor changes in water quality in Tail Lake and, either commence active discharge if suitable conditions develop, or, project water quality into the future to the time that the FSL will be reached. The effects of natural discharge would be re-assessed for that time and if acceptable for natural discharge, Tail Lake would be allowed to fill to its FSL and then allowed to overflow naturally until solute concentrations approach CCME guidelines to enable discharge of excess water contained in Tail Lake and allow breaching of the North Dam. This represents the first contingency strategy.

A second contingency is available for the management of the water contained in Tail Lake. The water quality monitoring undertaken in the early stages of the ‘holding’ period will identify the solutes that may be of concern at the time the FSL is reached. This will provide ample time to identify water treatment requirements, if any, that may be required to enable discharge of excess water when the FSL is reached. Construction and commissioning of a water treatment plant would represent a second level contingency; however it is unlikely that this contingency would ever have to be developed.

This report, **“Water Quality Model, Doris North Project, Hope Bay, Nunavut, Canada”**, has been prepared by SRK Consulting (Canada) Inc.

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6 References

AMEC 2003a. *ARD and Metal Leaching Characterization Studies in 2003, Doris North Project*, prepared by AMEC Earth & Environmental Ltd., dated November 2003.

AMEC. 2003b. *Meteorology and Hydrology Baseline, Doris North Project, Nunavut, Canada*. Report submitted to Miramar Hope Bay Limited, August 2003.

Bianchi, M, Feliatra, D. Lefevre. 1999. *Regulation of nitrification in the land-ocean contact area of the Rhone River plume*. Published in AME Vol. 18, No. 3 (1999) on August 20.

Chapman, John, William Coedy, Terry Mudder, Mike Botz , Michael Nahir and Octavio Melo. 2003. *Enhanced Natural Degradation of Cyanide and Related Compounds in an Abandoned Tailings Lake Using Mono-Ammonium Phosphate (MAP)*. In Proceedings of Third Biennial Assessment and Remediation of Contaminated Sites in Arctic and Cold Climates (ARCSACC), Edmonton, May 4-6, 2003. Eds. M Nahir, K Biggar and G. Cotte.

Ferguson, K.D. and Leask, S.M. 1988. *The export of Nutrients from Surface Coal Mines. Environment Canada, Conservation and Protection, Pacific and Yukon Region*. Regional Program Report 87-12.

Golder Associates Ltd. 2006. *Doris North Project hydroclimatic parameter re-evaluation*. Prepared for Miramar Hope Bay Ltd., North Vancouver, BC by Golder Associates Ltd., Edmonton, AB. Golder Report No. 06-1373-026: 33 p. + 4 app.

Grady, C.P.L and H.C. Lim. 1980. *Biological Waste Water Treatment. Theory and Application.* Publ. Marcel Dekker Inc., New York. ISBN 0-8427-1000-2

McIntosh Redpath Engineering. 2003. *Hard Rock Miner's Handbook, Chapter 22, Explosives and Drilling*. http://www.mcintoshengineering.com/Hard%20Rock%20Handbook/hardrock.htm

Miramar Hope Bay Limited. MHBL. 2005. *Final Environmental Impact Statement for the Doris North Project, Nunavut, Canada*. October 2005.

Rescan. 2001. *Supplemental Environmental Baseline Data Report, Hope Bay Belt Project.* Report submitted to Hope Bay Joint Venture.

SRK Consulting Inc. 2005a. *Tail Lake Water Quality Model, Doris North Project, Hope Bay, Nunavut, Canada*. Report submitted to Miramar Hope Bay Limited, October 2005.

SRK Consulting Inc. 2005b. *Groundwater Assessment, Doris North Project, Hope Bay, Nunavut, Canada*. Report submitted to Miramar Hope Bay Limited, October 2005.

SRK Consulting Inc. 2006a. *Engineering Drawings for Tailings Containment Area and Surface Infrastructure Components, Doris North Project, Hope Bay, Nunavut, Canada*. Drawings submitted to Miramar Hope Bay Limited, October 2006.

SRK Consulting Inc. 2006a. *Design of Tailings Containment Area, Doris North Project, Hope Bay, Nunavut, Canada*. Report submitted to Miramar Hope Bay Limited, October 2006.

SRK Consulting Inc. 2006a. *Design of Surface Infrastructure Components, Doris North Project, Hope Bay, Nunavut, Canada*. Report submitted to Miramar Hope Bay Limited, October 2006.

Tomaszek J.A. & E. Czerwieniec. 2002. *Denitrification and oxygen consumption in bottom sediments: factors influencing rates of processes*. 4th Int. Conf. České Budějovice, August 12-16, 2002. Proceedings: 350-353.

Water Pollution Control Federation. 1983. *Nutrient Control, Manual of Practice FD-7*. Facilities Design. Library of Congress Catalogue No. 65-5192. ISBN 0-943244-44-7.