Report No. 118001/1

WATER & LOAD BALANCE STUDY FOR ROSE CREEK TAILINGS STORAGE FACILITY, FARO MINE, YUKON TERRITORY

Submitted to:

Deloitte.

DELOITTE & TOUCHE INC.

On behalf of

Faro Mine Closure Planning Office

Prepared by:

Robertson GeoConsultants Inc.
Mining, Geotechnical and Environmental Engineers

In association with:

SRK Consulting
Engineers and Scientists

March 2006

EXECUTIVE SUMMARY

One of the primary issues in the context of closure planning for the Anvil Range Mining Complex will be the development and assessment of decommissioning options for the Rose Creek Tailings Facility. As part of the 2004/05 planning meetings, two projects were identified which address water management issues related to closure of the Rose Creek Tailings Facility: (i) Complete Groundwater Collection Design (Task 16f) and (ii) Assess Surface Water Management Requirements (Task 16g). An initial review of the available groundwater monitoring data for the Rose Creek valley and overlying Tailings Storage Facility indicated that surface water and groundwater flow are interrelated and their management should be assessed jointly. The two proposed programs were therefore combined into a single project.

The revised scope of work called for the development of a comprehensive water and load balance model for the Rose Creek valley (surface water and groundwater) to better understand the current and future sources of contaminant loading to the Rose Creek aquifer and Rose Creek. The water and load balance model was developed and parameterized based on an extensive review of all relevant data, including characterization studies of the tailings and underlying aquifer materials as well as historic monitoring data of surface water and groundwater quality.

The water and load balance model was used to predict the loading of sulphate and zinc to Rose Creek for three different conditions:

i. current conditions (October 2004)

ii. future conditions assuming no remediation measures are implemented

iii. future conditions assuming alternative remediation scenarios

The major findings for these three conditions are summarized below.

Current Conditions

A synoptic field survey consisting of flow measurements and water quality sampling in surface flow and seeps in the Rose Creek valley was carried out in October 2004 under moderate low flow conditions. The key findings from this survey are as follows:

- The seepage discharging at the mouth of the old Faro Creek Canyon is substantial (~10.2 L/s) and represents a large contaminant load (~1,700 t SO4 per year and ~100 t Zn per year) to the Rose Creek valley; most of this seepage flow is lost to the subsurface via leakage before it can reach the Intermediate Pond;
- The Rose Creek Diversion experiences significant leakage (about 200 L/s) between the Intermediate Dam and the end of the diversion; this leakage provides an important source of dilution to the south side of the aquifer;
- The area between the Cross Valley Dam and Rose Creek (X14) represents a major groundwater discharge zone; the combined flow of this “Cross Valley Seepage” was 83 L/s, representing a total load of ~1,400 t SO4 per year but only 0.05 t Zn per year;

- Rose Creek remains a gaining stream downstream of the confluence (where it flows in its natural streambed); flow measurements suggest that as much as 200 L/s of groundwater discharges into the creek between X14 and station RC1 (just upstream of the inflow of Next Creek);

The results of the October 2004 survey were used to calibrate the water and load balance model for current conditions. A unique calibration of the **sulphate load balance** model for current conditions was not possible because of uncertainties in (i) the average solute travel time in the aquifer (influencing the time of loading) and (ii) the historic water quality in tailings seepage. Instead, different scenarios were simulated to bracket the likely range of sources contributing to the loading currently observed (October 2004) in Rose Creek.

The major conclusions from a simulation of current sulphate loading to Rose Creek are as follows:

- Those scenarios assuming loading from Faro Creek seepage (i.e. Scenarios C1 and C2) provided an overall better match with field observations than those scenarios assuming only seepage from the tailings (Scenarios 3 and 4);
- The primary sources contributing to current sulphate loading in Rose Creek (~2,500 t/yr) include:
    - Upstream Sources (591 t/yr or 24%);
    - Faro Creek seepage (644 t/yr or 25%);
    - Historic Tailings Seepage (323-416 t/yr or 12-15%); and
    - Seepage from Intermediate & Polishing Ponds (811 t/yr or 32%)

A calibration of the **zinc load balance** model is even more uncertain because of the added complexity of attenuation which influences the travel time and therefore the time of loading from a given tailings impoundment. Zinc loading calculations were therefore carried out assuming different degrees of retardation along the flow path (R=1, 2 and 7).

The major conclusions from a simulation of current zinc loading to Rose Creek are as follows:

- Assuming no attenuation (R=1), the **simulated** zinc load to Rose Creek ranges from ~30 to 58 t/yr; these estimates are significantly (!) higher than the currently **observed** zinc load in Rose Creek (at RC9) of only about 0.7 t/yr; the large discrepancy between observed and predicted zinc loading may be a result of several factors including:
    - Zinc concentrations in tailings pore water are significantly lower than estimated based on leach extraction data;
    - Zinc is attenuated along the flow path (hence resulting in significantly longer travel times in the aquifer);
- Assuming a retardation factor of R=2, travel times in the aquifer would increase such that only process water from the Second and Intermediate Impoundments would contribute to current loading in Rose Creek; despite this drastic reduction in zinc loading from the tailings this scenario still overpredicts the zinc load to Rose Creek by a factor of ~6;

- A retardation factor of R=7 would increase the average travel time even further, which would imply that the only source of current zinc loading to Rose Creek would be seepage from the Intermediate Pond dating back to 1989 when tailings were still actively discharged into the Intermediate Impoundment and zinc concentrations were very low (0.21 mg/L based on historic water quality data); this scenario provides the best match with the zinc loading and zinc concentrations observed in toe seepage and groundwater discharge downstream of the Cross Valley Dam.
- The zinc load balance modeling convincingly indicates that zinc is attenuated in the system (relative to sulphate); however, the model does not provide insight into the actual mechanism of zinc attenuation. For example, zinc attenuation may not only occur in the aquifer soils (as was assumed here) but may also occur within the tailings profile or within the unsaturated soils above the water table; the uncertainty in many model input parameters (in particular the nature and magnitude of zinc attenuation) precludes a definitive estimation of the retardation factor.

The primary calibration target for the “current” loading model was the current loading to Rose Creek. However, because of the considerable travel times in the aquifer (5-20 years) the current (2004) loading to Rose Creek is influenced by historic tailings seepage (and loading) that occurred many years ago. As a result the calibration of the “current” load balance model does not provide any validation of our estimates of current loading from the tailings to the aquifer.

In order to provide an independent check on the plausibility of the estimated seepage rates and pore water concentrations used in the load balance model, the loads from tailings seepage estimated for current conditions were compared against sulphate and zinc concentrations currently observed beneath the Original and Second Impoundment. The major findings from this analysis are as follows:

- The current sulphate loading from tailings seepage to the aquifer is estimated to range from 375 t/yr (for average propagation rates) to 741 t/yr (for maximum propagation rates) using leach extraction data (collected in 2001); these estimates agree fairly well with our estimates of the total sulphate load in the aquifer beneath the Original and Second Impoundment based on observed zinc concentrations in groundwater (542 to 780 t/yr);
- The current zinc loading from tailings seepage to the aquifer is estimated to range from 59.6 t/yr (for average propagation rates) to 126 t/yr (for maximum propagation rates) using leach extraction data (collected in 2001); these estimates are about one to two orders of magnitude higher than our estimates of the total zinc load in the aquifer beneath the Original and Second Impoundment (0.8 to 4.0 t/yr);

This discrepancy suggests that significant attenuation of zinc along the flow path (either within the tailings and/or in natural soils) might be occurring. The process of attenuation introduces significant uncertainty into any prediction of future zinc concentrations, in particular the timing of peak breakthrough, in the groundwater and, by extension, in Rose Creek. The predicted maximum concentrations are not significantly affected by this uncertainty in attenuation, provided zinc loading occurs over the long-term (centuries) and zinc uptake is due to finite and linear sorption. A better understanding of the attenuation processes controlling zinc transport will be required in order to improve our ability to predict zinc concentrations in groundwater and Rose Creek for alternative remediation strategies.

Future Conditions (No remediation)

The water and load balance model was used to predict future loading to Rose Creek assuming that no remediation measures for the Rose Creek tailings facility are implemented. These simulations represent the “base case” or “Do Nothing” option and provide a basis for comparison with the simulation of remediation scenarios. A series of sensitivity runs were also carried out in order to evaluate the sensitivity of the model predictions to uncertainty in model input parameters. It should be noted that all simulations of future conditions assumed a ‘moderate’ base flow in Rose Creek of 502 L/s at X14, or about twice that of the 7-day 2-year base flow in Rose Creek (240 L/s). Extended base flow in Rose Creek would therefore result in an approximate doubling of the modeled ‘peak’ concentrations. All simulations of future conditions further assumed that all contaminant loading from sources other than tailings (e.g. from the Faro waste rock dumps) would not increase in the future.

The main conclusions from these simulations are as follows:

- The sulphate load in Rose Creek (just upstream of the confluence with Next Creek) is predicted to increase by a factor of 2 compared to current loading; the sulphate concentrations in Rose Creek (200-250 mg/L) are predicted to remain below the CCME guideline for sulphate (500 mg/L SO4) for the protection of freshwater aquatic life (CCME, 2003); however, this guideline may be exceeded at times of extended base flow (not modeled here);
- The total zinc load in Rose Creek (just upstream of the confluence with Next Creek) is predicted to increase to about 320 t/yr (assuming average propagation rates); this load would result in peak zinc concentrations in Rose Creek (under moderate low flow conditions) of about ~15 mg/L, i.e. more than two orders of magnitude higher than the CCME guideline for zinc (0.03 mg/L Zn) for the protection of freshwater aquatic life (CCME, 2003);
- The assumption of a higher K and retardation generally influences the arrival time of the breakthrough curve but does not change the peak concentrations significantly;
    - A retardation factor of R=2 delays the early breakthrough by some 20 years but has no significant effect on the timing of the **peak** breakthrough;
    - A retardation factor of R=7 delays the entire zinc breakthrough significantly with peak breakthrough predicted to occur in 250-300 years from today;
    - The assumption of a higher permeability in the aquifer results in a slightly earlier arrival of the zinc breakthrough curve (by ~10 years) but does not affect the peak concentrations significantly;
- The assumption of maximum propagation rates “compresses” the zinc loading to Rose Creek into a shorter time period, generally resulting in higher peak concentrations (~24 mg/L) and earlier peak breakthrough (~2080) compared to the case of average propagation rates;
- The model predictions of future loading to Rose Creek suggest that future zinc loading will be of much greater concern to the water quality of Rose Creek than sulphate loading. While the interception of Faro Creek seepage (currently allowed to discharge uncontrolled into the Rose Creek Tailings Facility) is predicted to reduce the zinc loading significantly, this

remediation measure alone is not predicted to achieve acceptable water quality in Rose Creek.

Future Conditions with Remediation

The water and load balance model was used to predict the future loading to Rose Creek for alternative remediation scenarios including remediation options for the tailings impoundments and/or collection and treatment of impacted groundwater. As for the base case, all simulations of future conditions with remediation assumed (i) a ‘moderate’ base flow in Rose Creek of 502 L/s and (ii) no increase in contaminant load from sources other than tailings.

Table E1 summarizes the predicted zinc loading to the aquifer and Rose Creek for the various alternative remediation scenarios. Note again that the simulated ‘peak’ zinc concentrations shown in Table E1 refer to moderate low flow conditions and extended base flow conditions in Rose Creek could result in doubling of those modeled peak concentrations.

Table E1.
Summary of predicted zinc loading to aquifer and Rose Creek for alternative remediation options.

Run ID	**Option**	**Zinc Load to Aquifer**		**Zinc Peak Load in Rose Creek**[2] **(at station RC9)**		
		Duration	**Total Load**[1]	Year	mg/L	t/year
Run F2	*"No remediation"*	*>750 years*	*79,686*	*2174*	*15.2*	*326*
Groundwater Collection only						
Run R1a	"Collect & Treat" only	> 750 years	79,686	2174	3.0	56
Run R2a	"Collect, pump & Treat"	> 750 years	79,686	2174	1.1	21
Tailings Remediation only						
Run R3a	"Full Relocation"	~ 20 years	1,008	2047	3.3	66
Run R4	"Partial Relocation & Dry Cover"	>>750 years	12,379	2047	3.4	67
Run R5	"Partial Relocation & Water Cover "	~ 60 years	2,642	2047	5.0	108
Run R6	"Full Water Cover"	~ 50 years	93,625	2052	159	3,444
Run R7	"Dry Cover"	>> 750 years	16,826	2047	3.4	68
Tailings Remediation plus Groundwater Collection						
Run R8	"Full Relocation" & "Collect, Pump & Treat"	~ 20 years	1,008	2047	0.33	6.1
Run R9	"Partial Relocation w/ Dry Cover" & "Collect, Pump & Treat"	>>750 years	12,379	2047	0.34	6.2
Run R10	"Dry Cover" & "Collect, Pump & Treat"	~ 60 years	2,642	2047	0.36	6.6

Notes:
1) load from 2001 - 2750
2) all runs assume R=2

Remediation scenarios R1 and R2 assume that remediation is limited to groundwater collection without any remediation of the Rose Creek tailings facility. The modeling results for those scenarios can be summarized as follows:

- In Option R1, all shallow seepage day-lighting before the confluence of the Rose Creek Diversion and Rose Creek is intercepted, representing a flow of 73 L/s and a zinc load of 171 t/yr, respectively; this remediation option does not prevent any loading from the tailings to the aquifer; however, this mitigation measure is predicted to substantially reduce the loading to Rose Creek resulting in peak zinc concentrations of about 3.0 mg/L Zn;
- In Option R2, the interception system is upgraded (using a fence of interceptor wells downgradient of the X Valley Dam) to achieve an efficiency of 90% groundwater interception, in this scenario, the combined flow intercepted is 80.5 L/s representing a zinc load of 213 t/yr; this option is predicted to further reduce the loading to Rose Creek (compared to option 1) resulting in peak zinc concentrations of ~1.1 mg/L Zn;

Remediation scenarios R3 to R7 simulate different remediation options for the Rose Creek tailings facility assuming <u>no collection of impacted groundwater</u> downstream of the facility. The modeling results for those scenarios can be summarized as follows:

- In Option R3, all tailings are assumed to be removed between 2008 and 2020; “full relocation” is predicted to reduce the total zinc load entering the groundwater system dramatically (by 98-99%); however, a significant load of zinc (~1,000 tonnes) may still enter the aquifer prior to completion of the relocation project; this residual load is predicted to result in significantly elevated zinc concentrations (~3 mg/L) over the next 40-60 years;
- In Option R4, the tailings of the Intermediate Impoundment are relocated and the tailings of the Original and Second Impoundments are covered to limit infiltration; the very low rate of net infiltration assumed in this scenario (5 mm/yr) reduces the rate of zinc loading significantly; however, this option does not eliminate the loading over the mid- to long-term and the zinc concentrations in Rose Creek are predicted to remain elevated (~0.5-1.0 mg/L) for a very long time (beyond year 2750);
- In option R5, all tailings above an elevation of 1042m amsl are removed and the residual tailings are flooded with a 3m deep water cover; this option is predicted to result in an initial reduction in zinc loading to the aquifer (primarily because of the removal of the coarse tailings in the Original Impoundment); however, subsequent flooding is predicted to “flush” all of the soluble zinc inventory stored in the residual tailings into the aquifer over a relatively short period of time; this release is predicted to result in higher peak zinc concentrations (~5.0 mg/L) around year 2047; in the mid- to long-term (>2060) the system is predicted to return to background conditions as all soluble zinc is flushed out of the tailings and the underlying aquifer system;
- In Option R6, a water cover is implemented in all three tailings impoundments by the year 2010; this option is predicted to result in the “flushing” of all soluble zinc in the tailings currently stored in the tailings over a short time period; the predicted zinc concentrations in Rose Creek for this option would approach 160 mg/L which is clearly unacceptable; flooding of all the tailings would very likely require the interception of significant quantities of toe

seepage and groundwater for a period of 80-100 years to prevent the discharge of this "pulse" of contaminants into Rose Creek;

- In Option R7, a high quality dry cover is placed over all tailings by the end of 2010; this option is predicted to reduce the zinc load to the aquifer by about 50% over the net 20 years and by as much as 85% by 2100; however, despite this load reduction, the zinc concentrations are predicted to increase to about 3.4 mg/L over the next 40 years and remain elevated (0.5 – 1.5 mg/L) thereafter for a very long time;

Remediation scenarios R8 to R10 simulate selected remediation options for the Rose Creek tailings facility also <u>assuming collection of impacted groundwater</u> downstream of the facility (at the toe of the Cross Valley Dam). The modeling results for those scenarios can be summarized as follows:

- In option R8, the tailings option of "full relocation" (R3) is combined with a groundwater interception system; assuming 90% capture efficiency, the groundwater interception system is predicted to remove about 45 L/s representing a zinc load of 61 t/yr at peak zinc breakthrough; this removal of impacted groundwater is predicted to reduce the peak zinc concentrations in Rose Creek by a factor of 10 (from 3.3 mg/L to 0.33 mg/L);
- In option R9, the tailings option of "partial relocation with dry cover" (R4) is combined with a groundwater interception system; assuming 90% capture efficiency, the groundwater interception system is predicted to remove about 45 L/s representing a sulphate load of 62 t/yr at peak sulphate breakthrough; this removal of impacted groundwater is predicted to reduce the peak zinc concentrations in Rose Creek by a factor of 10 (from 3.4 mg/L to 0.34 mg/L);
- In option R10, the tailings option of "dry cover" (R7) is combined with a groundwater interception system; assuming 90% capture efficiency, the groundwater interception system is predicted to remove about 45 L/s representing a sulphate load of 63 t/yr at peak sulphate breakthrough; this removal of impacted groundwater is predicted to reduce the peak zinc concentrations in Rose Creek by a factor of 10 (from 3.4 mg/L to 0.36 mg/L);

In summary, implementation of a groundwater collection system at the toe of the Cross Valley Dam **in addition** to tailings relocation and/or dry cover placement is predicted to reduce the peak zinc concentrations in Rose Creek significantly (by a factor of 10). However, the resulting zinc concentrations in Rose Creek are still predicted to be about one order of magnitude above the CCME guideline for zinc (0.03 mg/L Zn). According to these model calculations, the capture efficiency of the groundwater interception system at the Cross Valley Dam would have to be very high (99% or higher) in order to achieve zinc concentrations in Rose Creek (at RC9) below the CCME guideline for zinc, regardless of which tailings remediation option is selected.

The modeling results suggest that the primary advantage of tailings relocation over dry cover placement would be the time period over which groundwater collection would be required. Assuming full relocation, groundwater collection may be required for 40-60 years, whereas in-situ remediation using a dry cover may require collection and treatment of impacted groundwater in perpetuity.

It should be emphasized that all remediation scenarios were carried out assuming only limited attenuation of zinc in the aquifer (R=2) and no attenuation within the tailings profile. These assumptions tend to provide conservative (early) estimates of arrival times of peak zinc concentrations in Rose Creek. However, this conservative approach may result in overly pessimistic estimates of future zinc concentrations, in particular for those remediation scenarios with full source removal (i.e. tailings relocation). Our analysis of current conditions (see above) suggests that the current zinc load in the aquifer beneath the Original and Second Impoundment is about one to two orders of magnitude **lower** than our estimates of current zinc loading from tailings seepage. This would imply that our predictions of future loading to Rose Creek, at least in the short-term, might also be too high by one to two orders of magnitude. A better understanding of the sources and magnitude of zinc attenuation along the flow path (in tailings and within the aquifer) will be required to reduce the uncertainty in predictions of future zinc concentrations in groundwater and Rose Creek.

REPORT NO. 118001/1

WATER & LOAD BALANCE STUDY FOR ROSE CREEK TAILINGS STORAGE FACILITY, FARO MINE, YUKON TERRITORY

Table of Contents

APPENDICES

LIST OF TABLES

LIST OF FIGURES

REPORT NO. 118001/1

WATER & LOAD BALANCE STUDY FOR ROSE CREEK TAILINGS STORAGE FACILITY, FARO MINE, YUKON TERRITORY

1 INTRODUCTION

1.1 Terms of Reference

One of the primary issues in the context of closure planning for the Anvil Range Mining Complex will be the development and assessment of decommissioning options for the Rose Creek Tailings Facility. As part of the 2004/05 planning meetings, two projects were identified which address water management issues related to closure of the Rose Creek Tailings Facility:

Task 16: Develop Tailings Decommissioning Methods

f) Complete Groundwater Collection Design

Field investigations (including a pump test) for a system to collect contaminated groundwater from beneath the tailings area will be completed. The results from last year's study, which focussed on the assessment of groundwater collection in the tailings area, will be reviewed and integrated into this work. Preliminary engineering designs and cost estimates will be prepared.

g) Assess Surface Water Management Requirements

Assess possible configurations for managing surface water after the tailings areas are stabilized. Estimate quantities of clean and contaminated surface water. Requirement for collecting guardhouse creek will also be considered. Flow estimates of water quality and quantity will also be conducted.

An initial review of the available groundwater monitoring data for the Rose Creek valley and overlying Tailings Storage Facility (see Appendix A) indicated that surface water and groundwater flow are interrelated and their management should be assessed jointly. The two proposed programs were therefore combined into a single project (see below).

This report has been prepared as part of the ongoing technical evaluation for the closure planning of the Faro Mine. Aspects of this report may have been superceded by subsequent technical studies.

1.2 Scope of Work

A scope of work for this study was presented in a memorandum from Robertson GeoConsultants Inc. (RGC) to Deloitte&Touche Inc., dated September 16, 2004. This memorandum included an initial data review of selected water quality data and is reproduced in Appendix A of this report. The initial data review illustrated the need for a comprehensive water and load balance model to better understand the current (and by extension future) sources of contaminant loading to the Rose Creek aquifer and Rose Creek itself.

The scope of work for tasks 16f&g was modified from the original descriptions stated in the term of references (section 1.1) in order to reflect the findings of the initial data review (Appendix A). Most importantly, the originally proposed hydrogeological field investigations (including pump tests) were replaced by the development of a comprehensive water and load balance model for the Rose Creek Valley (see Appendix A for more details).

The revised scope of work for Tasks 16f&g consists of four main tasks:

- Task 1. Data Review
- Task 2. Water Balance Model
- Task 3. Load Balance Model
- Task 4. Reporting

Task 1 includes a detailed review of groundwater and surface water monitoring data collected in the vicinity of the Rose Creek Tailings Storage Facility. Task 1 also included a detailed review of the available leach testing data for the Rose Creek tailings to estimate the current loading via tailings seepage. A detailed streamflow and water quality survey under baseflow conditions (October 2004) was also included in Task 1 to determine (i) seepage losses from X23/X7 along its flow path to Intermediate Pond; (ii) leakage along Rose Creek Diversion; and (iii) groundwater discharge into Rose Creek.

Tasks 2 and 3 consist of the development of a water and load balance model for the Rose Creek valley aquifer and associated surface water (Rose Creek, Rose Creek Diversion, Faro Creek seepage etc). Load balances were developed for the key constituents sulphate and zinc only. Other constituents may be added at a later stage, if required. The water and load balance model was used to evaluate the following conditions:

- Current Conditions (October 2004);
- Future Conditions assuming no remediation;
- Future Conditions assuming different remediation scenarios.

For each set of conditions, sensitivity analyses were carried out to illustrate the influence of uncertainty in input parameters (e.g. seepage rates, travel time, degree of retardation) on the estimated loading to the aquifer and Rose Creek.

1.3 Previous Work

In 1996, Robertson GeoConsultants Inc. developed a historical water balance for the entire Faro mine site (including the Rose Creek tailings area) as part of the Integrated Comprehensive Abandonment Plan (ICAP) for the Anvil Range Mining Complex (RGC, 1996). This historical water balance covered the period 1990-1995.

In 2000, Anvil Range Mining Corporation (in Interim Receivership) developed a water and load balance for Rose Creek at station X14, i.e. immediately downstream of the Rose Creek tailings facility (ARMC, 2000). This study built on the water balance work developed in the ICAP and provided estimates of summer and winter loads of sulphate and total zinc for the period 1990 to 1995. The study concluded that seepage from the Cross Valley Dam was the primary contributor of sulphate to Rose Creek at X14. However, the model accounted only for 53% of the actual sulphate load observed in Rose Creek at X14. The author suggested that the source for this unaccounted sulphate loading at location X14 could be an underestimation of the contributions from groundwater discharge (ARMC, 2000).

In 2002, this water and load balance model was updated to cover the period 1995 to winter 2000/2001 (GLL, 2002). This model included updated estimates of groundwater recharge and tailings seepage (based on the 2001 groundwater flow model) and additional groundwater monitoring data from recently completed wells for model input (GLL, 2001). This updated model predicted 61% of the observed sulphate loading and 68% of the observed total zinc loading to Rose Creek at station X14 suggesting an “imprecise or unknown source term” (GLL, 2002).

Nicholson and co-workers have carried out independent studies on zinc loading from the Rose Creek tailings facility to Rose Creek (Nicholson et al., 1996; Beak International Ltd., 1999; Stantec Consulting Ltd., 2003). In 1996, the WATAIL model was applied to predict the incremental loadings of oxidation products (SO4 and Zn) from the tailings to the Rose Creek aquifer. The purpose of this initial study was to compare the relative differences in the water quality in Rose Creek resulting from the application of different decommissioning alternatives and the uncertainties within those alternatives.

In 1999, the groundwater monitoring data were reviewed and reconciled with sulphate and zinc loadings predicted using the WATAIL model (Beak International Ltd., 1999). The data review indicated elevated sulphate concentrations in groundwater beneath the tailings facility suggesting contamination by tailings pore water affected by pyrite oxidation. However, it was noted that zinc concentrations were lower than anticipated suggesting the influence of chemical attenuation. The zinc concentrations predicted using WATAIL were found to be in good agreement with observations in Rose Creek but the sulphate concentrations were about a factor of ten lower than the average concentrations observed (Beak International Ltd., 1999).

In 2003, a one-dimensional contaminant transport model was used to calculate zinc migration from the tailings, through groundwater, to Rose Creek (Stantec Consulting Ltd., 2003). For the purpose of this modeling exercise, only the Original and Second Impoundments were considered as a source of soluble sulphate and zinc, with averages of 10.0 and 1.7 kg/tonne, respectively. These values equate to average pore water concentrations of 95,000 mg/L SO4 and 16,150 mg/L Zn, respectively. Using these estimates the maximum predicted concentrations of sulphate and zinc in Rose Creek were about 145 mg/L SO4 and 25 mg/L Zn, respectively (Stantec Consulting Ltd., 2003). The transport model was also used to illustrate the sensitivity of zinc breakthrough in Rose Creek on the uncertainty in groundwater velocity, zinc attenuation and the delay in time prior to tailings relocation.

1.4 Project Review Committee

A project review committee was formed at the inception of this project in order to facilitate input from various stakeholders throughout this project. The project review committee consisted of individuals from the Type 2 Mines Project Office and their consultant (Brodie Consulting Ltd.), Environment Canada (Environmental Protection – Yukon) and their consultant (EcoMetrix Inc.) and the Interim Receiver of ARMC (Deloitte Touche Inc.). Individuals from other consulting firms involved in the closure planning of the Anvil Range Mining Complex (Gartner Lee Limited and SRK Consulting Inc.) also participated regularly in the committee meetings.

The project review committee first met (via conference call) on September 27, 2004 to review the proposed scope of work for this study (Appendix A). Throughout the remainder of the study, regular progress meetings (via conference call) were scheduled with the project review committee to receive feedback on the work completed and to discuss the work still to be completed.

1.5 Acknowledgements

The authors of this report would like to thank all members of the project review committee for their assistance and guidance in this project. The project review committee included the following individuals (in alphabetical order with affiliation shown in parenthesis): John Brodie (Brodie Consulting), Valerie Chort (Deloitte), Eric Denholm (Gartner Lee Limited), Vic Enns (Environment Canada), Daryl Hockley (SRK), Bud McAlpine (Type 2 Mines Group), John Miller (Environment Canada), Ron Nicholson (EcoMetrix) and Bill Slater (Type 2 Mines Group). The authors would also like to acknowledge the assistance of Ken Nordin (Laberge Environmental Services) and Martin Guilbeault (Gartner Lee Limited) in field surveys and data presentation.

1.6 Organization of Report

This report summarizes the methodology and results of the water and load balance study. Section 2 summarizes the results of an extensive data review, including the results of field surveys carried out as part of this study.

Section 3 describes the development of the water and load balance model and section 4 describes the simulation results for current loading conditions.

Section 5 describes the predicted loading for future conditions, assuming no remediation measures are implemented. Section 6 describes the predicted loading for future conditions assuming alternative remediation scenarios are implemented.

Section 7 summarizes the main conclusions of this report.

2 DATA REVIEW & FIELD SURVEYS

2.1 Rose Creek Tailings

2.1.1 Description of Facility

Figure 2.1 shows a layout plan of the Rose Creek tailings facility. The tailings are stored in three separate facilities: (i) the Original Impoundment, (ii) the Second Impoundment and (iii) the Intermediate Impoundment. Table 2.1 summarizes the surface area and the estimated total volume of tailings stored in each facility. Runoff from the Faro mine site and the tailings facility itself is allowed to pond against the Intermediate Dam (referred to as “Intermediate Pond”). The size of the Intermediate Pond varies depending on runoff conditions and water management. Runoff from the Intermediate Impoundment is currently treated (by lime addition) in the Polishing Pond, located immediately downstream of the Intermediate Dam, prior to release into Rose Creek.

Table 2.1

Summary Statistics of Rose Creek Tailings Facility

	Area	**Area**	**Volume**
Tailings Impoundment	m^2	ha	m^3
Original Impoundment	663,761	66	10,884,663
Second Impoundment	289,274	29	5,270,793
Intermediate Impoundment	769,213	77	9,338,767
TOTAL	1,722,248	172	25,494,223

2.1.2 History of Deposition

Table 2.2 provides a brief summary of the history of tailings deposition into the three tailings impoundments in the Rose Creek valley (based on RGC, 1996 and Golder Associates, 2004).

The Original Impoundment received tailings between 1969 and 1975. However, there is evidence that suggests that tailings were deposited in this impoundment intermittently at least until 1979 (as evidenced in aerial photographs). A recent review by Golder Associates (2004) suggests that tailings may have been deposited as recently as 1982. Tailings were deposited from both sides of the Impoundment, resulting in inter-layering of fine and coarse tailings. However, single discharges from the Faro Creek channel during the winter months resulted in the deposition of predominantly coarse tailings in the northwestern section of this impoundment.

The Second Impoundment received tailings from mid-1975 to 1982, at which time production ceased. Tailings deposition re-commenced in 1986 (from June – October), which likely raised the tailings surface by one to two meters. Various deposition strategies were utilized, including coarse tailings spigotted from the crest of the Secondary Dam and various discharges at the toe of the Original Dam.

The Intermediate Impoundment received tailings from 1986 to 1992. Tailings discharge to the impoundment occurred predominantly from the northeast corner just below the Secondary Dam, which resulted in a long beach with fines generally deposited against the Intermediate Dam.

Table 2.2

History of Tailings Deposition

Tailings Impoundment	**Period of Discharge**	**Production (t/yr)**	**Discharge Pattern**
Original Impoundment	Sep 1969 to mid 1975 1975-1979 (intermittent) 1975-1982 (intermittent?)	8,000 t/day	Multiple discharges from original embankment during summer; single discharge from Faro Creek channel during winter
Secondary Impoundment	mid-1975 to Jun 1982 Jun-Oct 1986	13,000 t/day	Multiple discharges along the East and West Dams (summer) and single discharge from Original Dam (winter); From 1978-82, single point discharge from northern hill side and Original Dam
Intermediate Impoundment	Oct 1986 to Jul 1992	13,000 t/day	Single discharge at the northeast corner

2.1.3 Spatial Distribution of Tailings

The tailings deposition and results of various drilling programs were reviewed to develop a spatial zonation of the tailings impoundments suitable for the water and load balance model. A review of the discharge patterns (section 2.1.2) would suggest that a clear segregation into coarse tailings beach and slimes area only occurred in the Original Impoundment (with a coarse beach near the Faro Creek channel) and in the Intermediate Impoundment (coarse beach in the NE and slimes in the S and SW). The frequent changes in discharge points (including seasonal changes) during deposition into the Secondary Impoundment and much of the Original Impoundment likely resulted in significant inter-layering of coarse and fine tailings throughout most of these facilities.

Twenty holes were drilled in the Original and Secondary Impoundments in October 1992 to characterize the tailings (Curragh Resources, 1993). Figure 2.2 shows the drilling locations and a spatial classification of the Original and Secondary Impoundments into (i) “sands”, (ii) “mid” and (iii) “slimes” determined by Environment Canada based on grain size analyses on tailings recovered in these 20 boreholes (V. Enns, pers. com.).

“Sandy” tailings were defined here as tailings with less than 50% passing #200 (or <30% passing #325) and “slimes” were defined as tailings with more than 55% passing #325. The proposed zonation is generally consistent with the reconstructed tailings history, with “sandy” zones (consisting of relatively uniform profiles of coarser tailings) limited to the northern portion of the Original Impoundment and only small reaches in the Secondary Impoundment (downstream of the Original Dam). It should be noted that the intermediate zone (“mid”) also contains fairly fine-grained tailings (intermediate tailings with 30-50% passing #325) and shows significant contributions of slimes. This zone is therefore more akin to a slimes zone than to a coarse beach with respect to its hydraulic properties (i.e., high residual water content, low effective hydraulic conductivity).

The 2001 and 2003 drilling programs completed by Gartner Lee Limited (GLL, 2002, 2003) provide additional information on the spatial zonation of the tailings. Figure 2.3 shows the location of the boreholes and test pits completed as part of the 2001 and 2003 drilling programs. The spatial zonation of tailings developed by Environment Canada for the Original and Second Impoundments is reproduced on Figure 2.3 for ease of comparison. Tables 2.3 and 2.4 summarize relevant results of the 2001 and 2003 drilling and sampling programs carried out in the Rose Creek tailings facility.

Note that the tailings descriptions listed in Tables 2.3 and 2.4 are based on (visual) field descriptions of the tailings. Nevertheless, the field logs of tailings texture generally agree fairly well with the zoning developed earlier by Environment Canada (Figure 2.3). Proximal to the winter discharge point (A7), the coarse beach zone in the Original Impoundment consists of fairly uniform (coarse) tailings, which explains the lack of a water table in this area (A7). At greater distance from the discharge point (e.g. P01-10), an inter-layering of coarser and finer tailings is evident.

The field logs of P03-06 supports the coarse beach area (“sands”) suggested for the northern portion of the Secondary Impoundment (Figure 2.3). However, the coarse beach area suggested for the eastern portion of the Secondary Impoundment (Figure 2.3) appears to be less well-defined, and according to field logs in this area (P01-09A, P03-02, P03-01) represents a complex mix of coarser and finer tailings.

The field logs for boreholes (and test pits) completed in the Intermediate Impoundment generally support a grading trend from the discharge point (NE corner) towards the Intermediate Pond. However, the presence of thick deposits of relatively coarse tailings (silty sand) at P01-05 suggests that the coarse “beach” extends significantly to the south of the impoundment.

In 2003, Golder Associates carried out CPT measurements across several transects to determine the spatial distribution of the tailings stored in the three impoundments (Golder Associates, 2004).The CPT measurements generally indicated significant inter-layering of coarse and fine tailings in the Original and Secondary Impoundments consistent with the variable discharge patterns used over time. Figure 2.3 shows a simplified qualitative interpretation of the CPT logs, classifying the various holes into “coarse”, “intermediate” and “fine” tailings for the upper and lower portion of the tailings deposit. The CPT measurements illustrate that there is significant variability in tailings texture, both across the facilities and also with depth at a given location. While many of the CPT measurements in the upper tailings profile agree with the Environment Canada classification shown in Figure 2.2, many of the CPT measurements in the deeper tailings profile do not.

Table 2.3

Summary of 2001 Drilling & Test Pitting Program

Borehole ID	Depth of Tailings (m)	Depth to SWL^2 (m bTOC)	Depth of Acid Front (paste pH<4.0)	Depth of EC front (paste EC>1,000)	Description of Tailings	Notes
Original Impoundment						
TP1-01	>4.2	N/A	1.5	>4.2	mix of silty SAND & SILT	
A7 (dry test pit)	11.3	>11.3	2.5	>11.3	silty SAND	highly elevated EC profile throughout the tailings profile
P01-08A (A2)	>15.9	12.3	1.5	~10.0	silty SAND over SILT	thick deposit of SILT at depth; frozen at 16.0m
P01-10A (A1)	18.4	9.2	1.5	13.8	interlayered silty SAND & SILT	large drop-off in paste EC across first silt layer
Secondary Impoundment						
TP2-01	>4.2	N/A	1.4	>4.2	predominantly silty SAND	SILT at base of excavation
TP3-01	>4.2	N/A	0.75	>4.2	predominantly SILT	thin top layer of silty SAND
TP4-01	>4.2	N/A	0.75	>4.2	silty SAND over SILT	
TP5-01	>4.2	N/A	0.75	>4.2	interlayered silty SAND & SILT	
TP6-01	>4.2	N/A	~0.5	>4.2	predominantly silty SAND	thin layer of SILT at base of excavation
P01-07A (A4)	24.4	10.9	1.7	12.2	interlayered silty SAND & SILT	very high pH and low EC in SILT suggest residual process water
P01-09A (A3)	13.7	6.0	2	>13.7	silty SAND mixed w/ SILT	elevated paste EC along entire profile
Intermediate Impoundment						
TP7-01	>4.2	N/A	<0.5	>4.2	predominantly silty SAND (non-cohesive)	coarse tails at significant distance from NE discharge point
TP8-01	>4.2	N/A	0.75	>4.2	predominantly silty SAND (non-cohesive)	neutral paste pH at ~4m
P01-05A (A5)	14.9	2.9	<0.5	~11.5	predominantly silty SAND w/ SILT at base (3m thick)	relatively low paste EC throughout profile
P01-06A (A6)	6.5	4.7	N/A	N/A	silty f. SAND to f. SAND	lithology from X21

Note: all depths are in m below ground surface
SWL taken Sept 2003

Table 2.4

Summary of 2003 Drilling Program

Borehole ID	Depth of Tailings (m)	Depth to SWL (m)	Depth of Acid Front (paste pH<4.0)	Depth of EC front (paste EC>1,000)	Description of Tailings	Notes
Original Impoundment						
P03-07	19.1	12.1	1.2	~2.2	f. SAND w/ occasional silt layers	frozen tailings
Secondary Impoundment						
P03-01	10.8	5.5	1.6	8.8	very fine SAND	high paste pH at depth suggest residual process water?
P03-02	12.3	4.6	<0.75	~7.0	fine SAND w/ layers of SILT and CLAY	fairly uniform paste pH & EC throughout tailings profile
P03-03	16.0	6.3	2.2	~10.0	fine SAND w/ silt; ~1m of SILT/CLAY at base	paste pH profile suggests 2 acid fronts
P03-04	13.9	12.6	<0.5	~1.5	fine SAND w/ silt	low paste EC suggests well flushed profile
P03-05	20.1	7.9	1.2	~2.5	interlayered f. SAND & SILT/CLAY	uniform (low) paste EC readings suggest flushing?
P03-06	13.3	12.5	~0.5	~9.0	m.-f. SAND, trace silt	potential for lateral flow in permeable tailings
Intermediate Impoundment						
P03-08	~17.0	4.5	0.5	0	f. SAND interlayered w/ SILT & CLAY	sigificant core losses (underconsolidated slimes?)

Note: all depths are in m below ground surface

The data reviewed in sections 2.1.2 and 2.1.3 were used to develop a simplified classification of the tailings into “coarser” and “finer” tailings zones. The results of this updated zonation of the Rose Creek tailings are presented in section 3.2.

2.1.4 Physical Properties

Selected samples collected during the 2001 drilling program were submitted to a laboratory for grain size analysis and permeameter testing in the Golder Associates laboratories (Eric Denholm, pers. comm.). Table 2.5 summarizes the results of these laboratory tests. The field descriptions are shown for comparison.

In general, the field descriptions agree fairly well with the laboratory results (sample P01-07 at 21.3m is an exception) providing some confidence in the field logging. The coarse tailings (for example at A7) generally represent a silty sand ranging in fines content from ~10-36% (D_{50}=0.1-0.2 mm). The fine tailings (for example at P01-07) represent a silt with a fines content of >95%, a D_{50} = 0.01-0.2 mm and a D_{10}= 0.0001-0.04mm. The results of the permeameter testing were generally consistent with the grain size analyses. The coarse tailings are moderately permeable with a saturated hydraulic conductivity ranging from 1.7*10-3 to 3.4*10-4 cm/s. The fine tailings have a much lower permeability. The saturated hydraulic conductivity of one representative sample (P01-05) was determined to be 9*10-7 cm/s.

Golder Associates (2004) composited several “coarse” sub-samples from P03-05 and P03-06 as well as “fine” sub-samples from P03-04 and P03-08 for further geotechnical characterization work. The “coarse” sub-sample represents a silty SAND with approximately 30% silt-sized or smaller (D_{50}=0.1 mm, D_{10}=0.05mm); the “fine” sub-sample represents a sandy SILT with approximately 66% silt-sized or smaller (D_{50}=0.05 mm, D_{10}=0.005mm). The range in particle-size distribution of these two composite samples is significantly smaller than that previously determined in the 1992 drilling program (likely due to the mixing of sub-samples).

Table 2.5

Summary of 2001 Geotechnical Testing on Tailings Samples

Drill Hole (Field Code)	Depth (m)	Field Description	%sand (>#200)	%fines (<#200)	D50 (mm)	D10 (mm)	Ksat (cm/s) ASTM2434-68
Original Impoundment							
P01-10 (A1-1)	15.2	silt, wet, plastic, grey	6.1	93.9	0.03	0.004	-
P01-08 (A2-1)	15.2	silt, wet, plastic, grey	2	98	0.01	0.0015	-
A7 (A7-1)	4.5	silty sand, moist, non-cohesive, grey	63.8	36.2	0.1	n.a.	1.7*10-3
A7 (A7-1)	7.6	silty sand, moist, non-cohesive, grey	90.2	9.8	0.22	0.007	-
Second Impoundment							
P01-09 (A3-1)	4.5	silty sand, moist, non-cohesive, grey; mixed with plastic wet silt layers	73.5	26.5	0.13	n.a.	3.4*10-4
P01-09 (A3-1)	9.1	silty sand, wet, non-cohesive, grey	76	24	0.13	0.05	-
P01-07[1] (A4-1)	18.3	silty sand, wet, non-cohesive, grey	14.5	85.5	0.05	0.01	-
P01-07 (A4-1)	21.3	silt, wet, plastic, grey	3.6	96.4	0.023	0.0035	-
Intermediate Impoundment							
P01-05 (A5-1)	9.1	silty sand, wet, non-cohesive, grey	54.3	45.7	0.08	n.a.	-
P01-05 (A5-1)	13.7	silt, wet, plastic, grey	3.7	96.3	0.012	~0.001	9.0*10-7

Notes:

[1] field desciption does not match with laboratory results

In 2003, SRK carried out additional physical characterization work on the Rose Creek tailings required for soil cover modeling (SRK, 2004). Guelph permeameter testing on coarse tailings of the Original Impoundment (near P01-10) indicated an in-situ hydraulic conductivity ranging from 1.8-4.4*10-3 cm/s. These readings agreed very well with single ring infiltrometer readings taken on a coarse beach at FA-TB (see Figure 2.3 for location). Single ring infiltrometer readings taken on a slimes portion of the Second Impoundment at FA-TS (see Figure 2.3) ranged from ~9*10-8 cm/s to 3.0*10-5 cm/s. These field measurements are generally consistent with earlier laboratory testing data (Table 2.5).

2.2 Tailings Geochemistry

Mehling Environmental Services carried out a detailed geochemical characterization program of the Rose Creek tailings as part of the 2001 drilling program (GLL, 2002). This program included detailed field logging of texture and paste pH/EC during drilling and test pitting and leach extraction testing on drill cuttings. Field logging of paste pH/EC on drill cuttings was also carried out during the 2003 drilling program on the tailings impoundments (GLL, 2003).

The results of this characterization work was reviewed by John Chapman (SRK Consulting) as part of this study to estimate source concentrations in tailings seepage for input into the load balance model (see Appendix B for details). This section provides a summary of the review of the tailings characterization data.

2.2.1 Development of Chemical Fronts in Tailings Profile

Earlier investigations (GLL, 2002) have shown that a number of fronts have developed in the tailings which include:

i) an acid front which has a low pH and elevated metal concentrations,

ii) an elevated zinc concentration front, and

iii) a neutral high TDS front containing elevated concentrations of sulphate and some metals.

There is also evidence of an oxidation front that has developed, which is shallow compared to the TDS and acidic fronts. The development of these fronts will have been influenced by the method and timing of tailings deposition, which will have led to segregation (particle size) and inundation of pre-existing fronts.

The development of such “chemical fronts” is related to the tailings deposition in a given impoundment. The following observations can be made about the potential develoment of fronts in the various impoundments:

Original Tailings Impoundment

Tailings were deposited in the Original Impoundment until 1975. However, there is evidence that suggests that tailings were deposited in this impoundment intermittently at least until 1979 (as evidenced in aerial photographs). A recent review (Golders, 2004) suggests that tailings may have been deposited as recently as 1982. Because tailings were deposited from both sides of the impoundment, generally inter-layering of fine and coarse tailings resulted across this tailings deposit.

Intermittent tailings discharge after 1979 would have resulted consecutively in the oxidation of the surface tailings, formation of a high TDS/Zn front, and, possibly an acid front. Following deposition of a fresh layer of tailings, the existing oxidation zone would have been inundated by process water, probably neutralizing the acid front, and likely accelerating the rate of transport of the TDS/Zn front. A new oxidation front would develop at the surface of the newly deposited tailings and the process would be repeated. The net result is that several fronts could have been formed during the period of intermittent deposition, which are not necessarily associated with the current oxidation zone. This may also explain some of the ‘smaller’ fronts that have been detected in the tailings.

Secondary Tailings Impoundment

Tailings were deposited in the Second Impoundment from mid 1975 to 1982, at which time production ceased. Tailings deposition occurred again in 1986 (from June to October), which likely raised the tailings surface by between one and two meters.

Various deposition strategies were utilized, including coarse tailings spigoted from the crest of the secondary dam and various discharges at the toe of the original dam. The result would have been to push the fines to the centre of the impoundment.

As for the Original Impoundment, the period of inactivity between 1982 and 1986 would have led to the oxidation of surface tailings and the concurrent formation of TDS/Zn and acid fronts. Inundation occurred in 1986 and the oxidation front would have been re-adjusted to the current surface of the tailings deposit.

<u>Intermediate Tailings Impoundment</u>

Tailings were deposited in the Intermediate Impoundment from 1986 to 1992. Tailings discharge to the impoundment occurred predominantly from the north east corner just below the secondary dam, which resulted in a long beach with fines generally deposited against the intermediate impoundment. A pond remains against the intermediate dam, indicating that the fines are fully saturated.

As noted, the long beach, which resulted from the deposition strategy consists predominantly of coarse tailings. These exposed tailings will have been oxidizing since deposition in the impoundment ended. The seasonal variation of the pond size will have affected the extent of oxidation. CPT testing (Golders, 2004) and drill logs (GLL, 2002) have also shown that while the upstream tailings are coarser, some coarse-fines interlayer is evident in these tailings.

2.2.2 Tailings Pore Water Quality

Pore water quality has been obtained for saturated tailings from the wells installed in the tailings. However, to date, actual pore water from the unsaturated tailings, which is of interest for this evaluation, has not been extracted and analyzed. Therefore, the primary source for estimating solute concentrations in pore water are the results from the leach extraction tests completed in 2001. The results from these tests together with measured moisture contents at corresponding depths were used to estimate the pore water concentrations. It should be noted that the leach extraction tests reflect oxidizing conditions, whereas below the oxidation zone in the tailings anoxic conditions prevail which will effect the concentrations of some parameters including iron. It should also be noted that these calculations are sensitive to the moisture content and hence are likely prone to error, but nonetheless serve as a ‘starting point’ for estimating pore water concentrations.

The results for the Original impoundment are shown in Table 2.6, those for the Second Impoundment in Table 2.7 and the results for the Intermediate Impoundment are shown in Table 2.8. The tables show a corrected sulphate concentration, which has been corrected for gypsum precipitation; however, only the original calcium concentrations are shown. A series of plots representing these data have also been prepared and are included in Appendix B. The following observations can be drawn from these tables and graphs:

- The presence of residual process water is clearly evident from the sodium concentrations (see also section 2.3). Depending on the sodium concentrations in the process water, it is possible that the pore water concentrations may have been overestimated by a factor of 2 or more in some cases.

- The acid fronts and associated metal concentrations in the Original Impoundment are very similar and appear to be “mature”, i.e. concentrations have peaked and are unlikely to exceed the concentrations shown.

Table 2.6

Summary of calculated pore water concentrations in the Original Impoundment

Location		**pH**	**Sulphate (mg/L)**	**Sulphate Corrected (mg/L)**	**Calcium (mg/L)**	**Iron (mg/L)**	**Magnesium (mg/L)**	**Sodium (mg/L)**	**Zinc (mg/L)**
P01-10 - Original - Fines									
A1-1	0.5	1.1	92321	81348	4972	26509	311	0	1274
A1-1	1	1.0	662278	632671	12736	293440	2802	0	42691
A1-1	1.5	2.2	153497	140795	5693	8031	4134	0	46761
A1-1	2.5	2.3	86128	81737	2230	2489	6169	0	34665
A1-1	3.5	2.4	71005	65607	2649	16659	2130	0	12836
A1-1	4	2.4	72231	70439	1147	27335	1558	0	7819
A1-1	4.5	2.6	100529	90838	4438	20678	4040	0	18133
A1-1	7.6	5.3	27451	15057	5564	1	2311	95	2374
A1-1	12.2	2.9	12052	9058	1647	629	315	287	2731
A1-1	13.7	5.9	6849	2280	2304	0	181	224	626
A1-1	15.2	6.6	5039	1084	2048	0	182	211	45
A1-1	16.8	6.5	1904	764	875	0	124	159	14
P01-08 - Original - Fines									
A2-1	0.5	1.3	123717	103497	8825	9403	4512	0	15836
A2-1	1	0.8	224401	202497	9527	39237	3803	0	32115
A2-1	1.5	1.9	184678	152003	14015	8186	21218	0	16765
A2-1	3	2.3	327267	265448	26158	7789	32961	0	47741
A2-1	4	2.3	211862	177579	14685	6950	26230	0	16478
A2-1	4.5	3.1	411750	367472	18849	20862	52155	**1464**	34404
A2-1	6.1	4.5	25324	23351	1222	918	3588	317	1864
A2-1	7.6	3.2	47283	40558	3202	1826	5216	483	5747
A2-1	9.1	5.3	6229	3885	1376	0	756	83	210
A2-1	10.7	6.2	2137	743	981	0	92	57	44
A2-1	12.2	7.0	2157	235	1200	0	193	53	8
A2-1	13.7	6.5	3118	980	1291	0	57	99	66
A2-1	15.2	6.1	4380	1771	1487	1	208	41	89
Original Coarse									
A7-1	0.5	0.59	136187	117733	8089	38655	937	0	4838
A7-1	2	1.01	196122	167937	12144	23768	974	0	44550
A7-1	2.5	1.87	164081	140663	10157	4818	10591	0	39761

Table 2.7

Summary of calculated pore water concentrations in the Second Impoundment.

Location		pH	Sulphate (mg/L)	Sulphate Corrected (mg/L)	Calcium (mg/L)	Iron (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Zinc (mg/L)
P01-09 Second Impoundment Coarse									
A3-1	0.5	1.1	213120	202514	4819	79488	1096	0	8448
A3-1	1.5	1.8	83632	80230	1817	6546	2187	0	24446
A3-1	2	2.4	141708	134732	3307	4760	6335	0	59686
A3-1	3	2.3	85756	80977	2391	1763	4248	0	39405
A3-1	4	2.8	67507	62197	2612	835	4656	0	22502
A3-1	6.1	3.0	33550	32118	997	4972	1276	0	10296
A3-1	7.6	2.9	19484	18149	956	5160	1024	0	1828
A3-1	9.1	3.4	20047	15468	2308	126	2282	53	2229
A3-1	10.7	3.2	36429	30360	2929	886	3191	119	6381
A3-1	12.2	3.2	31201	24461	3208	977	1484	118	7977
A3-1	13.7	3.7	10306	6028	2182	49	375	495	1020
P01-07 - Second - Fines									
A4-1	0.5	1.58	95818	92439	1808	39238	1054	0	4335
A4-1	1	2.19	79255	73010	3002	17412	1397	0	13825
A4-1	1.5	1.81	157978	148303	4431	34789	4078	0	26946
A4-1	2	2.87	76675	73577	1690	18263	2460	0	12497
A4-1	2.5	1.23	164391	146466	7869	15086	10124	0	39043
A4-1	3	2.34	37228	34609	1491	5087	2197	0	5145
A4-1	4	4.81	13452	12397	840	1345	1370	65	2087
A4-1	4.5	5.27	12417	9515	1609	118	1229	76	1432
A4-1	6.1	4.03	11155	3823	3455	2	913	117	586
A4-1	7.6	4.48	7400	5173	1328	1	674	145	380
A4-1	9.1	6.79	5895	2157	1958	0	290	247	50
A4-1	10.7	6.77	2812	2111	692	0	87	414	7
A4-1	13.7	7.08	2951	1064	1186	0	161	304	7
A4-1	15.2	4.56	17003	7413	4396	18	441	329	2492
A4-1	16.8	5.22	1700	1409	522	0	49	88	98
A4-1	18.3	3.33	8830	5883	1628	115	330	304	1218
A4-1	19.8	5.98	4835	2356	1433	0	154	416	17
A4-1	22.9	4.22	5052	3505	1045	2	149	190	978

- Iron concentrations are elevated only in the acidic zone, which is an artefact of the leach extraction testing (i.e. oxidizing conditions) since porewater for example in X21A has elevated iron concentrations at depth. The reducing conditions at depth maintain iron as ferrous and prevent oxy-hydroxide formation.

- Maximum zinc concentrations in the pore water appear to be on the order of about 40,000 to 50,000 mg/L. If indeed the pore water concentrations are overestimated by a factor of 2, then the maximum concentrations would be in the order of about 20,000 to 25,000 mg/L

Table 2.8

Summary of Estimated Pore water Concentrations in the Intermediate Impoundment

Location		pH	Sulphate (mg/L)	Sulphate Corrected (mg/L)	Calcium (mg/L)	Iron (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Zinc (mg/L)
P01-05 Intermediate - Coarse									
TP-7	0	0.8	179705	168673	4997	80893	1229	0	5376
TP-7	0.5	2.6	54940	41889	5838	286	5910	0	2572
TP-7	1	5.4	374174	299084	31688	1641	30906	0	61118
TP-7	1.5	5.1	10382	7006	1807	0	1004	0	860
TP-7	2	5.2	8661	5822	1583	0	1305	57	233
TP7	3.5	6.2	8604	3362	2584	0	789	86	30
A5-1	4.5	5.7	2577	1586	813	0	112	42	79
A5-1	6.1	3.1	1886	2264	243	166	105	28	351
A5-1	7.6	5.7	2825	1813	822	0	135	117	92
A5-1	10.7	3.2	4817	3691	869	215	322	85	520
A5-1	12.2	7.0	2590	1399	896	0	196	125	6
A5-1	13.7	6.7	5188	1983	1735	0	259	141	20

2.2.3 Implications for Tailings Loading Model

The back-calculated profiles of pore water concentrations (Table 2.6 to 2.8) were used to develop a source model of current and future loading from the tailings to the aquifer. This tailings loading model provided a critical input to the water and load balance model. The modeling approach and the estimated sulphate and zinc loads for different reaches of the Rose Creek tailings facility are described in section 3.2.

2.3 Groundwater Quality

A detailed review of all available groundwater quality monitoring data (until mid-2004) was carried out as part of this project. The results of this review, including time trend plots of selected constituents for all monitoring wells, are provided in Appendix C. This section summarizes the major findings of this review. For a more detailed discussion and data presentation the reader is referred to Appendix C.

One aspect of the review was to evaluate which wells might be compromised by potential internal leakage (see Appendix C for details). The following conclusions can be drawn with respect to the “integrity” of the monitoring wells completed in 2001 and 2003:

- The groundwater quality data collected from the P01 wells is suspect due to leakage of highly impacted tailings pore water from the upper (oxidized and potentially acidic) tailings profile into the well bore; however, initial monitoring data collected in the fall 2001 are likely representative of “true” groundwater quality in the aquifer (at that time);
- The groundwater quality data collected in the P03 wells appears to be generally representative of “true” groundwater quality (where screened in aquifer) and “true” tailings pore water (where screened in tailings).

These observations suggest that only the initial 2001 monitoring data from the P01 series of wells can be used for calibration of the water and load balance model (section 4). In contrast, there are no limitations on the use of monitoring data from the P03 series of wells for model calibration. These initial conclusions are supported by additional field testing carried out in the summer of 2004 (GLL, 2005).

For all monitoring stations summary statistics were prepared for four selected constituents: sulphate, magnesium, sodium and zinc. For existing compliance stations (“X-wells”) and the P03 wells, all available monitoring data between 2003 and 2004 were used. For the P01 wells, only the initial readings (in Sep 2001) were used. Table 2.9 shows summary statistics for those wells screened into tailings, i.e. representing tailings pore water quality. Table 2.10 shows summary statistics for those wells screened into the upper 5m of the Rose Creek aquifer, i.e. representing shallow groundwater. Table 2.11 shows summary statistics for those wells screened at greater depth (>5m) in the Rose Creek aquifer, i.e. representing deep groundwater. Note that Tables 2.10 and 2.11 only list those wells screened directly beneath the tailings. Table 2.12 shows summary statistics for those wells that are screened in the Rose Creek aquifer downgradient of the tailings, i.e. along the Intermediate and X-Valley Dams and further downgradient in the Rose Creek Valley.

Figures 2.4 and 2.5 show the spatial distribution of sulphate and zinc for the tailings pore water (piezos screened in tailings), the upper aquifer (piezometers screened in upper 5m of aquifer) and lower aquifer (piezometers screened at depths greater than 5m in aquifer). The following conclusions can be drawn from an inspection of Tables 2.9 to 2.12 and Figures 2.4 and 2.5:

- Pore water in the Rose Creek tailings shows a very large variability ranging from dilute process water (e.g. P01-08A, P01-07A, P03-08-7) to highly concentrated seepage from the oxidation zone (e.g. P03-01, P03-05, P01-09A); the most likely factors for these differences are (i) time since deposition **and** (ii) physical characteristics of tailings controlling “flushing rate” and depth of oxidation;
- Most of the highly concentrated tailings pore water also shows highly elevated Na concentrations (e.g. 600-700 mg/L in P03-01); the only significant source of Na would have been the process water originally discharged with the tailings slurry (e.g., ~ 150 mg/L at P01-07A); the cause for highly elevated Na in tailings pore water dominated by water percolating from the upper oxidation zone is currently not understood;

Table 2.9

Water quality statistics of tailings pore water.

Borehole ID	SO4 (mg/L)			Mg (mg/L)			Na (mg/L)			Zn (mg/L)		
	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average
Original Impoundment												
P01-08A	206	206	206	6.6	6.6	6.6	90	90	90	0.024	0.024	0.024
P01-10A	298	298	298	5.1	5.1	5.1	305	305	305	0.284	0.284	0.284
Secondary Impoundment												
P01-07A&B	349	360	355	1.1	1.2	1.15	267	363	315	<0.005	<0.005	<0.005
P01-09A	20,000	20,000	20,000	571	571	571	155	155	155	658	658	658
P03-01 (#8-9)	3,040	44,500	20,702	77	714	447	370	693	565	57	2330	1246
P03-02 (#7-9)	2,680	22,500	11,287	237	400	321	128	465	277	0.010	0.040	0.025
P03-03 (#7-9)	404	19,000	8,891	7	391	188	9	306	190	0.052	114	29
P03-04 (#8-9)	1,380	9,410	5,637	11.4	109.0	59.6	16	46	25	0.024	2.730	1.248
P03-05 (#6-8)	1,440	6,750	4,129	133	397	254	221	319	267	0.005	0.849	0.165
P03-06 (#6-7)	1,450	1,450	1,450	50.1	50.1	50.1	29	29	29	0.609	0.609	0.609
Intermediate Impoundment												
P01-05A	1,210	1,210	1,210	45.2	45.2	45.2	173	173	173	0.15	0.15	0.15
X21A	1,730	9,840	6,580	151	990	662	28	63	43	1.06	16	10
P03-08 (#7-8)	47	1520	451	5.8	22.1	12.6	31	181	103	0.005	0.017	0.011

Notes:
P01 series: initial reading in Sep 2001
P03 series: Sep 2003 - Sep 2004
X series: 2003-2004

- Sulphate concentrations in groundwater (beneath the tailings) generally increase from the upstream end (P03-01) to the downstream end (P03-09); however, this increase is not very systematic (in particular at very shallow depth below the tailings), likely due to large local variations in loading from the tailings deposits;
- Detailed monitoring of groundwater quality with depth in the aquifer (using multi-level piezometers) indicates a characteristic “dilution profile” in the upper reaches of the valley (beneath tailings), with highest concentrations of oxidation products (SO4, Mg, Zn) just below the tailings-aquifer interface and significantly lower concentrations at greater depth;
- The northern portion of the aquifer shows significantly higher SO4 and Mg concentrations than the southern portion; while this spatial pattern is very consistent in all monitoring stations located at and downstream of the Intermediate Dam, this spatial pattern is **NOT** apparent (and may even be reversed) in the upstream sections of the valley (beneath the Original and Secondary Impoundment);
- The groundwater quality improves markedly within a short distance downstream of the Cross Valley Dam (even on the north side) suggesting very localized discharge of “impacted” groundwater and/or dilution by “clean” groundwater (e.g. from the Rose Creek Diversion); the groundwater flow and discharge pattern in this reach is critical for evaluating the loading to Rose Creek via groundwater;

- The transport of zinc in the aquifer generally lags behind that of SO4 and Mg with significantly elevated zinc concentrations (say >0.1 mg/L) only observed at shallow depth below the Original/Secondary Impoundment[1];

Table 2.10

Groundwater quality statistics in shallow aquifer (<5m) beneath tailings.

	SO4 (mg/L)			Mg (mg/L)			Na (mg/L)			Zn (mg/L)		
Borehole ID	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average
Original Impoundment												
P01-08B	342.0	342.0	342.0	23.2	23.2	23.2	32.0	32.0	32.0	0.7	0.7	0.7
P01-10B	94.0	94.0	94.0	11.8	11.8	11.8	54.0	54.0	54.0	0.01	0.01	0.01
P03-07 (#4-5)	613	613	613	46	46	46	64	64	64	0.011	0.011	0.011
Secondary Impoundment												
P01-07C	370	370	370	26.5	26.5	26.5	40	40	40	<0.005	<0.005	<0.005
P01-09B	711	711	711	34.7	34.7	34.7	19	19	19	12.4	12.4	12.4
P03-01 (#6-7)	178	8,360	1,685	5	158	37	20	407	142	2	189	41
P03-02 (#4-6)	176	5,160	2,651	10	365	202	7	530	315	0.005	0.077	0.023
P03-03 (#5-6)	388	763	522	22	38	27	26	103	47	0.007	0.033	0.017
P03-04 (#6-7)	1,390	10,100	5,505	31	130	97	31	122	75	0.7	6.5	3.9
P03-05 (#4-5)	336	1,190	691	23	75	44	10	50	27	<0.005	0.047	0.014
P03-06 (#4-5)	331	1,160	614	12	66	35	19	37	25	0.04	9.77	2.24
Intermediate Impoundment												
P01-05B	780	780	780	35	35	35	47	47	47	0.074	0.074	0.074
P01-06	2,610	2,610	2,610	281	281	281	39	39	39	1.02	1.02	1.02
X21B	446	1010	667	31	46.1	36	60	63.4	61	0.114	4.23	1.150
P03-08 (#4-6)	147	1,560	878	9	61	34	31	181	100	0.009	0.633	0.126

Notes:
P01 series: initial reading in Sep 2001
P03 series: Sep 2003 - Sep 2004
X series: 2003-2004

---

[1] elevated Zn concentrations observed at great depth in P03-03 are uncharacteristic and clearly suggest leakage from P01-09C and/or P01-09D

Table 2.11

Groundwater quality statistics in deep aquifer (>5m) beneath tailings.

Borehole ID	SO4 (mg/L)			Mg (mg/L)			Na (mg/L)			Zn (mg/L)		
	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average
Original Impoundment												
P01-08C	482	482	482	28.4	28.4	28.4	15	15	15	0.73	0.73	0.73
P03-07 (#1-3)	511	1,870	1,127	27	121	62	26	212	116	0.027	1.410	0.520
Secondary Impoundment												
P01-07D&E	433	580	507	36.5	39.3	37.9	30	30	30	0.011	0.017	0.014
P01-09C&D	623	1180	902	31.9	48.9	40.4	16	17	16.5	13.4	43.7	28.55
P03-01 (#1-5)	18	280	95	5	18	12	2.0	9.0	4.7	0.005	0.032	0.011
P03-02 (#1-3)	47	151	87	7	13	10	2.6	4.0	3.1	0.005	0.011	0.007
P03-03 (#1-4)	3	1,860	504	10	54	22	6.0	16.3	10.2	0.006	148	27
P03-04 (#1-5)	14	908	548	5	51	31	3	106	45	0.006	0.109	0.036
P03-05 (#1-3)	312	688	433	23	41	30	10	26	15	0.006	0.078	0.017
P03-06 (#1-3)	386	967	704	34	66	49	12	58	35	0.007	1.240	0.279
Intermediate Impoundment												
X21C	7.7	10.7	9	8.87	10	9	3.0	4.8	3.7	0.006	0.046	0.020
P03-08 (#1-3)	33	154	96	21	30	25	2.6	15.1	8.9	0.005	0.011	0.008

Notes:
P01 series: initial reading in Sep 2001
P03 series: Sep 2003 - Sep 2004
X series: 2003-2004

Table 2.12

Groundwater quality statistics downstream of tailings.

Borehole ID	SO4 (mg/L)			Mg (mg/L)			Na (mg/L)			Zn (mg/L)		
	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average
Intermediate Dam												
P01-03	1130	1130	1130	82	82	82	41	41	41	0.011	0.011	0.011
P01-04 (A&B)	43	399	171	28	51	40	40	72	55	<0.005	<0.005	<0.005
X24 (A-D)	598	1450	1158	43	100	81	26	47	37	0.003	0.056	0.021
X25 (A&B)	229	366	295	25	31	28	21	53	37	<0.005	0.021	0.007
Cross Valley Dam												
P01-02 (A&B)	119	383	181	21	104	42	11	16	13	<0.005	0.234	0.033
P01-11	812	862	845	50	60	54	43	48	45	<0.005	0.007	0.004
P03-09 (1-9)	323	443	379	22	58	38	19	50	35	<0.005	0.009	0.005
Downstream of Cross Valley Dam												
P01-01(A&B)	212	580	425	35	53	42	23	85	36	<0.005	0.068	0.016
X16 (A&B)	22.0	35.2	26.5	10.6	17.1	13.7	<2.0	<2.0	<2.0	<0.005	0.010	0.005
X17 (A&B)	32.5	65.0	43.6	19.3	32.4	24.1	2.0	27.5	9.5	<0.005	<0.005	<0.005
X18 (A&B)	378	596	492	39	49	44	19	24	21	<0.005	0.011	0.006

Notes:
All series: 2003-2004

These observations assisted in the development of a conceptual framework for the water and load balance model. The implications for the modeling work proposed for this study can be summarized as follows:

- Source terms (e.g. SO4 concentrations & loads) for the load balance model need to be defined for sub-regions of the Rose Creek tailings, taking into consideration time of deposition and hydrogeological properties (e.g. PSD, water table depth); as a first approximation, the three impoundments will therefore be subdivided into a “coarse” zone with favourable conditions for tailings oxidation and seepage and a “finer” zone representing less favourable conditions;
- Local heterogeneity in loading and resulting groundwater quality cannot be included in the proposed loading model; hence, groundwater quality data will only provide limited constraints (i.e. upper and lower bounds) to the load balance model; “calibration” of the load balance model will primarily be achieved by matching measured (and estimated) loads discharging to surface and entering Rose Creek below the Cross Valley Dam;
- The water and load balance model will be subdivided into a northern and southern portion to account for the significant differences in observed groundwater quality between the north and south side of the aquifer; the model will also include spatially distributed source terms (e.g. seepage from X23 along the north side, leakage from Rose Creek Diversion along the south side) in order to allow an assessment of likely factors contributing to this spatial distribution;
- Natural attenuation (sorption and precipitation/dissolution) along the flow path (within the tailings profile and in the aquifer) are responsible for the delay in Zn breakthrough in the aquifer; the water and mass balance model cannot be “calibrated” using observed zinc concentrations since the system has not reached steady-state; attenuation of zinc in the system will have to be accounted for in the load balance model.

2.4 Surface Water Quality

This section reviews the historical water quality of those surface water monitoring stations, which are critical for an understanding of the interaction of groundwater and surface water in the Rose Creek valley. Figure 2.6 shows the locations of the existing surface water monitoring stations in the Rose Creek Valley.

2.4.1 Faro Creek Channel

Waste rock dump (WRD) seepage from the Faro Dumps discharges into the old Faro Creek valley (“Emergency Tailings Area”) as surface flow (X23) and as subsurface seepage (SRK-04-3A/B). Much of the subsurface seepage discharges south of the access road (“X7”) and mixes with seepage from X23 along the Faro Creek Canyon (Figure 2.6).

The combined seepage is diverted along the northern side of the Secondary Impoundment and is allowed to flow into the Intermediate Pond. This water is highly contaminated and represents a significant source of acid rock drainage (ARD) load to the Rose Creek Valley system. Figure 2.7 shows the water quality time trends observed at X23 (toe of WRD) and X7 (below access road). The WRD seepage has experienced a significant rise in ARD products (SO4, Mg and Zn) over the last 18 years. Significant “flushing” of oxidation products with peak zinc concentrations as high as 1,000 mg/L have been observed in fall 2000 and fall 2004. At estimated flow rates in the order of 2 to >10 L/s, this surface flow clearly represents a significant ARD load to the system. Visual observations suggest that a significant quantity of this seepage is lost to groundwater (or tailings pore water?) before it reaches the Intermediate Pond. Detailed flow surveys were therefore carried out as part of this study to quantify the amount of loss along the flow path (see section 2.5 below).

2.4.2 Intermediate and Cross Valley Ponds

The Intermediate and Cross Valley Ponds represent storage reservoirs, which may receive inflows from surface (e.g. X23 and surface runoff) and/or subsurface (tailings pore water, groundwater). Figure 2.8 shows the water quality time trends at X4 (Intermediate Pond at spillway) and X5 (Cross Valley Pond at spillway).

Between 1986 and 1992, the intermediate pond collected the decant from tailings discharge (“process water”) and the Cross Valley Pond served as a polishing pond without additional (lime) treatment. During this period, the two ponds showed very similar water quality with SO4 averaging ~400 mg/L, Mg ~20 mg/L, Na ~125 mg/L and Zn ~0.1-1.0 mg/L. This water quality is likely representative of process water for this period.

After 1992, tailings were no longer discharged and zinc concentrations in the Intermediate Pond began to rise significantly. In order to control the release of zinc, lime has sine been added to the water discharged from the Intermediate Pond, either along the spillway of the Intermediate Dam or (more recently) directly into the Polishing Pond. The effect of this liming is clearly visible in the disparate zinc concentrations in the two ponds since 1992.

In recent years, SO4 in the Intermediate Pond has ranged from 500-750 mg/L and Mg from 40-70 mg/L. These concentrations are lower than typical groundwater concentrations along the north side of the valley (Figures 2.4 and 2.5), suggesting that seepage from the Intermediate Pond is not the primary source of ARD to the aquifer. A similar argument can be made for the Polishing Pond, which has even lower SO4 and Mg concentrations than observed in the Intermediate Pond.

2.4.3 Seepage along toe of Cross Valley Dam

Seepage along the toe of the Cross Valley Dam is monitored at stations X11 (north side), X12 (south side) and X13 (combined seepage). Figure 2.9 shows water quality time trends at these stations. The following observations can be made:

- Both seeps show similar general trends with a breakthrough of Na between 1986-1992 (discharge period), followed by a general increase in SO4 and Mg; these general trends are similar to those observed in the Intermediate and X-Valley Pond,

- The north side seep (X11) dominates water quality at X13 because this seep represents the majority of total seepage flow (not shown); sulphate concentrations in this seep have been significantly above those of the Cross Valley Pond in recent years suggesting significant discharge of groundwater from the aquifer;

- The south side seep (X12) shows significantly lower concentrations of SO4, Mg and Na than the north side seep throughout the observation period, the fact that Na concentrations during the early discharge period also remained well below those observed in the Polishing Pond would suggest that this seep receives contributions of “clean” groundwater (perhaps leakage from the Rose Creek Diversion)

In summary, the seep water quality data are consistent with groundwater monitoring data indicating significant differences in groundwater quality between the north and the south side. They also demonstrate that seepage from the Polishing Pond is not the only source of seepage below the Cross Valley Pond but instead is augmented by discharge of local groundwater.

2.4.4 Rose Creek

Rose Creek is of particular interest in this study as it represents the primary aquatic habitat downstream of the Rose Creek tailings facility, which receives toe seepage and potentially impacted groundwater from the tailings facility. Rose Creek is monitored for water quality at station X3 (in Rose Creek upstream of Rose Creek tailings facility), X10 (in Rose Creek Diversion Canal before confluence with X-Valley seepage) and X14 (in Rose Creek downstream of confluence with Cross Valley seepage). Figure 2.10 shows the water quality time trends at these three stations over time.

The following observations can be made:

- The water quality at X3 and X10 track fairly well suggesting very little influence of tailings seepage into the Rose Creek Diversion (along the reach of the Original and Secondary Impoundment);

- The discharge of seepage from the Cross Valley Dam area (just downstream of X10) results in significant increases in SO4, Mg and Na in Rose Creek, in particular during base flow conditions; note, however, that both high and base flow concentrations for SO4 (and Mg) at X14 have not increased over the 19 years of record despite the general increase in SO4 (and Mg) in the toe seepage;

- Na concentrations have declined at X14 as a result of cessation of tailings discharge in 1992 (and associated discharge of process water with elevated Na);

- Total zinc concentrations in Rose Creek have been fairly steady (since 1995) with maximum concentrations during base flow of about 0.1 mg/L; the trends of zinc differ from those of SO4, Mg and Na in that there is very little incremental increase in total zinc between X10 and X14 suggesting that the primary loading of zinc occurs upstream of the Cross valley Dam;

The water quality in Rose Creek clearly shows strong seasonal fluctuations due to the large variations in stream flow. The greatest impact of tailings seepage can be expected at times of low flow conditions. For this reason, the water and load balance model will be developed for low flow conditions (see section 3).

One of the primary calibration targets for the proposed water and load balance model are the sulphate and zinc loads associated with toe seepage and groundwater discharge to Rose Creek downstream of the Cross Valley Dam. In order to calculate constituent loads, constituent concentrations and flow rates need to be known. Unfortunately, reliable flow measurements in the Rose Creek valley are only available for Rose Creek at station X14. For this reason, detailed synoptic surveys of flow and water quality of all surface flows (including Rose Creek and toe seepage downstream of Cross Valley Pond) were carried out during low flow conditions as part of this study (see section 2.5 below).

2.5 Field Surveys

Laberge Environmental Services of Whitehorse, Yukon, carried out two field surveys as part of this project to determine stream flow and constituent loading in various streams and seeps in the Rose Creek Valley. The first survey was carried out on October 19-20, 2004 under moderate low flow conditions (~500 L/s at X14). The second survey was conducted on April 15-17, 2005 under winter base flow conditions (~235 L/s at X14).

The field survey included flow measurements at 27 locations along three reaches including (i) old Faro Creek valley to Intermediate Pond, (ii) Rose Creek Diversion and (iii) downstream of X-Valley Dam (see Figures 2.12 and 2.13 for locations). At each location, the flow rate was measured using one of several techniques including (i) stop-watch and bucket (ii) flow meters, and/or (ii) salt dilution methods. In addition, pH, specific conductivity (S.C.) and/or total dissolved solids (TDS) were measured at each monitoring station and a water sample was obtained for laboratory analysis.

All water samples were submitted to ALS Environmental Laboratories in Vancouver for analysis. The samples collected during the October 2004 survey were analysed for specific conductance, sulphate and total metals. The samples collected during the April 2005 survey were analysed for a full suite of analytes, including specific conductance, sulphate, Br, Cl, nitrate, nitrite, total metals and dissolved metals. Dissolved metals were analysed on samples filtered through a 0.45µm filter and preserved in the field. QA/QC analyses included duplicate samples, field blanks, filter blanks and internal replicate analyses.

The following sections briefly summarize the findings of these two surveys. The complete chemical analysis reports for the two surveys are provided in Appendix D.

2.5.1 Results of October 2004 Field Survey

Figure 2.11 shows the stream flow in Rose Creek at station X14 (downstream of Rose Creek Diversion). The plot illustrates that the field survey was undertaken under low flow conditions as a result of very dry and cold weather in the days preceding the survey. The Rose Creek stream flow at X14 averaged about 500 L/s during the 2-day survey. This value is approximately twice the estimated 2-year 7-day low flow for this station of 240 L/s (Pat Bryan, pers. comm.).

Table 2.13 summarizes the flow measurements and selected water quality results (pH, S.C., sulphate and total zinc). These results are also reproduced on an air photo of the Rose Creek valley showing the location of the various monitoring stations along the upper reach (Figure 2.12) and the lower reach (Figure 2.13) of the study area.

Table 2.13

Summary of October 2004 Field Survey

				Water Quality (Field)		Water Quality (Lab)	
Station ID	Location	Oct' 2004 Date/Time	Flow (L/s)	Spec. Cond. (uS/cm)	pH	SO4 (mg/L)	Zn_T (mg/L)
Reach 1							
RC1	Rose Crk u/s of Next Creek inflow	19/16:00	678	549	7.77	108	0.0328
RC2	Rose Creek between Next Creek confluence and R2	19/15:00	715	557	7.77	112	0.0317
RC3	Rose Creek at R2	19/13:50	601	557	7.68	-	-
RC4	Rose Creek at X14	19/12:20	505	558	7.67	116	0.0348
RC5	Rose Creek halfway between X14 & inflow of X Valley seepage (channel)	19/11:00	473	578	7.61	-	-
CVS1	X-Valley seepage just u/s of confluence with Rose Creek flow	19/10:15	83	1481	7.42	532	0.0196
CVS2	X-Valley seepage just u/s of confluence with Northwall Interceptor trench	19/17:20	76	1537	7.21	587	0.0054
CVS3	North wall interceptor trench just u/s of inflow into X-Valley seepage channel	19/17:05	0.5	860	7.35	236	0.1
CVS4	combined seepage from X-Valley Dam (at X13)	19/17:40	31.3	1640	7.37	719	0.0054
CVS5	North side seepage from X-Valley Dam (at X11)	19/17:30	10.2[1]	2090	7.17	942	<0.005
CVS6	Central seepage from X-Valley Dam (at weir 3)	19/18:00	3.9	1495	7.38	550	<0.005
CVS7	South side seepage from X-Valley Dam (at X12)	19/18:30	4.6	1111	7.57	380	<0.005
RCDC1	Rose Creek diversion channel near X10	19/19:00	473	324	8.19	33.2	0.0437
Reach 2							
CCR	Cornish Creek tributary	20/09:45	22.5	422	8.24	-	-
RCDC2	Rose Creek diversion channel near Intermediate Dam	20/11:20	669	336	8.33	-	-
GCR	Goodall Creek tributary	20/13:05	6.7	499	8.32	-	-
SCH	seepage channel on Intermediate Impoundment (d/s of ponded areas)	20/12:30	37.3	1204	7.18	480	3.43
RCDC3	Rose Creek diversion channel just d/s of emergency spillway	20/13:45	648	319	8.06	-	-
RCDC4	Rose Creek Diversion at new staff gauge (upstream of tailings facility)	20/14:30	659	313	7.23	27.9	0.0182
Reach 3							
FCS1	WRD seepage in old Faro Creek channel (at X23)	20/15:00	1.3	6470	6.71	5580	371
FCS2	surface seepage discharging below road (below road at culvert)	20/15:30	4.07	7810	6.50	-	-
FCS3	subsurface seepage discharging at seepage face below road (at X7) (w/ organic smell)	20/15:50	3.51	7410	5.96	5790	309
FCS4	combined seepage below confluence of X7 and X23 (at mouth of Faro Creek canyon)	20/16:20	10.2	7080	6.69	5490	319
FCS5	seepage flow at end of diversion ditch (prior to discharge into Interm. Impoundment)	20/16:50	5.35	6880	6.50	-	-
FCS6	seepage flow appr. Halfway towards Interm. Pond	20/17:00	3.4	3780	5.45	-	-
FCS7	seepage flow near pond (but u/s of inflow from Guardhouse Creek)	20/17:30	<1.0	1535	6.49	610	3.56
GHC	Guardhouse Creek before discharge into Intermediate Impoundment (at road)	20/18:15	8.7	1234	7.57	448	2.83

Notes:

[1] the flow estimate of 20.2 l/s for station CVS5 (X11) reported in earlier drafts of this report was incorrect and has been corrected here

The following conclusions can be drawn from an inspection of Table 2.13 and Figures 2.12 and 2.13:

- The seepage discharging at the mouth of the old Faro Creek Canyon is substantial (~10.2 L/s) and represents a large contaminant load (~1,700 t SO4 per year and ~100 t Zn per year);
- Most of this seepage flow is lost to the subsurface via leakage before it can reach the Intermediate Pond; some of this leakage occurs along the diversion channel and likely infiltrates directly into the local groundwater system; the remaining portion appears to infiltrate into the coarse tailings beaches (in particular of the Intermediate Impoundment);
- The Rose Creek Diversion experiences significant (!) leakage (about 200 L/s) between the Intermediate Dam and the end of the diversion; this estimate is in very good agreement with earlier measurements of leakage losses along this reach (190 L/s in Sept 2002); much of this leakage is believed to occur downstream of the Polishing Pond where the diversion traverses an area which appears to be an alluvial fan with potentially very permeable soils;
- The combined seepage from the X Valley Dam (at X13) was about 31 L/s which is similar to earlier measurements (24.5 L/s) at X13 carried out in October 2002 (GLL, 2004);
- The area downstream of X13 represents a major groundwater discharge zone; between X13 and the confluence of the RCCD and the former creek bed, an additional discharge of approximately 50L/s was observed, resulting in a combined total of 83 L/s of “Cross Valley Seepage”;
- Rose Creek remains a gaining stream downstream of the confluence (where it flows in its natural streambed); flow measurements suggest that as much as 200 L/s of groundwater discharges into the creek between X14 and station RC1 (just upstream of the inflow of Next Creek).

The results of the October 2004 survey were used to calibrate the water and load balance model for current conditions (see sections 3 and 4)[2].

2.5.2 April 2005 Field Survey

A second field survey was conducted in April 2005 (after completion of all modeling work) to get a better understanding of the variability in flow and loading conditions. Stream flow conditions during this second survey represented true winter base flow conditions with only about half the flow compared to the 2004 fall survey. The observed stream flow (~235 L/s at X14) was essentially equal to the 2-year 7-day low flow for this station (240 L/s).

Table 2.14 summarizes the flow measurements and selected water quality results (pH, S.C., sulphate and total zinc). The results of this second field survey are generally similar to those observed during the October survey: (i) most of the seepage from the Faro Creek Canyon was lost to the subsurface

---

[2] Problems with the staff gauge rating curve for X11 (station CVS5) resulted in incorrect flow estimates for this station in the October 2004 flow survey (Ken Nordin, pers. Comm..). The corrected value is reported in Table 2.13. This error was only discovered just prior to final submission of this report and could therefore not be considered for model calibration. However, the error is not considered to effect modeling results significantly.

prior to reaching the Intermediate Pond, (ii) the Rose Creek diversion experienced significant leakage and (iii) Rose Creek is a gaining stream downgradient of X14.

Table 2.14

Summary of April 2005 Field Survey.

				Water Quality (Field)		Water Quality (Lab)	
Station ID	Location	April 2005 DD/Time	Flow (L/s)	Spec. Cond. (uS/cm)	TDS (mg/L)	SO4 (mg/L)	Zn_T (mg/L)
Reach 1							
RC1	Rose Crk u/s of Next Creek inflow	15/10:15	411	633	278	161	0.0186
RC2	Rose Creek between Next Creek confluence and R2	15/11:35	264	655	285	162	0.0180
RC3	Rose Creek at R_2 (Biological site)	15/12:46	263	642	283	161	0.0173
RC4	Rose Creek at X14	15/13:50	236	644	287	164	0.0180
RC5	Rose Creek halfway between X14 & inflow of X Valley seepage (channel)	15/15:20	214	649	289	166	0.0188
CVS1	X-Valley seepage just u/s of confluence with Rose Creek flow	15/16:00	44	1442	679	592	0.0129
CVS2	X-Valley seepage just u/s of confluence with Northwall Interceptor trench	15/16:30	46	1531	719	650	0.0069
CVS3	North wall interceptor trench just u/s of inflow into X-Valley seepage channel	15/16:45	<0.5	1413	638	586	0.2020
CVS4	combined seepage from X-Valley Dam (at X13)	15/17:10	19.3	1595	733	551	0.0186
CVS5	North side seepage from X-Valley Dam (at X11)	15/17:40	n/a[1]	2090	962	1060	0.0066
CVS6	Central seepage from X-Valley Dam (at weir 3)	15/18:10	2.2	1415	657	572	<0.005
CVS7	South side seepage from X-Valley Dam (at X12)	15/18:30	0.3	1234	548	460	0.0051
RCDC1	Rose Creek diversion channel near X10	15/9:00	177	342	147	34.6	0.0277
Reach 2							
CCR	Cornish Creek tributary	16/08:10	5	484	211	45.9	0.0093
RCDC2	Rose Creek diversion channel near Intermediate Dam	16/10:30	222	342	147	34.3	0.0289
GCR	Goodall Creek tributary	16/15:50	<0.1	-	-	-	-
SCH	seepage channel on Intermediate Impoundment (d/s of ponded areas)	16/15:20	~5	847	381	306	4.69
RCDC3	Rose Creek diversion channel just d/s of emergency spillway	16/14:30	261	340	146	34.3	0.0326
RCDC4	Rose Creek Diversion at new staff gauge (upstream of tailings facility)	16/15:30	n/a	336	144	34.3	0.0284
Reach 3							
FCS1	WRD seepage in old Faro Creek channel (at X23)	17/13:30	1.3	5240	2540	5030	295
FCS2	surface seepage discharging below road (below road at culvert)	17/13:00	0 (frozen and dry)	-	-	-	-
FCS3	subsurface seepage discharging at seepage face below road (at X7)	17/12:45	4.78	5710	2800	5550	309
FCS4	combined seepage below confluence of X7 and X23 (at mouth of Faro Creek canyon)	17/12:00	6.6	5190	2450	4170	174
FCS5	seepage flow at end of diversion ditch (prior to discharge into Interm. Impoundment)	17/11:30	4.5	5180	2370	4870	125
FCS6	seepage flow appr. Halfway towards Interm. Pond	17/10:40	~1.0	5140	3360	3750	164
FCS7	seepage flow near pond (but u/s of inflow from Guardhouse Creek)	17/09:50	0 (frozen and dry)	-	-	-	-
GHC	Guardhouse Creek before discharge into Intermediate Impoundment (at road)	17/08:00	3.0	1117	485	416	1.21

Notes:

[1] the flow estimate of 17 l/s for station CVS5 (X11) reported in earlier drafts of this report is incorrect; no reliable flow measurement is available

Table 2.15

Comparison of flow and contaminant loads for selected stations.

Station ID	Model ID[1]	Flow (L/s)		SO4 Load (t/yr)		Zn Load (t/yr)	
		Oct '04	Apr '05	Oct '04	Apr '05	Oct '04	Apr '05
Rose Creek below Cross Valley Dam							
RC1	RC9	678	411	2,309	2,087	0.70	0.24
RC4 (X14)	RC8	505	236	1,847	1,221	0.55	0.13
CVS1	XV-Seep7	83	44	1,393	821	0.05	0.02
CVS5 (X11)	GWdisN6	20.6	17	612	568	<0.003	0.004
RCDC1 (X10)	RCD7	473	177	495	193	0.65	0.15
Faro Creek							
FCS1 (X23)	n/a	1.3	1.3	229	206	15.2	12.1
FCS3 (X7)	n/a	3.5	4.8	641	837	34.2	46.6
FCS4	FCin	10.2	6.6	1,766	868	102	36.2

Notes:
[1] see section 3 of report for more details on model setup

However, there were differences in the amount of flow and associated loads (see below). Table 2.15 provides a direct comparison of flows and constituent loads for the October 2004 and April 2005 surveys for selected monitoring stations. The station IDs for the water and load balance model (see section 3) are also shown for cross-reference.

The following conclusions can be drawn with respect to changes in flow and/or loading between the two surveys:

- The contaminant load discharging at the mouth of the old Faro Creek Canyon was significantly smaller in April 2005 (868 t/yr SO4 and 36.2 t/yr Zn) than observed during October 2004 (1,766 t/yr SO4 and 100 t/yr Zn); this reduced loading is primarily a result of surface flow from the ETA area under winter base flow conditions;

- The total load of sulphate in Rose Creek (at station RC1) observed in April 2005 (2,087 t/yr at station RC1) was surprisingly similar to that observed in October 2004 (2,309 t/yr) considering the much lower stream flow; furthermore, the incremental sulphate loading between stations X10 and RC1 was nearly identical for both surveys (~1,850 t/yr); these results suggest a fairly constant source of sulphate loading (likely groundwater) in this reach of Rose Creek;

- At the same time, the flow and sulphate load discharging to surface below the Cross Valley Dam (821 t/yr SO4 at CVS1) was only about half of the flow and load observed during October 2004; these results suggest that under base flow conditions, a greater proportion of the impacted groundwater flows further downgradient (beyond X14) before discharging into Rose Creek;

- Zinc loading showed a distinctly different pattern; zinc loading was more than three times lower in April 2005 compared to October 2004 at all stations, i.e. both in Rose Creek and in seepage downstream of the Cross Valley Dam; furthermore, both surveys indicated that the majority of zinc loading to Rose Creek occurs upstream of the Cross Valley Dam (i.e. along the Rose Creek Diversion and further upgradient).

2.5.3 Implications for Water and Load Balance Model

The water and load balance model was developed in the fall and winter of 2004. At that time, only the results of the October 2004 survey were available and were therefore used for model conceptualization and model calibration (see section 3). The three key findings of the October 2004 survey that influenced model development were as follows:

- The survey indicated that significant groundwater discharge occurred to Rose Creek downstream of station X14 (the primary gauging station for Rose Creek downstream of the Rose Creek tailings facility); this finding suggested that the model domain should be extended further downstream;
- The survey indicated that the Rose Creek Diversion Canal exhibits significant leakage, which may provide a significant source of dilution to the south side of the aquifer; this finding suggested that this source of clean water to the aquifer should be included in the model;
- The survey indicated that the seepage from Faro Canyon represents a large source of sulphate and zinc load to the north side of the aquifer; this finding suggested that this source of contaminant loading should be included in the model.

The April 2005 survey generally confirmed all of these key findings providing some confidence in the model conceptualization and set-up.

As expected, most of the flow rates of seeps and streams, and in many cases the associated contaminant load, differed between the two surveys. These differences illustrate the limitations of extending the modeling results to flow conditions other than for which the model was calibrated. For example, the surveys clearly indicated the variability in the magnitude of loading from the Faro Creek seepage flows, which represents one of the major sources of sulphate and zinc load to the Rose Creek valley under current conditions. Similarly, the surveys indicated seasonal differences in the magnitude of seepage flow and associated loading in the various reaches downstream of the Cross Valley Dam. However, the total gains in flow and sulphate load to Rose Creek downstream of the Cross Valley Dam (i.e. between stations X10 and RC1) were very similar in both surveys. The total gains in flow and sulphate loading to Rose Creek along this reach represent the primary calibration target for the water and load balance models, respectively. It is therefore concluded that the calibrated water and load balance model represents a reasonable representation of the overall loading, not only for moderate low flow conditions, but also for extended winter base flow conditions.

3 DEVELOPMENT OF WATER AND LOAD BALANCE MODEL

3.1 Objectives

The objectives of the water and load balance model are as follows:

- Determine the contributions of various ARD sources (e.g. tailings seepage from Original Impoundments, Second Impoundment, Faro WRD seepage etc) to the total ARD load (SO4, Zn) in the aquifer under current conditions;
- Evaluate the "assimilative capacity" of the aquifer (i.e. dilution, dispersion and geochemical processes) under current conditions;
- Evaluate the interaction of surface water and groundwater in the Rose Creek valley (e.g. contributions of Intermediate and X-Valley Ponds to groundwater and toe seepage, leakage from diversion ditches etc.);
- Provide order-of-magnitude predictions of SO4 and Zn concentrations in groundwater and Rose Creek for alternative remediation scenarios (i.e. "do nothing", complete or partial removal of tailings, low permeability cover etc);

3.2 Model Set-up

The water and load balance model for the Rose Creek area is a spreadsheet model developed using MSEXCEL. The model domain covers the Rose Creek valley from just upstream of the Rose Creek tailings facility to the confluence of Rose Creek and Next Creek (Figure 3.1). Along the flow path (east-west axis) the Rose Creek valley is "discretized' into nine reaches selected based on known sources of loading (e.g. tailings impoundments, ponds) and zones of groundwater discharge (Figure 3.1).

Figure 3.2 shows a simplified "box-and-stick" diagram of the water and load balance model, i.e. a graphical representation of all the inflows and outflows between the various sub-domains. The arrow shows the direction of flow (or load flux). The model includes surface water flow and groundwater flow. The Rose Creek aquifer is subdivided into a northern and a southern portion, resulting in a total of 18 sub-domains. Within a given reach (sub-domain) all inflows and loads are mixed and the resulting outflows and associated loads are calculated assuming steady-state conditions (i.e. no change in storage) and conservation of mass. As a first approximation, the model assumes that transverse mixing of groundwater (between the north and south side) can be ignored.

The major surface water components interacting with the groundwater system include the Faro Creek seepage (FCS) and the Rose Creek Diversion (RCD) and Rose Creek (RC) itself (Figure 3.2). The flux of flow and associated constituent load (SO4 and Zn) in these surface water "conduits" are tracked separately from those in the aquifer. Within a given reach, surface water may either recharge the aquifer (e.g. leakage along Faro Creek Diversion Canal and Rose Creek Diversion Canal) or may receive discharge of groundwater (e.g. groundwater discharge to Rose Creek below Cross Valley Dam). In those reaches, where surface water is lost, the flow and load of the stream entering the next reach is reduced accordingly. In reaches where there is inflow to the stream (i.e. groundwater discharge) all inflows and loads are mixed and the resulting outflows and associated loads are calculated assuming steady-state conditions.

One of the primary sources of sulphate and zinc loads to the aquifer is seepage from the tailings impoundments. Tailings seepage and the associated loads represent an external input to the water and load balance model, which had to be specified in the first three reaches of the model (Figure 3.2). The tailings seepage and associated contaminant loads for each of those model domains were estimated based on a detailed review of the geochemical characterization work available for the Rose Creek tailings (see section 3.3 for details). Other (secondary) sources of contaminant loading included seepage from the Intermediate Pond and the Cross Valley Pond (Figure 3.2).

3.3 Tailings Source Model

3.3.1 Source Areas

For the purpose of this study, the tailings impoundments were sub-divided into zones of predominantly coarse tailings (referred to as “coarse“ zones and identified in the model code with a suffix “c“) and zones of predominantly mixed and very fine tailings (slimes) tailings (referred to as “fines“ zones and identified in the model code with a suffix “f“).

Figure 3.3 shows the spatial extent of these tailings zones superimposed on a layout plan of the Rose Creek tailings facility. Table 3.1 summarizes pertinent summary statistics of the tailings source areas.

Table 3.1

Summary statistics of tailings source areas in different model sub-domains.

Sub-domain	**Area** m^2	**Area** ha	**Volume** m^3	**Average Thickness** m	**Average Depth to Water Table** m
Original Impoundment					
IN-c	114,989	11.5	1,435,133	12.48	11.9
IN-f	271,687	27.2	5,065,763	18.65	10.9
Second Impoundment					
IS-c	91,949	9.2	1,408,759	15.32	5.8
IS-f	185,136	18.5	2,975,008	16.07	4.6
IIN-c	58,092	5.8	970,616	16.71	12.5
IIN-f	117,837	11.8	1,806,868	15.33	10.5
IIS-c	0	0.0	0	n/a	n/a
IIS-f	113,345	11.3	2,493,309	22.00	9.2
Intermediate Impoundment					
IIIN-c	112,869	11.3	850,206	7.53	4.2
IIIN-f	215,049	21.5	2,136,293	9.93	4.5
IIIS-c	72,984	7.3	853,666	11.70	4.2
IIIS-f	368,311	36.8	5,498,602	14.93	4.5
TOTAL	**1,722,248**	**172.2**	**25,494,223**	**-**	**-**

3.3.2 Tailings Seepage Rates

The seepage rate through the tailings deposit is defined as the volumetric flux of tailings pore water entering the aquifer. Assuming vertical flow and steady-state conditions this seepage rate is equal to the net infiltration (also referred to as the net percolation) entering the tailings surface. The tailings seepage rate is a critical input parameter to the load balance model because it determines the load of a solute entering the groundwater system. Note that this seepage rate also determines the advance of the solute front of leachable ARD products in the tailings profile (again assuming steady-state conditions).

The rate of advance of a solute front (also referred to as "propagation rate") was estimated by relating peaks in the TDS (and sulphate) concentration profiles to the estimated discharge periods (see Appendix B for details). The estimation of the propagation rate is illustrated in Figure 3.4. The propagation rate through the unsaturated tailings was estimated based on the time elapsed from the last (most recent) tailings deposition and the first peak below the surface of the tailings. In the example shown in Figure 3.4 (a TDS profile in the fine tailings zone of the Original Impoundment), the propagation rate was estimated to be 0.063 m/year, assuming the year of most recent deposition was 1982. The rate of net infiltration into the tailings (assumed to equal to the rate of tailings seepage at the base of the tailings) was back-calculated based on the measured water content (see Appendix B for details).

Table 3.2 summarizes the estimated average propagation (advance) rates and associated seepage rates for the coarse and fine tailings, respectively. These average rates represent an average based on all TDS depth profiles examined in coarse and fine tailings, respectively (from all three impoundments). The maximum rates represent the maximum rate determined from all TDS depth profiles analysed (see Appendix B).

Table 3.2

Estimated advance rates and tailings seepage rates for tailings source model.

	Average Advance		Maximum Advance	
Rate	Coarse Tailings	Fine Tailings	Coarse Tailings	Fine Tailings
Seepage Rate[1] (mm/y)	34	16	75	26
Advance Rate of Solute Front (m/yr):				
- in unsaturated tailings profile	0.203	0.047	0.444	0.074
- in saturated tailings profile	0.083	0.036	0.181	0.056

Notes:
[1] assumed equal to rate of net infiltration

Our estimates of net infiltration compare reasonably well with independent estimates obtained using infiltration modeling for the Rose Creek tailings carried out as part of a cover design study (SRK, 2004a). Assuming a uniform tailings profile, the simulated rate of net infiltration for an average year (using the 1D SoilCover code) was 28mm for fine tailings and 92 mm for coarse tailings. The simulated rate of 92mm for the coarse tailings profile likely represents an upper limit, since a uniform tailings profile consisting of very coarse tailings was assumed. In practice, some layers of finer-grained tailings can be expected to be present even in the coarse beaches, resulting in a reduction of the average rate of net infiltration.

It should be emphasized that the propagation rates for sulphate and zinc in the tailings profile were assumed to be equal. In other words, no special provisions were made for zinc attenuation within the tailings profile. This assumption is primarily based on field observations. Our analysis of the concentration depth profiles of various constituents in tailings pore water did not suggest any significant retardation of zinc concentration peaks relative to those of TDS and sulphate. Attenuation testing of tailings material in the laboratory also suggested that zinc attenuation within the tailings is not significant (SRK, 2004b). However, the tailings samples reportedly oxidized prior to the attenuation testing (while in storage), and resulted in acidic conditions at the onset of the tests. Therefore, it was unlikely that zinc attenuation, if present, could have been measured. Additional work will be required to assess the potential for zinc attenuation in the tailings profile.

3.3.3 Current Source Concentrations & Loads

For each of the tailings source areas summarized in Table 3.1 and shown in Figure 3.3 a source concentration was required as input to the load balance model. These source concentrations were estimated based on the depth profiles of sulphate and zinc concentrations in tailings pore water determined from the available leach extraction data (see tables 2.6 to 2.8). The average profile for each of the source areas was obtained by averaging the concentrations at approximately the same depth.

Figure 3.5 shows such an average zinc profile determined for the fine tailings in the Original Impoundment. Because of the non-uniform distribution of source concentrations (SO4 and Zn typically show peak concentrations in the upper portion of the tailings profile), the current (and future) source concentration will not be uniform across a given source area. For example, areas with thin deposits of tailings (near the margins of the impoundments) should exhibit significantly higher source concentrations than those areas with thick deposits of tailings (near the center of the impoundment).

In order to account for this depth-dependency in source concentrations, all tailings source areas were sub-divided into one meter thick slices and the surface areas of each slice was estimated. Subsequently, source concentrations were read off the calculated concentration profile for each incremental depth. The source concentration for a given source area was then determined by calculating the area-weighted average of all incremental source concentrations.

Table 3.3 shows the estimated sulphate and zinc source concentrations and associated load (in tonnes per year) in the various tailings areas source for current conditions (2001). The load is simply calculated from the source concentration by multiplying the concentration by the assumed seepage rate and the surface area of the respective source area. The load estimates presented in Table 3.3 are based on the assumption of “average” seepage rates. In other words, they represent our best estimate of current loading from the tailings to the aquifer.

Table 3.3

Estimated SO4 and zinc load in current tailings seepage (2001) assuming average seepage rates.

Source Area		Tailings Seepage Rate	Sulphate Load in Tailings Seepage		Zinc Load in Tailings Seepage	
Tailings Sub-domain	**Model Code**		**[SO4]**	**SO4 Load**	**[Zn]**	**Zn Load**
		mm/yr	mg/L	t/year	mg/L	t/year
Original Impoundment						
Reach 1N - coarse	IN-c	34	57,311	224	10,838	42.4
Reach 1N - fine	IN-f	16	7,509	33	889	4.0
Second Impoundment						
Reach 1S - coarse	IS-c	34	10,074	32	1,896	5.9
Reach 1S - fine	IS-f	16	6,127	19	643	1.9
Reach 2N - coarse	IIN-c	36	12,012	24	1,558	3.1
Reach 2N - fine	IIN-f	16	7,540	15	699	1.3
Reach 2S - coarse	IIS-c	-	-	-	-	-
Reach 2S - fine	IIS-f	16	5,564	10	517	1.0
Intermediate Impoundment						
Reach 3N - coarse	IIIN-c	34	2,904	11	280	1.1
Reach 3N - fine	IIIN-f	16	4,656	16	373	1.3
Reach 3S - coarse	IIIS-c	34	2,099	5	136	0.3
Reach 3S - fine	IIIS-f	16	5,931	36	496	3.0
TOTAL		**-**	**-**	**425**	**-**	**65.3**

Notes:
concentrations based on interpretation of 2001 leach extraction data (see text for details)

Table 3.4 shows the estimated sulphate and zinc source concentrations and associated load (in tonnes per year) in the various tailings areas source for current conditions assuming maximum seepage rates. The sulphate and zinc loads shown in Table 3.4 were used for sensitivity analyses, representing our estimate of an upper bound of current loading from thetailings to the aquifer.

Table 3.4

Estimated SO4 and zinc load in current tailings seepage (2001) assuming maximum seepage rates.

Source Area		Tailings Seepage Rate	Sulphate Load in Tailings Seepage		Upper Bound (Maximum Advance Rate)	
Tailings Sub-domain	**Model Code**		**[SO4]**	**SO4 Load**	**[Zn]**	**Zn Load**
		mm/yr	mg/L	t/year	mg/L	t/year
Original Impoundment						
Reach 1N - coarse	IN-c	75	57,311	492	10,838	93.0
Reach 1N - fine	IN-f	26	7,509	53	889	6.2
Second Impoundment						
Reach 1S - coarse	IS-c	75	10,074	69	1,896	13.0
Reach 1S - fine	IS-f	26	6,127	29	643	3.1
Reach 2N - coarse	IIN-c	75	12,012	52	1,558	6.8
Reach 2N - fine	IIN-f	26	7,540	23	699	2.1
Reach 2S - coarse	IIS-c	-	-	-		
Reach 2S - fine	IIS-f	75	7,772	23	722	2.1
Intermediate Impoundment						
Reach 3N - coarse	IIIN-c	75	2,904	24	280	2.4
Reach 3N - fine	IIIN-f	26	6,504	36	521	2.9
Reach 3S - coarse	IIIS-c	75	2,099	11	136	0.7
Reach 3S - fine	IIIS-f	26	8,284	79	693	6.6
TOTAL		**-**	**-**	**891**	**-**	**138.9**

Notes:
concentrations based on interpretation of 2001 leach extraction data (see text for details)

3.3.4 Future Source Concentrations & Loads

Future source concentrations of sulphate and zinc were estimated by assuming the estimated concentration profile gradually migrates downward through the tailings profile (Figure 3.5). For the purpose of this study the rate of advance was assumed to be equal to the "propagation rates" estimated from the existing profiles (see table 3.2). Note that the rate of advance is slower in the saturated portion of the tailings profile (all void space filled with water).

Table 3.5 summarizes the total cumulative release of sulphate and zinc estimated with this method assuming no further oxidation (and production of sulphate and/or zinc). These estimates therefore represent an estimate of the total "inventory" of stored sulphate and zinc in the tailings impoundments[3].

---

[3] In theory, the estimates of total inventory for average and maximum advance rates should be the same. The minor differences in the two estimates are a result of rounding errors that occur as the peaks pass through the base of the tailings.

Table 3.5

Summary of total cumulative releases to base of tailings assuming no future oxidation.

Area	Average Advance (720 years)		Maximum Advance (470 years)	
	SO4 Load	**Zn Load**	**SO4 Load**	**Zn Load**
	Tones	**tonnes**	**tonnes**	**tonnes**
Original Impoundment	153,459	25,838	152,679	25,541
Second Impoundment (East)	75,309	12,435	75,297	12,461
Second Impoundment (West)	93,174	14,790	110,704	17,384
Intermediate Impoundment	131,044	21,257	178,893	29,057
TOTAL	452,985	74,320	517,573	84,443

Using our approach, the total inventory of zinc currently stored in all tailings combined is about 75,000 to 85,000 tonnes.

In practice, some tailings oxidation will continue to occur in the future which might increase the cumulative loading to the aquifer. The potential effects of ongoing oxidation were assessed by fitting a simple curve to the estimated change in oxidation rate over time (see Appendix B for details). The curve that best fits the data is as follows:

$$R(t) = R_0 * t^{-0.532}$$

Where $R(t)$ is the production rate at time t

R_0 is the production rate at time $t = 0$

Using this equation and the current sulphate and zinc production rates at the surface, the future production was estimated and allowed to ‘propagate’ through the tailings as before. Table 3.6 shows the total cumulative release of sulphate and zinc assuming on-going oxidation (and production of sulphate and/or zinc).

A comparison of tables 3.5 and 3.6 illustrates that on-going oxidation increases the total release of sulphate and zinc, albeit not by a large margin. The primary influence of assuming on-going oxidation is to extend loadings into the future. Ongoing oxidation does not affect the peak release rates (see Appendix B for details). For all future loading calculations the estimated release rates assuming “on-going oxidation” were used.

The predicted future load inputs to the aquifer from tailings seepage assuming no remediation of the tailings area are described in section 5.2. The predicted future load inputs to the aquifer from tailings seepage for different remediation scenarios are described in section 6.2.

Table 3.6

Summary of total cumulative releases to base of tailings assuming on-going oxidation.

	Average Advance (720 years)		Maximum Advance (470 years)	
	SO4 Load	Zn Load	SO4 Load	Zn Load
Area	tonnes	tonnes	tonnes	tonnes
Original Impoundment	176,208	26,916	208,666	28,203
Second Impoundment (East)	104,851	13,872	150,412	16,146
Second Impoundment (West)	113,597	15,739	169,137	20,047
Intermediate Impoundment	161,310	23,115	259,846	34,027
TOTAL	555,966	79,643	788,062	98,422

3.4 Travel Time in Aquifer

The travel time of a solute (e.g. sulphate or zinc) in the Rose Creek aquifer can range from years to decades depending on the travel distance, the hydraulic and transport properties of the aquifer and the degree of attenuation within the aquifer. This travel time causes a significant delay between the release of a contaminant at the source and its impact on Rose Creek downstream of the Cross Valley Dam. Since loading to the aquifer is not constant but changes over time (see section 3.3) this travel time needs to be taking into account in the load balance model.

3.4.1 Travel Time of Sulphate

The travel time, T, of a conservative solute (e.g. SO4) is defined as:

$T = L / V$

where L is the travel distance and V is the average groundwater velocity. The average groundwater velocity is defined as:

$V = K * i / n$

where:
K = hydraulic conductivity;
i = hydraulic gradient; and
n = effective porosity

At present, there is some uncertainty about the average groundwater velocity and thus the travel time in the Rose Creek aquifer. The largest uncertainty in travel time stems from the difficulty to estimate an average K for the aquifer. Hydraulic testing in the Rose Creek aquifer indicated a significant range in hydraulic conductivity values ranging from ~1*10-5m/s to as high as 6*10-3m/s (see Table J4 in GLL, 2002). Calibration of the groundwater flow model indicated a hydraulic conductivity of 1.5*10-4 m/s for the sand and gravel aquifer underlying most of the tailings facility (GLL, 2002). Using this range of K values, the average groundwater velocity in the Rose Creek aquifer could range anywhere from a ~0.03 m/day to 2 m/day.

For the purposes of this study we assumed an average K of 1.2*10-4m/s and an effective porosity of n=0.25 for the sand and gravel aquifer. Using these estimates the average groundwater velocity in the aquifer is about 0.4m/day (the average hydraulic gradient between P03-01 and X16 is about 0.0093). This average groundwater velocity is about three times higher than an earlier estimate by Stantec (0.13m/day) used as a base case for their transport calculations (Stantec, 2002).

Table 3.7 shows estimated mean travel times for a conservative solute (e.g. sulphate), which is released in the different reaches of the model, assuming an average saturated hydraulic conductivity of Ksat=1.2*10-4 m/s and an effective porosity of n_e=0.25.

The observed “breakthrough” of sulphate and zinc in P03-03-#2, which was likely introduced into the aquifer by leakage from P01-09D, provided a check on our estimates of Ksat and n_e. Based on our estimates of Ksat and n_e, a conservative solute would take about 2.5 years to travel the 150m distance between P01-09D and P03-03. Assuming leakage started immediately after installation of P01-09D in the fall of 2001, the breakthrough of sulphate and zinc should have occurred around spring 2003. This estimate agrees fairly well with the observed “breakthrough” of sulphate and zinc between September 2003 and September 2004 (see Appendix C). Unfortunately the early part of the breakthrough curve is not available to determine the average travel velocity with more accuracy[4].

Note that any uncertainty in travel time translates into uncertainty about the time of loading and therefore the magnitude of loading. This is particularly problematic for calibration of the load balance model for current conditions (see section 4). Detailed water quality monitoring of one of the major source terms (Faro Creek seepage) has shown that there has been a significant increase in sulphate (and zinc) over the last 20 years (from ~1,800mg/L in 1986 to ~6,000 mg/L in recent months) (see section 2.4). Similar increases in sulphate (and zinc) concentrations likely occurred in tailings seepage since the start of tailings deposition some 35 years ago. However, those increases are not well documented. The uncertainty in average travel times and the limited information on past loading trends from the tailings limits the ability to calibrate the load balance model.

---

[4] Preliminary results from a bromide injection test obtained by Environment Canada after completion of this modeling work suggest that the average groundwater velocity between P01-09 and P03-03 may be as high as 1.13m/day (John Miller, pers. comm.). These (preliminary) results would suggest that the travel time in high permeability zones of the aquifer could be as much as 6-7 times faster than assumed in the model.

Table 3.7

Distances and estimated travel times along model reaches.

Area	Description	Travel to downstream end of reach Average Distance	Hydraulic gradient	Incremental Travel Time (yrs)	Travel to toe of X Valley Dam (end of Reach V) Average Distance	Hydraulic gradient	Incremental Travel Time
		(m)	unitless	years	(m)	unitless	years
Reach I	Original & Second	500	0.0051	6.5	3150	0.010	20.4
Reach II	Second	300	0.0040	5.0	2350	0.012	12.8
Reach III	Intermediate	600	0.0104	3.8	1450	0.014	6.6
Reach IV	Intermediate Pond	200	0.0104	1.3	650	0.020	2.1
Reach V	Polishing Pond	225	0.0290	0.5	225	0.029	0.5

Assumptions:

n=	0.25	
Ksat	1.20E-04	m/s

3.4.2 Travel Time of Zinc

A review of the groundwater quality data has indicated that the increase in zinc concentrations in the aquifer (in particular downstream of Cross Valley Dam) lag significantly behind the observed increase in sulphate concentrations suggesting that zinc is attenuated in the system (see section 2.4). These findings are consistent with laboratory studies carried out by others, which suggested significant attenuation potential of zinc in the soils of the Rose Creek aquifer (Gartner Lee Limited, 2002; SRK, 2004b).

Assuming attenuation of zinc is controlled by sorption, which is completely reversible and can be described by a linear isotherm, the travel time of zinc in the aquifer is defined as:

$T = L * R / V$

R is known as the retardation factor and is defined as:

$R = 1 + (\rho K_d/n)$

Where ρ is the dry bulk density of the soil and K_d is the distribution coefficient. In general, the greater the sorption potential (K_d), the greater will be the retardation factor and the greater will be the travel time for the reactive solute (here zinc) relative to a non-reactive solute (here sulphate).

Recent column studies carried out by SRK using soils from the Rose Creek aquifer suggested K_d values of about 1-2 L/kg (SRK, 2004b). Assuming a bulk dry density of 1.8 kg/L and a porosity of 0.3, the authors estimated retardation factors for zinc ranging from 7-13 (SRK, 2004b). It should be noted, however, that the soils used for those column tests represented sandy and silty TILL, i.e. presumably with significantly more fines than the typical soils in the Rose Creek aquifer. Contact tests with a more representative soil sample (coarse sand with gravel and cobble) did not show any sorption potential (in fact Kd values were negative indicating leaching of zinc from the soil sample) (SRK, 2004b).

In summary, the laboratory studies indicate significant uncertainty about the magnitude of zinc attenuation in the aquifer. The retardation of zinc in the aquifer was therefore treated as a calibration parameter for current conditions (see section 4) and as a sensitivity parameter for prediction of future conditions (section 5 and 6).

3.4.3 Implementation in Load Balance Model

The primary focus of this study is the loading of sulphate and zinc to Rose Creek. Essentially all of this loading occurs in the few reaches downstream of the Cross Valley Dam (Reaches 6 to 9) with much of this load emerging within a short distance of the toe of Cross Valley Dam. Therefore the toe of the Cross Valley Dam was used as a reference point for estimating the travel time for load inputs occurring in the upstream reaches.

Table 3.7 lists the average travel times assumed for sulphate from the various reaches to the toe of the Cross Valley Dam used in the modeling. For example, the average travel time from Reach 1 to the toe of the Cross Valley Dam used in the sulphate load model would be 20 years. In other words, the current (2004) loading to Rose Creek is assumed to be influenced by sulphate loading in Reach 1 dating back to 1984.

As mentioned above the travel times for zinc will have to be adjusted to account for the attenuation in the aquifer. Hence, the travel times used for the zinc load model would be those listed in Table 3.7 multiplied by the appropriate retardation factor. For example, assuming a retardation factor of 2, the average travel time for zinc from Reach 1 to the toe of the Cross Valley Dam would be ~41 years. In other words, the zinc loading occurring ~41 years ago (1964) should be used in the model to estimate current zinc loading to Rose Creek. In this example, no tailings were present back in 1964 in this (or any other) reach, hence no load would be assumed as input along this reach to the zinc load model for current conditions.

3.5 Modeling Approach

The following general step-wise process in modeling was followed:

Step 1: “calibrate” the water and SO4 load balance for current conditions (Section 4); the model was primarily calibrated using a detailed field survey carried out in the fall of 2004 (section 2.5); observed groundwater quality (2003-2004 averages) was also used to constrain the model;

Step 2: “calibrate” the Zn load balance for current conditions (Section 4); in this iteration, the water balance was not modified; however, attenuation of zinc in the system was accounted for by introducing a retardation factor to match the observed zinc loads;

Step 3: predict SO4 and Zn load balances for future conditions without any remediation measures (Section 5); this step includes sensitivity runs to assess the influence of uncertainty in model input parameters on predicted loads and contaminant concentrations in Rose Creek;

Step 4: predict SO4 and Zn load balances for future conditions for alternative remediation measures (Section 6)

3.6 Model Assumptions and Limitations

The water and load balance model represents a highly simplified model of the actual field conditions in the Rose Creek valley. The key assumptions of the water and load balance model may be summarized as follows:

- The model assumes a uniform (single layer) aquifer with homogeneous aquifer properties;
- The model assumes steady-state flow conditions in the surface water and groundwater system;
- The model assumes complete mixing in a given reach and sub-domain of the aquifer;
- The model assumes “plugflow”, i.e. no longitudinal or transverse dispersion, during transport of a solute in the aquifer;
- The model assumes that zinc sorption is reversible and can be described by a linear isotherm;
- The model assumes steady-state seepage through the tailings; furthermore, the model assumes that vertical seepage dominates over lateral seepage within the tailings.

The third assumption of complete mixing is perhaps most limiting since field observations clearly indicate significant variability in sulphate and zinc concentrations within a given reach suggesting only limited mixing within the aquifer. Any modeling predictions should therefore be assessed with those limitations in mind. In particular, any predictions of sulphate or zinc concentrations in the aquifer or Rose Creek should be considered approximate estimates only.

Nevertheless, the water and load balance model presented here is considered a useful tool for an assessment of current loading conditions and for a semi-quantitative comparison of the effects of different remediation scenarios on water quality in Rose Creek.

4 CURRENT CONDITIONS

4.1 Overview

In total, four different scenarios were simulated to bracket the likely range of sources contributing to the loading currently observed (October 2004) in Rose Creek. The essential features of these scenarios may be summarized as follows:

Scenario C1.	assume Faro Creek seepage (at currently observed leakage rates) and match loading to Rose Creek by increasing tailings seepage rates (assuming process water quality);
Scenario C2.	assume Faro Creek seepage (at currently observed leakage rates) and match loading to Rose Creek by increasing tailings pore water concentrations (assuming steady-state seepage rates of 75 and 24 mm/yr);
Scenario C3.	assume no loading from Faro Creek seepage and match loading to Rose Creek by increasing tailings seepage rates (assuming process water quality);
Scenario C4.	assume no loading from Faro Creek seepage and match loading to Rose Creek by increasing tailings pore water concentrations (assuming steady-state seepage rates of 75 and 24 mm/yr);

Scenarios C1 and C2 are believed to be more realistic of actual field conditions. Scenarios C3 and C4 were included as sensitivity runs to demonstrate which seepage rates and tailings pore water concentrations would be required to explain current loading to Rose Creek (as an upper bound) if none of the Faro Creek seepage reported to groundwater.

Loading calculations for current conditions were carried out for sulphate and zinc. Sulphate loading calculations were only carried out assuming no retardation (R=1). Zinc loading calculations were carried out assuming different degrees of retardation along the flow path (R=1, 2 and 7). Retardation results in a reduction in the average groundwater velocity and a resulting increase in travel time from the source area to the discharge point (below Cross Valley Dam). Table 4.1 summarizes our estimates of the average "loading year" for each reach of the Rose Creek Valley for the base case (no retardation) and the retardation runs.

Table 4.1

Average "loading year" assumed for estimating current load balance.

Simulation	Original Impoundment	Second Impoundment		Intermediate Impoundment	Intermediate Pond	Polishing Pond
	Reach 1N	Reach 1S	Reach 2N&S	Reach 3N&S	Reach 4N&S	Reach 5N&S
Current - No Retardation	1984	1984	1991	1997	2002	2004
Current - R=2	1963	1963	1978	1991	2000	2003
Current - R=7	1861	1861	1914	1958	1989	2000

Legend:
⬜ prior to operation
🟦 during initial tailings discharge
🟨 after cessation of tailings discharge

Table 4.1 illustrates that the period of loading contributing to the current load to Rose Creek via the groundwater pathway varies significantly between reaches and covers very different operating conditions (including pre-mining conditions). For loading periods prior to operation, the loading for this particular reach was set equal to zero. For loading periods during initial tailings discharge the tailings pore water concentrations were set equal to those observed in tailings slurry (0.2 mg/L Zn, see table 2.2 in SRK memo dated November 14, 2004). For loading periods after cessation of tailings discharge the assumed pore water concentrations varied from scenario to scenario (see below).

4.2 Calibration Targets

The primary calibration targets for the water and load balance model under “current loading” conditions included:

- Measurements of streamflow and sulphate load along the Rose Creek Diversion and in Rose Creek itself;
- Measurements of seepage flows and sulphate load downstream of the X Valley Dam;

Where available, observed sulphate concentrations in groundwater provided secondary calibration targets. Tables 4.2 and 4.3 summarize the surface water and groundwater calibration targets used for model calibration. All primary (surface water) calibration targets were measured during low flow conditions on October 19/20, 2004. Note that the secondary (groundwater) calibration targets bracket a range of dates, to account for the assumed travel time in the aquifer. No groundwater calibration targets were available for model reaches 1 to 3 due to the lack of historic groundwater monitoring in these reaches.

Table 4.2

Surface water calibration targets for “current conditions”.

Description	Code	Flow Rate	SO4		Zn-T		Source
		L/s	mg/L	t/year	mg/L	t/year	
X-Valley Seepage							
northern toe seepage at X11	GWdisN6	20.6	942	612	<0.005	<0.002	"Laberge field survey"
southern toe seepage at X12&weir 3	GWdisS6	10.7	289	98	0.005	<0.002	"Laberge field survey"
combined toe seepage at X13	XV-Seep6	31.3	719	710	0.0054	0.01	"Laberge field survey"
combined seepage u/s of confluence	XV-Seep7	83	532	1,393	0.0196	0.05	"Laberge field survey"
Rose Creek (Diversion)							
at emergency spillway	RCD-1	648	28	570	0.0182	0.37	"Laberge field survey"
at Intermediate Dam	RCD-4	669	28	589	N/A	N/A	"Laberge field survey"
below rock weirs (at X10)	RCD-7	473	33	495	0.0437	0.65	"Laberge field survey"
d/s of RCDC (at X14)	RC-8	505	116	1,847	0.0348	0.55	"Laberge field survey"
u/s of Next Creek	RC-9	678	108	2,309	0.0328	0.70	"Laberge field survey"

Notes

Laberge field survey carried out on October 19-20, 2004

Table 4.3

Groundwater calibration targets for “current conditions”.

Description	Reference Period	Code	SO4 mg/L	Zn-D mg/L	Source
Reach 1					
northern portion of aquifer	1986	GW-N1	N/A	N/A	P03-07(#2-5); P03-06(#3-5)
southern portion of aquifer	1986	GW-S1	N/A	N/A	P03-05(#1-5); P01-08A/B
Reach 2					
northern portion of aquifer	1994	GW-N2	N/A	N/A	X21B/C; P01-06
southern portion of aquifer	1994	GW-S2	N/A	N/A	P03-04(#2-7)
Reach 3					
northern portion of aquifer	2000	GW-N3	N/A	N/A	none available
southern portion of aquifer	2000	GW-S3	N/A	N/A	P03-08(#2-7)
Reach 4					
northern portion of aquifer	2003	GW-N4	1,022	0.015	X24A,B,C,D; P01-03
southern portion of aquifer	2003	GW-S4	233	0.034	X25A/B; P01-04A/B
Reach 5					
northern portion of aquifer	2004	GW-N5	862	<0.005	P01-11
southern portion of aquifer	2004	GW-S5	131	<0.005	P01-02A/B
Reach 6					
northern portion of aquifer	2004	GW-N6	454	0.008	X18A/B
southern portion of aquifer	2004	GW-S6	380	0.006	P03-09(#3-9)
Reach 7					
northern portion of aquifer	2004	GW-N7	~420	~0.0137	P01-01A/B
southern portion of aquifer	2004	GW-S7	40	<0.005	X17A/B

Notes:
N/A = not available

It should be emphasized that all primary calibration targets (observed flows and loading in seeps and streams) represent a “snapshot” in time and that all of the observed flows and associated loads vary depending on flow conditions. A comparison of the October 2004 survey with the results of the April 2005 survey (section 2.5) had indicated that the incremental gains of flow and solute load upgradient of the official monitoring station X14 (i.e. model ID “RC8”) varied significantly but were fairly constant at the most downgradient survey station RC1 (i.e. model ID “RC9”). For this reason, all modeling results pertaining to loading of Rose Creek are reported for model ID “RC9” (just upstream of confluence with Next Creek).

4.3 Calibration of Water Balance

As outlined in section 4.1, four different scenarios were “calibrated” to bracket the likely range of sources contributing to the loading currently (October 2004) observed in Rose Creek. The four models differed primarily in the relative magnitude of loading from Faro Creek seepage and tailings seepage. Table 4.4 summarizes the seepage rates from Faro Creek and the tailings impoundments that were either assumed (shown in italics) or calibrated (shown in bold) to match the observed sulphate load to Rose Creek. The respective sulphate concentrations and loads are discussed in section 4.4.

Table 4.4

Selected input parameters for water balance model.

Inflow Parameter	**C1**	**C2**	**C3**	**C4**
Leakage from Faro Creek (L/s)	**9.9**		**0**	
Tailings Seepage (mm/yr)				
Coarse Tailings	*300*	**75**	*1,000*	**75**
Fine Tailings	*104*	**26**	*150*	**26**

Notes:
values in italics are calibrated
values in bold are assumed (held constant during calibration)

In all four scenarios, the following inflows and outflows were held constant during model calibration (based on observations):

- Groundwater flow entering the model at the upstream boundary was assumed to be 23 L/s based on groundwater flow modeling (GLL, 2002);
- A significant amount of leakage (30 L/s) from the Rose Creek Diversion to the **tailings surface** was assumed based on field observations (~37 L/s have been observed flowing as surface runoff towards the Intermediate Pond); most of this seepage is believed to flow into the Intermediate Pond and from there infiltrates into the groundwater system (see next point);
- Seepage from the Intermediate Pond was assumed to be 30 L/s based an a review of the pond level changes over the winter 2003/2004 (water level changes suggest a small increase of ~ 7 L/s over the winter months whereas ~37 L/s surface seepage is believed to enter the pond year round);
- Seepage from the Polishing Pond was assumed to be 9.3 L/s based an a review of the pond level changes over the winter 2003/2004;
- In Reach 8, leakage from the Rose Creek diversion to the groundwater system was assumed to account for the observed stream losses between X10 to X14.

Figures 4.1 to 4.4 show “box-and-stick” diagrams of the water balance model of the four different scenarios for current conditions. These figures illustrate the inflows and outflows between the various sub-domains. The arrow shows the direction of flow (or load flux) and the values in the box illustrate the magnitude of flow (in L/s). The upper value shows the modeled flow value and the lower value shows the observed value (where available). Table 4.5 compares key inputs and outputs of the water balance for the alternative scenarios.

Table 4.5

Summary of water balances for “current loading conditions”.

	Reference	**Run C1**	**Run C2**	**Run C3**	**Run C4**
Inputs	**Date(s)**	**L/s**	**L/s**	**L/s**	**L/s**
Surface Inputs					
Faro Creek Leakage	1984-1997	9.9	9.9	0	0
Rose Creek (at inflow to diversion)	Oct' 2004	659	659	659	659
Goodall & Cornish Creeks	Oct' 2004	29	29	29	29
Northwall Interceptor Trench	Oct' 2004	0.5	0.5	0.5	0.5
Groundwater Inputs					
Groundwater Inflow	1980	23	23	23	23
Tailings Seepage Inputs					
Original Impoundment	1984	2.0	0.5	4.9	0.5
Second Impoundment	1984-1991	2.8	0.7	6.7	0.7
Tailings Spill Area (along RCD)	Oct ' 2004	0.4	0.4	0.4	0.4
Intermediate Impoundment	1997	3.7	0.9	8.7	0.9
Intermediate Pond Leakage	2002	30.0	30.0	30.0	30.0
Polishing Pond Leakage	2004	9.3	9.3	9.3	9.3
	Total IN	**770**	**763**	**772**	**754**
Outputs					
Surface Water Discharge to Tailings Impoundment					
Leakage from Rose Creek Diversion	Oct' 2004	30	30	30	30
Groundwater Discharge to Rose Creek					
Shallow toe seepage (X13)	Oct' 2004	31	31	31	31
X Valley seepage between X13 and X14	Oct' 2004	51	51	51	48
Groundwater discharge below X14	Oct' 2004	175	175	172	169
Surface Water Discharge to Rose Creek					
Northwall Interceptor Trench	Oct' 2004	0.5	0.5	0.5	0.5
Rose Creek Diversion	Oct' 2004	423	423	423	423
Groundwater Load in Underflow					
Groundwater Outflow	Oct' 2004	59	53	64	52
	Total OUT	**770**	**763**	**772**	**754**

An inspection of Tables 4.4 and 4.5 indicates that the four scenarios differ mainly in the amount of tailings seepage and leakage from Faro Creek. Scenarios C1 and C2 are believed to be a better approximation of current loading conditions than C3 and C4 because they match the observed losses along the Faro Creek diversion canal (Figures 4.1 to 4.4). However, the water balance model is not very sensitive to the subtle differences in assumed tailings seepage rates between C1 and C2. Hence both calibration scenarios are plausible based on water balance considerations alone.

Scenarios C1 and C2 illustrate some key features of the water balance for the Rose Creek valley:

- Estimates of current tailings seepage from all three impoundments combined range from a low of 2.5 L/s (scenario C2) to a high of 8.5 L/s (scenario C1); these seepage rates represent only a small proportion of the total groundwater flow discharging to Rose Creek downstream of the Cross Valley Dam (~257 L/s);
- Seepage losses from the Faro Creek channel (WRD seepage) are substantial (~10 L/s) and are higher than estimated tailings seepage from all three tailings impoundments combined;

- Seepage losses from the Rose Creek Diversion Canal are very high (~200 L/s) and represent a significant source of dilution to groundwater;
- Toe seepage at the Cross Valley Dam (~31 L/s at X13) represents only about 12% of all groundwater discharge to Rose Creek downstream of the Rose Creek tailings facility;
- Significant additional groundwater discharge to Rose Creek occurs in reach 9, i.e. between the official gauging station X14 (model ID “RC8”) and the confluence of Rose Creek with Next Creek (model ID “RC9”);
- The amount of groundwater flow leaving the downstream model boundary as “underflow” ranges from about 50-60 L/s.

The calibration of the water and sulphate load balance model has provided significant new insight into the groundwater flow regime along the Rose Creek valley. Among other things, it has illustrated the importance of leakage from the Rose Creek Diversion and provides more realistic estimates of seepage from the Intermediate and Polishing Ponds. These results differ substantially from the most recent version of the groundwater flow model for the Rose Creek tailings (GLL, 2004). We therefore recommend that the current version of the groundwater flow model be updated (using this “calibrated” water balance as a guide) before using the existing groundwater flow model for any additional predictive modeling (e.g. transport modeling, capture scenarios etc.).

4.4 Sulphate Load Balance

Table 4.6 summarizes the sulphate input concentrations assumed for the four different scenarios C1 to C4. As noted in section 4.1, scenarios 1 and 3 assume that tailings seepage has sulphate concentrations representative of (modified) tailings process water pore (shown in italics). In those scenarios, the tailings seepage rate was increased until a good match with observed sulphate loading to Rose Creek was achieved (Table 4.4). In scenarios 2 and 4, seepage rates were held constant (Table 4.4) and sulphate concentrations were increased to match the observed sulphate loading to Rose Creek (shown in bold).

Figures 4.5 to 4.8 show the “calibrated” sulphate load balance models for the four scenarios C1 to C4. These “box-and-stick” diagrams illustrate the movement of sulphate load between the various sub-domains. The values on the left side of each box represent the sulphate concentration (in mg/L) and the value on the right side of each box represents the sulphate load (in tonnes/year). The arrows indicate the direction of the flux and the upper values represent modeled values. Where available, the observed concentrations or loads are shown below for comparison.

Table 4.7 summarizes the simulated sulphate inputs and outputs for the four scenarios and Table 4.8 compares the simulated and observed sulphate concentration and load in Rose Creek (at RC9) for the four different scenarios representing “current conditions”.

The results of the first calibration scenario (“C1”) can be summarized as follows:

- Assuming tailings seepage is dominated by modified process water (Table 4.6), the tailings seepage rate had to be increased about fourfold (i.e. to 300mm in the coarse and 104 mm in the fine tailings) to provide a good match with the observed total sulphate load;

- The estimated sulphate load caused by tailings seepage (from all three impoundments combined) is of similar magnitude (542 t/yr) as our estimate of contributions from Faro Creek leakage (640 t/yr) and seepage from the Intermediate Pond (640 t/yr);
- The calibrated model reproduces the observed spatial variability in groundwater quality (with significantly higher sulphate concentrations on the north side of the aquifer) very well (Figure 4.5); the model suggests that past loading from Faro Creek on the north side and dilution by leakage from the Rose Creek Diversion on the south side are the primary factors for this spatial variability;

Table 4.6

SO4 concentrations in tailings seepage for current conditions.

	[SO4] in Tailings Seepage (mg/L)			
Area	**C1**	**C2**	**C3**	**C4**
Original Impoundment				
Coarse Tailings	*930*	**8,000**	*930*	**57,311**
Fine Tailings	*930*	*930*	*930*	**7,509**
Second Impoundment				
Coarse Tailings	*1,892*	**8,000**	*1,892*	**11,043**
Fine Tailings	*1,892*	*1,892*	*1,892*	**7,146**
Intermediate Impoundment				
Coarse Tailings	*1,691*	**8,000**	*1,691*	**2,502**
Fine Tailings	*1,691*	*1,691*	*1,691*	**7,394**

Notes:
values in italics are assumed (held constant during calibration)
values in bold are calibrated

The results of the second calibration scenario (“C2”) can be summarized as follows:

- Assuming a fixed tailings seepage rate of 75mm for coarse tailings and 26mm for fine tailings (believed to be a reasonable upper bound for steady-state recharge conditions) sulphate concentrations in tailings seepage from **coarse tailings** would have to be ~8,000 mg/L to provide a good match with the observed current loading to Rose Creek;
- The total sulphate load from tailings seepage (all three tailings impoundments combined) is somewhat lower (449 t/yr) than simulated for the first scenario (542 t/yr); however, the sulphate load discharging to Rose Creek is essentially the same in both scenarios providing equally get matches to the observed loading to Rose Creek;
- This scenario yields a higher sulphate load to the north side of the aquifer and a lower yield to the south side of the aquifer than the first scenario resulting in an overall better match with observed groundwater concentrations.

Table 4.7

Simulated SO4 load balances for “current conditions”

		Run C1		Run C2		Run C3		Run C4	
	Reference	SO4 Load		SO4 Load		SO4 Load		SO4 Load	
Inputs	**Date(s)**	**t/year**	**%**	**t/year**	**%**	**t/year**	**%**	**t/year**	**%**
Surface Inputs									
Faro Creek Leakage	1984-1997	639	24.3%	639	25.2%	0	0.0%	0	0.0%
Rose Creek (at inflow to diversion)	Oct' 2004	580	22.1%	580	22.9%	580	22.6%	580	23.5%
Goodall & Cornish Creeks	Oct' 2004	40	1.5%	40	1.6%	40	1.6%	40	1.6%
Northwall Interceptor Trench	Oct' 2004	4	0.1%	4	0.1%	4	0.1%	4	0.2%
Groundwater Inputs									
Groundwater Inflow	1980	11	0.4%	11	0.4%	11	0.4%	11	0.4%
Tailings Seepage Inputs									
Original Impoundment	1984	58	2.2%	76	3.0%	145	5.6%	547	22.2%
Second Impoundment	1984-1991	161	6.1%	110	4.3%	388	15.1%	197	8.0%
Tailings Spill Area (along RCD)	Oct ' 2004	126	4.8%	126	5.0%	126	4.9%	126	5.1%
Intermediate Impoundment	1997	197	7.5%	137	5.4%	462	18.0%	152	6.1%
Intermediate Pond Leakage	2002	640	24.4%	640	25.3%	640	24.9%	640	25.9%
Polishing Pond Leakage	2004	171	6.5%	171	6.8%	171	6.7%	171	6.9%
	Total IN	**2,628**	**100%**	**2,534**	**100%**	**2,568**	**100%**	**2,469**	**100%**
Outputs									
Surface Water Discharge to Tailings Impoundment									
Leakage from Rose Creek Diversion	Oct' 2004	32	1.2%	32	1.3%	32	1.3%	32	1.3%
Groundwater Discharge to Rose Creek									
Shallow toe seepage (X13)	Oct' 2004	680	25.9%	711	28.1%	597	23.2%	817	33.1%
X Valley seepage between X13 and X14	Oct' 2004	698	26.6%	702	27.7%	697	27.1%	693	28.1%
Groundwater discharge below X14	Oct' 2004	523	19.9%	505	19.9%	514	20.0%	352	14.3%
Surface Water Discharge to Rose Creek									
Northwall Interceptor Trench	Oct' 2004	4	0.1%	4	0.1%	4	0.1%	4	0.2%
Rose Creek Diversion	Oct' 2004	461	17.5%	461	18.2%	461	17.9%	461	18.7%
Groundwater Load in Underflow									
Groundwater Outflow	Oct' 2004	231	8.8%	120	4.7%	263	10.2%	110	4.4%
	Total OUT	**2,628**	**100%**	**2,534**	**100%**	**2,568**	**100%**	**2,469**	**100%**

Table 4.8

Summary of Simulated Loading in Rose Creek just upstream of Next Creek (RC9) for current conditions (October 2004).

		Sulphate		Zinc	
Scenario	**Description**	**[SO4] mg/L**	**SO4 load t/year**	**[Zn] mg/L**	**Zinc load t/year**
observed	***October 19/20 2004***	***108***	***2,309***	***0.0328***	***0.7***
Run C1: assume process water only & use elevated seepage rates (300&104 mm/yr)					
Run C1	assume no retardation	110	2,365	1.404	30.1
Run C1a	as Run C1 but assuming R=2 for Zinc	-	-	0.193	4.15
Run C1b	as Run C1 but assuming R=7 for Zinc	-	-	0.048	1.03
Run C2: assume moderate seepage rates (75&28mm/yr) & use high pore water conc in coarse tails					
Run C2	assume no retardation	111	2,382	2.719	58.4
Run C2a	as Run C2 but assuming R=2 for Zinc	-	-	0.200	4.29
Run C2b	as Run C2 but assuming R=7 for Zinc	-	-	0.049	1.05
Run C3: assume no Faro Creek seepage & use very high seepage rates (1,000&150mm/yr)					
Run C3	assume no retardation	106	2,273	1.349	28.8
Run C3a	as Run C3 but assuming R=2 for Zinc	-	-	0.193	4.12
Run C3b	as Run C3 but assuming R=7 for Zinc	-	-	0.048	1.02
Run C4: assume no Faro Creek seepage & use very high pore water conc in all tailings (2001 estimates)					
Run C4	assume no retardation	110	2,327	7.168	151.8
Run C4a	as Run C2 but assuming R=2 for Zinc	-	-	0.204	4.32
Run C4b	as Run C2 but assuming R=7 for Zinc	-	-	0.050	1.05

In our opinion, both calibration scenarios are plausible. The first scenario is likely more realistic if actual transport times in the aquifer are equal to or slower than assumed here (see Table 4.1). Under those circumstances, the tailings seepage now contributing to loading in Rose Creek would have almost certainly been dominated by tailings process water. The elevated seepage rates could have been a result of intermittent discharge and subsequent final “draindown”. The second scenario may be more realistic if the actual travel times in the aquifer are significantly shorter (say half or less) than assumed here.

Note that scenarios 1 and 2 assume that essentially all of the seepage from the Faro Creek Canyon (i.e. seepage from the Faro WRDs and ETA area) ultimately enters the Rose Creek aquifer and contributes to loading in Rose Creek. There is some uncertainty as to how much of this leakage actually reaches the groundwater system. Scenarios 3 and 4 illustrate what seepage rates and/or tailings pore water concentrations would be required to match the current loading to Rose Creek without any loading from Faro Creek.

The results of the third calibration scenario (“C3”) can be summarized as follows:

- Assuming (i) no contributions from Faro Creek seepage and (ii) tailings seepage is dominated by modified process water (Table 4.6), the tailings seepage rate had to be increased to 1,000 mm/yr in the coarse and 150 mm/yr in the fine tailings to provide a good match with the observed total sulphate load to Rose Creek;
- The estimated sulphate load caused by tailings seepage (from all three impoundments combined) for this scenario would be about 995 t/yr representing about 39% of the current SO4 load to Rose Creek;
- This scenario does not match the observed spatial variability in groundwater quality (with significantly higher sulphate concentrations on the north side of the aquifer) very well; simulated SO4 concentrations in the northern portion of the aquifer are generally too high and in the southern portion too low (Figure 4.7).

Scenario C3 illustrates that in the absence of any Faro Creek leakage a uniform loading from the different tailings reaches cannot explain the significantly higher sulphate concentrations (and loads) observed in the northern side of the aquifer compared to the south side. The only other plausible explanation for the higher sulphate load in the northern portion of the aquifer would be a significantly higher loading from tailings placed in the northern portion of the valley compared to in the southern portion of the valley.

The geochemical testing carried out on tailings samples collected during the drilling in 2001 suggests that the “high conductivity front” has already broken through the base of the tailings in parts of the Original Impoundment which is located entirely within the northern portion of the aquifer. Hence this impoundment (and in particular the coarse beach downgradient of the Faro Creek Canyon) would be the most likely source of a significantly higher loading. Unfortunately, there is little information available on the tailings pore water concentrations dating back to the time period believed to be contributing to the current loading at Rose Creek (see table 4.1).

Our estimates of current sulphate loading via tailings seepage (using 2001 leach extraction data) suggest that the Original Impoundment is contributing a disproportionately high sulphate load to the aquifer (representing 58% of the total SO4 load; see Table 3.3 in section 3.3). These load estimates (for maximum propagation rates) can be considered a conservative upper bound for loading via tailings seepage and were assumed as input to the loading model in Scenario C4 (Table 4.6).

The results of the fourth calibration scenario (“C4”) can be summarized as follows:

- Assuming (i) no contributions from Faro Creek seepage and (ii) **current** (2001) loading via tailings seepage (assuming “maximum” propagation rates) provide a good match with the observed total sulphate load;
- The estimated sulphate load caused by tailings seepage (from all three impoundments combined) for this scenario would be about 896 t/yr representing about 36% of the current SO4 load to Rose Creek;
- This scenario provides an overall good match to the observed spatial variability in groundwater quality (with significantly higher sulphate concentrations on the north side of the aquifer) (Figure 4.8).

It should be kept in mind that any seepage originating from the Original Impoundment has been estimated to take on average 20 years to travel to the area downstream of X Valley Dam where it discharges and contributes to the load in Rose Creek. While the actual loading from the Original Impoundment around 1984 is not known it appears highly unlikely that it would have been in the same order of magnitude as our maximum (upper bound) estimate of tailings seepage load for current conditions (used in scenario C4). We therefore believe that scenarios C1 and C2 are more plausible to explain current loading to Rose Creek than scenario C4.

4.5 Zinc Load Balance

The zinc load balances were calculated using the same four scenarios C1 to C4 described above. Zinc loading calculations were carried out assuming different degrees of retardation along the flow path (R=1, 2 and 7). For the base case (R=1), the calibrated water balance model for a given scenario remained unchanged. Table 4.9 shows the assumed zinc concentrations in tailings seepage for the four different scenarios (assuming R=1). Again, scenarios C1 and C3 represent our best estimate of zinc concentrations in “modified” process water. In scenario C2, a high zinc concentration was selected for coarse tailings (1,000 mg/L) believed to be representative of tailings seepage with a “calibrated” sulphate concentration of 8,000 mg/L. As for the sulphate load balance, the estimated zinc concentrations for current (2001) conditions were used in scenario C4.

Note that the zinc concentrations shown in Table 4.9 only apply for the base case (R=1). For a retardation factor of 2, only early process water (w/ an assumed Zn=0.2 mg/L) from the Second Impoundment and the Intermediate Impoundment were assumed to contribute. For R=7, no tailings seepage would have reached the Cross Valley Dam (see below for more detail).

Figure 4.9 shows the calculated zinc load balance for the first calibration scenario “C1” (no retardation). Again, zinc concentrations believed to be representative of process water were used for this scenario. Table 4.10 summarizes the zinc load balance for this run.

Table 4.9

Zinc concentrations in tailings seepage for current conditions (for R=1).

	[Zn] in Tailings Seepage (mg/L)			
Area	**C1**	**C2**	**C3**	**C4**
Original Impoundment				
Coarse Tailings	*44*	*1,000*	*44*	*10,838*
Fine Tailings	*44*	*44*	*44*	*889*
Second Impoundment				
Coarse Tailings	*32*	*1,000*	*32*	*1,896*
Fine Tailings	*32*	*32*	*32*	*688*
Intermediate Impoundment				
Coarse Tailings	*13*	*1,000*	*13*	*208*
Fine Tailings	*13*	*13*	*13*	*607*

Notes:
values in italics are assumed (held constant during calibration)

Table 4.10

Summary of zinc load balances for Scenario C1.

	Run C1 (R=1)		**Run C1a (R=2)**		**Run C1b (R=7)**	
	Zn Load		**Zn Load**		**Zn Load**	
Inputs	**t/year**	**%**	**t/year**	**%**	**t/year**	**%**
Surface Inputs						
Faro Creek Leakage	10.91	32.8%	0.00	0.0%	0.00	0.0%
Rose Creek (at inflow to diversion)	0.37	1.1%	0.37	8.1%	0.37	32.1%
Goodall & Cornish Creeks	0.00	0.0%	0.00	0.0%	0.00	0.0%
Northwall Interceptor Trench	0.00	0.0%	0.00	0.0%	0.00	0.1%
Groundwater Inputs						
Groundwater Inflow	0.01	0.0%	0.01	0.2%	0.01	0.6%
Tailings Seepage Inputs						
Original Impoundment	2.76	8.3%	0.00	0.0%	0.00	0.0%
Second Impoundment	2.82	8.5%	0.01	0.2%	0.00	0.0%
Tailings Spill Area (along RCD)	0.50	1.5%	0.50	10.9%	0.50	43.2%
Intermediate Impoundment	1.51	4.6%	0.02	0.5%	0.00	0.0%
Intermediate Pond Leakage	14.33	43.1%	3.62	78.5%	0.20	17.3%
Polishing Pond Leakage	0.03	0.1%	0.07	1.6%	0.08	6.7%
Total IN	**33.3**	**100%**	**4.61**	**100%**	**1.17**	**100%**
Outputs						
Surface Water Discharge to Tailings Impoundment						
Leakage from Rose Creek Diversion	0.04	0.1%	0.04	0.9%	0.04	3.5%
Groundwater Discharge to Rose Creek						
Shallow toe seepage (X13)	11.88	35.7%	1.17	25.4%	0.09	8.1%
X Valley seepage between X13 and X14	11.60	34.9%	1.43	31.0%	0.13	11.4%
Groundwater discharge below X14	6.13	18.4%	1.01	22.0%	0.27	23.0%
Surface Water Discharge to Rose Creek						
Northwall Interceptor Trench	0.00	0.0%	0.00	0.0%	0.00	0.1%
Rose Creek Diversion	0.54	1.6%	0.54	11.6%	0.54	45.9%
Groundwater Load in Underflow						
Groundwater Outflow	3.08	9.3%	0.42	9.1%	0.09	8.1%
Total OUT	**33.3**	**100%**	**4.61**	**100%**	**1.17**	**100%**

The following conclusions can be drawn from this scenario:

- The **observed** zinc load in Rose Creek (at RC9) is only about 0.70 t/year, with only about half of this load (0.33 t/year) contributed within the reach of the Rose Creek tailings facility;
- The estimated total zinc load from tailings seepage (all three tailings impoundments combined) is significantly lower (7.6 t/yr) than our estimate of zinc load from Faro Creek leakage (10.9 t/yr) and Intermediate Pond leakage (14.3 t/yr);
- The **simulated** zinc load to Rose Creek (~30 t/yr) is significantly (!) higher than observed; the large discrepancy between observed and predicted zinc loading may be a result of several factors including:
    - Zinc concentrations in tailings process water are significantly lower than estimated based on leach extraction data (see Table 3.3 in section 3.3);
    - Zinc is attenuated along the flow path (hence resulting in significantly longer travel times in the aquifer).

These results are consistent with column and batch experiments carried out on silty aquifer soils, which suggested a retardation factor for zinc in the order of 7-13 (SRK, 2004b)[5]. If retardation factors were indeed as high as reported, travel times from the most downgradient major source of zinc (Intermediate Pond) would take 14-26 years to travel to the X Valley Dam and below. At that time, however, zinc concentrations in the Intermediate Pond were still below 1 mg/L. In other words, such a high retardation factor would explain the very low zinc concentrations still observed currently in the aquifer downgradient of the Intermediate and Cross Valley Dams.

Figures 4.10 and 4.11 show the simulated zinc load balance for the same scenario assuming a retardation factor of R=2 (“C1a”) and R=7 (“C1b”). The results of these load balances are also shown in Tables 4.9 and 4.10. The results of these simulations can be summarized as follows:

- A retardation factor of R=2 (scenario C1a) increases the average travel time for zinc such that Reach 1 (Original Impoundment & eastern section of Second Impoundment) would not yet contribute to current loading into Rose Creek; furthermore, loading from Reaches 2 and 3 would have been from a time of active tailings discharge (Table 4.9) resulting in much lower zinc input concentrations (0.2 mg/L); note also that any leakage from Faro Creek channel would not yet be contributing to Rose Creek (Faro Creek seepage is believed to have been discharged together with tailings slurry until 1992); therefore, seepage from the Intermediate Pond represents the primary source of zinc load to Rose Creek in this scenario;
- Although the assumption of R=2 drastically reduces the zinc load from the tailings and eliminates the potential load from the Faro Creek channel, this scenario still overpredicts the zinc load to Rose Creek by a factor of ~6;
- A retardation factor of R=7 would increase the average travel time even further, which would imply that loading from the Intermediate Pond would date back to 1989 when tailings were

---

[5] Note, however, that coarser aquifer soils (coarse sand with gravel and cobble) did not show any sorption potential indicating significant variability in the attenuation potential of the aquifer material (SRK, 2004b).

still actively discharged into the Intermediate Impoundment and zinc concentrations were very low (0.21 mg/L based on historic water quality data);

- The assumption of R=7 provides the best match with the zinc loading and zinc concentrations observed in toe seepage and groundwater discharge downstream of the X-Valley Dam.

Very similar overall findings were obtained when simulating zinc transport for scenarios C2 to C4 (not shown here). In all cases, a high degree of retardation (R=7) had to be invoked to obtain a reasonable match with the observed zinc loading to Rose Creek. It should be emphasized that the “calibrated” retardation factor (R=7) is strongly dependent on the assumed seepage rate from the Intermediate Pond. The seepage rate from the Intermediate Pond (and therefore the associated zinc load) is not well documented and had to be estimated by inference. It is possible that some of the estimated seepage (and hence zinc load) does not enter the aquifer but instead reaches the Cross Valley Pond via shallow subsurface flow through. Assuming all of the estimated seepage from the Intermediate Pond (30 L/s) and associated zinc load (14.3 t/yr) was discharging to the Cross Valley Pond, a retardation factor of R=2 would be required to match the observed (low) zinc concentrations in Rose Creek. While the uncertainty in many model input parameters precludes a definitive estimation of the retardation factor, there appears to be little doubt that zinc transport is delayed relative to sulphate transport.

4.6 Validation of Tailings Source Model

As outlined in section 4.2, the primary calibration target for the “current” loading model was the current loading to Rose Creek. However, because of the considerable travel times in the aquifer (5-20 years) the current (2004) loading to Rose Creek is influenced by historic tailings seepage (and loading) that occurred many years ago. As a result the calibration of the “current” load balance model does not provide any validation of our estimates of current loading from the tailings to the aquifer (Tables 3.3 and 3.4).

In order to provide an independent check on the plausibility of the estimated seepage rates and pore water concentrations used in the load balance model, the loads from tailings seepage estimated for current conditions (Tables 3.3 and 3.4) were compared against sulphate and zinc concentrations currently observed beneath the Original and Second Impoundment.

4.6.1 Sulphate Analysis

Table 4.11 summarizes the depth-weighted average sulphate concentrations in wells screened beneath (or immediately downstream) of the Original and Second Impoundments (2003-2004 data). While a flow-weighted average would be more appropriate for loading calculations no hydraulic data were available to calculate such an average. The depth-weighted average sulphate concentrations show significant spatial variability and no clear increasing trend with distance along the flow path (as might be expected with a uniform but cumulative loading along the flow path) can be discerned. For the purpose of this analysis we therefore averaged all depth-weighted concentrations to calculate the current load present in the aquifer between the Original and Second Impoundment. The estimated “average” sulphate concentrations range from 591 mg/L (median) to 850 mg/L (mean). Note that the elevated sulphate concentrations observed in the P01-09 wells were not included in the average as these wells are believed to be influenced by well leakage and are therefore not representative of the aquifer.

Table 4.11

Average sulphate concentrations observed in the Rose Creek aquifer beneath the Original and Second Impoundments (Sept 2004).

Well ID	Tailings Reach	Depth-weighted Average SO4 [mg/l]	SO4 (in mg/L) Mean [mg/l]	SO4 (in mg/L) Geometric Mean [mg/l]	SO4 (in mg/L) Median [mg/l]
P01-08	1st Impound.	405	682	465	405
P03-07	1st Impound.	1,474			
P01-10	1st Impound.	168			
P01-09	2nd Impound.	1,351	906	740	628
P03-01	2nd Impound.	402			
P03-02	2nd Impound.	628			
P03-03	2nd Impound.	553			
P03-05	2nd Impound.	502			
P03-06	2nd Impound.	654			
P01-07	2nd Impound.	1,039			
P01-06	2nd Impound.	1,910			
X21	2nd Impound.	346			
P03-04	2nd Impound.	2,122			
Average of All Wells [mg/l]			**850**	**659**	**591**

Notes:
all P03 and X series data from Sept 2004 survey
all P01 series data from Sept 2003 survey

Table 4.12 compares the estimated current sulphate load in the aquifer to the loading from tailings seepage estimated for 2001 assuming average propagation rates (Table 3.3). The estimated sulphate load in groundwater introduced from upstream sources and potential sulphate loading due to current seepage losses from the Faro Creek channel (X23) are also shown for comparison.

Assuming a steady-state groundwater flow of ~30 L/s (based on the calibrated water balance model) the total sulphate load moving in the aquifer beneath the Original and Second Impoundment would range from 542 to 780 t/yr (Table 4.12). This range is reasonably consistent with our estimates of sulphate loading from tailings seepage for current conditions (2001), which has been estimated to range from 375 t/yr (for average propagation rates) to 741 t/yr (for maximum propagation rates). This comparison suggests that the estimated SO4 loading rates are plausible without the need for invoking attenuation mechanisms.

Based on the October 2004 seepage survey, the SO4 load currently introduced to the north side of the Rose Creek aquifer via leakage from the Faro Creek channel could be as high as 848 t/yr (4.9 L/s at [SO4]=5,490 mg/L). Clearly, this seepage would not affect the groundwater quality in many of the wells listed in Table 4.11, except for P01-06 and potentially X21, P03-06.and P03-07. Among those wells, only P01-06 shows significantly higher sulphate concentrations, which could be indicative of the additional sulphate load from Faro Creek leakage. However, sulphate concentrations in this well are biased high because this well is only screened in the upper few meters of the aquifer. Additional multilevel piezometers along the northern side of the aquifer (ideally within a short distance of the Faro Creek diversion ditch) would be required to obtain direct evidence of the potential impact of Faro Creek leakage on the water quality in the Rose Creek aquifer.

Table 4.12

Comparison of current sulphate load estimates.

Case	**SO4 Load (t/yr)**
A. Estimated Load using observed GW Quality[1]	
Minimum (Median Concentration)	542
Maximum (Average Concentration)	780
B. Predicted Loading using Loading Model[1]	
- via underflow into tailings area	11
- via seepage from base of tailings (in 2001)	357
- via seepage from Faro Creek channel	848
Total	**1,205**

[1] assume:
- 23 L/s underflow
- 1.2 L/s tailings seepage from Original & Second Impoundment combined
- 4.9 L/s seepage losses from Faro Creek channel

4.6.2 Zinc Analysis

Table 4.13 summarizes the depth-weighted average zinc concentrations in wells screened beneath (or immediately downstream) of the Original and Second Impoundments (2003-2004 data). The depth-weighted average zinc concentrations show an even greater spatial variability than the sulphate data. Again, no clear increasing trend with distance along the flow path can be discerned. For the purpose of this analysis we therefore averaged all depth-weighted concentrations to calculate the current load present in the aquifer between the Original and Second Impoundment. The estimated "average" zinc concentrations range from 0.88 mg/L (geometric mean) to 4.32 mg/L (arithmetic average). Again, the elevated zinc concentrations observed in the P01-09 wells were not included in the average as these wells are believed to be influenced by well leakage and are therefore not representative of the aquifer.

Table 4.14 compares the estimated current zinc load in the aquifer to the loading from tailings seepage "predicted" for 2001 assuming average propagation rates. The estimated zinc load in groundwater introduced from upstream sources and potential zinc loading due to current seepage losses from the Faro Creek channel (X23) are also shown for comparison.

Assuming a steady-state groundwater flow of ~30 L/s (based on the calibrated water balance model) the total zinc load moving in the aquifer beneath the Original and Second Impoundment would range from 0.8 to 4.0 t/yr. This range is about one to two orders of magnitude **lower** than our estimates of zinc loading from tailings seepage for 2001, which has been estimated to range from 59.6 t/yr (for average propagation rates) to 126 t/yr (for maximum propagation rates). This comparison suggests that either (i) the estimated zinc loading rates from tailings seepage significantly overestimate actual loading to the aquifer and/or (ii) zinc is attenuated before reaching the aquifer (i.e. within the tailings and/or unsaturated soils above the water table). This conclusion is generally consistent with the calibration of the current zinc load balance modeling for the entire Rose Creek aquifer (see section 4.5 above).

Table 4.13

Average zinc concentrations observed in the Rose Creek aquifer beneath the Original and Second Impoundments (Sept 2004).

Well ID	Group	Depth-weighted Average Zn [mg/l]	Zn in Groundwater Mean [mg/l]	Zn in Groundwater Geometric Mean [mg/l]	Zn in Groundwater Median [mg/l]
P01-08	1st Impound.	3.15	1.49	1.05	0.91
P03-07	1st Impound.	0.91			
P01-10	1st Impound.	0.40			
P01-09	2nd Impound.	72.74	5.26	0.83	1.42
P03-01	2nd Impound.	7.35			
P03-02	2nd Impound.	0.02			
P03-03	2nd Impound.	28.46			
P03-05	2nd Impound.	0.03			
P03-06	2nd Impound.	2.21			
P01-07	2nd Impound.	0.07			
P01-06	2nd Impound.	6.87			
X21	2nd Impound.	1.42			
P03-04	2nd Impound.	0.91			
All Wells [mg/l]			**4.32**	**0.88**	**1.168**

Notes:
all P03 and X well data from Sept 2004 survey
all P01 well data from Sept 2003 survey

Based on the October 2004 seepage survey the zinc load currently introduced to the north side of the Rose Creek aquifer via leakage from the Faro Creek channel could be as high as 49.3 t/yr (4.9 L/s at [Zn]=319 mg/L). As discussed above, this seepage would not affect the groundwater quality in many of the wells listed in Table 4.13, except for P01-06 and potentially X21, P03-06.and P03-07. Among those wells, only P01-06 shows significantly higher zinc concentrations, which could be indicative of the additional zinc load from Faro Creek leakage. However, zinc concentrations in this well are biased high because this well is only screened in the upper few meters of the aquifer. Again, additional multilevel piezometers along the northern side of the aquifer (ideally within a short distance of the Faro Creek diversion ditch) would be required to obtain direct evidence of the potential impact of Faro Creek leakage on the water quality in the Rose Creek aquifer.

Table 4.14

Comparison of zinc load estimates.

Case	**Zn Load (t/yr)**
A. Estimated Load using observed GW Quality[1]	
Minimum (Median Concentration)	0.8
Maximum (Average Concentration)	4.0
B. Predicted Loading using Loading Model[1]	
- via underflow into tailings area	0.01
- via seepage from base of tailings (in 2001)	59.6
- via seepage from Faro Creek channel	49
Total	**108.6**

[1] assume:
- 23 L/s underflow
- 1.2 L/s tailings seepage from Original & Second Impoundment combined

In summary, this comparison between “observed” and predicted sulphate and zinc loading rates show reasonably good agreement for sulphate but not for zinc. As demonstrated previously with the load balance model, the observed zinc concentrations (and loads) in the Rose Creek aquifer are significantly lower than would be expected using our estimates of current loading from the tailings seepage and/or Faro Creek leakage.

This discrepancy suggests that significant attenuation of zinc along the flow path (either within the tailings and/or in natural soils) might be occurring. The process of attenuation introduces significant uncertainty into any prediction of future zinc concentrations, in particular the timing of peak breakthrough, in the groundwater and, by extension, in Rose Creek. The predicted maximum concentrations are not significantly affected by this uncertainty in attenuation, provided zinc loading occurs over the long-term (centuries) and zinc uptake is due to finite and linear sorption. A better understanding of the attenuation processes controlling zinc transport will be required in order to improve our ability to predict zinc concentrations in groundwater and Rose Creek for alternative remediation strategies.

4.7 Discussion

The primary uncertainties in the **sulphate** load balance model for current conditions include (i) the average travel time of sulphate in the aquifer and (ii) the historic water quality in tailings seepage. Because of these uncertainties, a unique calibration of the model against current conditions was not possible. To illustrate this point, several alternative scenarios were “calibrated” against current conditions. Of those four scenarios, three scenarios (C1, C2 and C4) provided reasonable matches to the (limited) calibration data. These three scenarios bracket the range of sources (and their relative magnitude) contributing to the overall sulphate loading to Rose Creek.

Although scenario 4 provides a reasonable match to the observed calibration targets (including total sulphate loading to Rose Creek and spatial pattern of sulphate concentrations in the aquifer), this scenario is unlikely to be correct because (i) this scenario assumed no loading from Faro Creek seepage (which has been observed in two field surveys and (ii) the assumed sulphate concentrations in tailings seepage are much higher than would be expected for the estimated time of loading.

Based on the information available today it is therefore concluded that both scenarios C1 or C2 provide a plausible model for current loading of sulphate in Rose Creek. A better knowledge of average travel times in the Rose Creek aquifer and/or historic sulphate concentrations in tailings seepage would be required to select one of these scenarios as the preferred option or calibrate a new model that may represent a combination of different scenarios (e.g. including some reduced loading from Faro Creek seepage).

A calibration of the **zinc** load balance model is even more uncertain because of the added complexity of attenuation which influences the travel time and therefore the time of loading from a given tailings impoundment. Although the zinc load balance modeling convincingly indicates that zinc is attenuated in the system (relative to sulphate) the model does not provide insight into the actual mechanism of zinc attenuation. For example, zinc attenuation may not only occur in the aquifer soils (as was assumed here) but may also occur within the tailings profile or within the unsaturated soils above the water table (see section 4.6). Furthermore, zinc attenuation may not necessarily be fully reversible, as was assumed implicitly by using a retardation factor approach.

As a result of these model limitations, caution should be exercised when interpreting the modeling results. This applies in particular to an estimation of the magnitude of the retardation factor. Recall, that the scenario with a retardation factor of 7 provided a slightly better fit to the zinc loading than the scenario with R=2 (Table 4.8). However, these two scenarios differ primarily in the assumed zinc loading from the Intermediate Pond, not with respect to loading from the tailings impoundments. A reduced loading from the Intermediate Pond to the aquifer (which cannot be ruled out based on the limited information available on seepage rates and zinc loading from the Intermediate Pond) would provide a similar match to the observed loading without invoking such a high retardation factor.

Although modeling assumptions and uncertainties in model calibration precludes a definitive estimation of the retardation factor, there appears to be little doubt that zinc transport is delayed relative to sulphate transport. Additional attenuation studies would be required to better understand the attenuation mechanisms and their relative magnitudes. Such information would further constrain the zinc load balance model and possibly provide more reliable estimates of zinc retardation in the Rose Creek aquifer.

5 FUTURE CONDITIONS – NO REMEDIATION

5.1 Overview

This section summarizes the results for the simulation of future conditions assuming that **no remediation** measures for the Rose Creek tailings facility (tailings relocation, cover placement etc) are implemented. These simulations represent the “base case” or “Do Nothing” option and provide a basis for comparison with the simulation of remediation scenarios to be presented later (section 6). In order to evaluate the sensitivity of the model predictions to uncertainty in model input parameters a series of sensitivity runs were carried out. The input parameters evaluated in this sensitivity analysis included (i) the loading term from tailings (ii) the permeability of the aquifer (influencing travel time of all solutes) and (iii) the retardation factor for zinc in the aquifer (influencing the travel time of zinc). Table 5.1 lists the various sensitivity runs and the assumed input parameters for each run.

Table 5.1

Summary of Sensitivity Runs for Future Conditions (no remediation).

	Tailings Source Term		**Transport Parameters**	
Run ID	Propagation Rate	Seepage Flux (mm/yr)	K (m/s)	Retardation factor (Zn only)
Run F1	"Average"	16 & 34	1.2*10-4	1
			2.4*10-4	2
Run F2	"Average"	16 & 34	1.2*10-4	2
Run F3	"Average"	16 & 34	1.2*10-4	7
Run F4	"Average"	16 & 34	2.4*10-4	1
Run F5	"Maximum"	26 & 75	1.2*10-4	1
			2.4*10-4	2
Run F6	"Maximum"	26 & 75	1.2*10-4	2
Run F7	"Maximum"	26 & 75	1.2*10-4	7
Run F8	"Maximum"	26 & 75	2.4*10-4	1

Originally, it had been planned to simulate future loading to Rose Creek for a 7-day 2-year low flow in Rose Creek estimated to be ~240 L/s at X14 (P. Bryan, pers. comm.). However, initial runs with this scenario indicated that leakage from the Rose Creek diversion would have to be adjusted downward to avoid unrealistically low flow at X14. While a reduction in leakage with reduction in flow along the diversion is intuitive it is difficult to quantify this relationship[6]. In order to avoid ambiguity we therefore used the “calibrated” flow regime (502 L/s inflow into Rose Creek diversion) for prediction of future

---

[6] Results of the field survey completed in April 2005 (under true base flow conditions) were not yet available at the time of modeling.

loading. This stream flow represents about 33% of the mean annual runoff (MAR) estimated for Rose Creek at station X14 (Pat Bryan, pers. comm.). Based on a comparison with other WSC stations, this flow is estimated to be exceeded about 61% of the time. The higher stream flow reduces the simulated concentrations (compared to a 7-day 2-yar low flow period). If required, the simulated solute concentrations could be scaled using the results of the April 2005 field survey (section 2.5) to obtain solute concentrations representative of extended base flow conditions.

5.2 Contaminant Release from Tailings

Figure 5.1 shows the predicted breakthrough of sulphate and zinc loads at the base of the tailings deposits assuming average advance rates. Recall that these average advance rates correspond to our best estimate of steady-state seepage through the tailings deposits (see section 3.3).

The total zinc release peaks at about 2028 at a loading of about 110 tonnes per year as the loading from the northern source area of coarse tailings in the Original Impoundment breaks through. A second peak of 220 tonnes per year is reached in about year 2150, when the southern area of the coarse tailings of the original impoundment breaks through together with the remainder of the coarse areas. The breakthrough curves of the fine tailings are delayed, peaking at about 140 tonnes at year 2380. The loading estimates shown in Figure 5.1 were used as input to the load balance model for model scenarios F1-F4.

Figure 5.2 shows the predicted breakthrough of sulphate and zinc loads at the base of the tailings deposits assuming maximum advance rates. Recall that these average advance rates correspond to our upper bound estimate of steady-state seepage through the tailings deposits (see section 3.3). Table 5.2 summarizes the total cumulative load released from the tailings impoundments for this scenario.

Increasing the rates of advance has two effects. First, the first and second peaks in zinc loading occur much sooner (in years 2012 and 2068 as opposed to years 2028 and 2150). Second, the first two peak loadings increase to 240 and 420 tonnes respectively, or about double the estimates for average conditions. The loading estimates shown in Figure 5.2 were used as input to the load balance model for model scenarios F5-F8.

5.3 Sulphate Loading to Rose Creek

Figure 5.3 shows the simulated sulphate concentrations and loads in Rose Creek (at RC9) for the various sensitivity runs. The solid symbols indicate the results assuming Faro Creek seepage is not collected and treated (and its load remains constant). The open symbols assume that the Faro Creek seepage is collected and treated. Table 5.2 summarizes the predicted peak breakthrough in Rose Creek (at station RC9) assuming no collection of Faro Creek seepage. The following conclusions can be drawn from these simulations:

- The total sulphate load in Rose Creek (just upstream of the confluence with Next Creek) is predicted to increase by a factor of 2 compared to current loading; the predicted sulphate concentrations is predicted to remain below the CCME guideline for sulphate (500 mg/L SO4) for the protection of freshwater aquatic life (CCME, 2003); however, this guideline may be exceeded at times of extended base flow (not modeled here);

- Leakage from Faro Creek (assuming current loading) will continue to represent a very substantial loading even under peak breakthrough of tailings seepage; clearly, collection and treatment of this seepage represents a very cost-effective measure of reducing sulphate loading to Rose Creek;
- Assuming average propagation rates and transport parameters (Run F1) the SO4 concentrations are predicted to increase to a maximum of 202 mg/L around year ~2175 representing a total load of 4,332 t/yr; intercepting the Faro Creek seepage (from the Faro waste rock dumps) upstream of the Rose Creek tailings facility is predicted to reduce the SO4 loading by ~40% at peak breakthrough;
- Assuming maximum propagation rates (Run F5) the SO4 concentrations are predicted to increase to a maximum of 247 mg/L around year 2100 representing a total load of 5,294 t/yr;
- The assumption of a higher K (Runs F4 and F8) results in a slightly earlier arrival of the breakthrough curves (by ~10 years) but does not affect the peak concentrations significantly.

Table 5.2

Predicted peak loading to Rose Creek (RC9) assuming no remediation.

Run ID	Porewater Propagation Rate	Transport Parameters	SO4 Peak Load in Rose Creek			Zinc Peak Load in Rose Creek		
			Year	mg/L	t/year	Year	mg/L	t/year
Run F1	"Average"	K = 1.2*10-4 m/s (R=1)	2174	202	4,332	2174	15.2	326
Run F2		as above w/ R=2	n/a	n/a	n/a	2174	15.2	326
Run F3		as above w/ R=7	n/a	n/a	n/a	2276	14.5	310
Run F4		K = 2.4*10-4 m/s (R=1)	2181	204	4,382	2161	15.3	328
Run F5	"Maximum"	K = 1.2*10-4 m/s (R=1)	2101	247	5,294	2081	24.0	516
Run F6		as above w/ R=2	n/a	n/a	n/a	2101	24.2	520
Run F7		as above w/ R=7	n/a	n/a	n/a	2201	22.6	485
Run F8		K = 2.4*10-4 m/s (R=1)	2081	255	5,481	2071	23.9	513

Notes:
n/a = not applicable
all results assuming no collection of Faro Creek seepage

5.4 Zinc Loading to Rose Creek

Figure 5.4 shows the simulated zinc concentrations and loads in Rose Creek (at RC9) for the sensitivity runs assuming average propagation rates (F1 – F4). Again, the solid symbols indicate the results assuming Faro Creek seepage is not collected and treated (and its load remains constant). The open symbols assume that the Faro Creek seepage is intercepted upstream of the Rose Creek tailings facility. Table 5.2 summarizes the predicted peak breakthrough in Rose Creek (at station RC9) assuming no collection of Faro Creek seepage.

The following conclusions can be drawn from these simulations:

- Assuming average propagation rates, the zinc concentrations are predicted to increase to a maximum of ~15 mg/L representing an annual total zinc load of 320 t/yr; intercepting the Faro Creek seepage (from the Faro waste rock dumps) upstream of the Rose Creek tailings facility is predicted to reduce the zinc loading substantially (by ~30% at peak breakthrough);
- Assuming no retardation and average K (Run F1) the peak breakthrough is predicted to occur around year 2174, i.e. in approximately 170 years from today;
- The assumption of a higher K and retardation generally influences the arrival time of the breakthrough curve but does not change the peak concentrations significantly;
    - A retardation factor of R=2 delays the early breakthrough by some 20 years but has no significant effect on the timing of the **peak** breakthrough;
    - A retardation factor of R=7 delays the entire zinc breakthrough significantly with peak breakthrough predicted to occur in 250-300 years from today;
    - The assumption of a higher K (Run F4) results in a slightly earlier arrival of the zinc breakthrough curve (by ~10 years) but does not affect the peak concentrations significantly;

Figure 5.5 shows the simulated zinc concentrations and loads in Rose Creek (at RC9) for the sensitivity runs assuming maximum propagation rates (F5 – F8). Again, Table 5.2 summarizes the predicted peak breakthrough in Rose Creek (at station RC9) assuming no collection of Faro Creek seepage. The following conclusions can be drawn from these simulations:

- The assumption of maximum propagation rates “compresses” the zinc loading to Rose Creek into a shorter time period, generally resulting in higher peak concentrations (~24 mg/L) and earlier peak breakthrough (~2080) compared to the case of average propagation rates;
- Again, the transport parameters K and R influence primarily the timing of the peak breakthrough but not the maximum concentrations:
    - a retardation factor of R=2 is predicted to delay the peak breakthrough of zinc by about 20 years (peak arrival around year 2100);
    - A retardation factor of R=7 is predicted to delay the peak breakthrough of zinc by approximately 120 years (peak arrival around year 2200);
    - The assumption of a higher K (Run F8) results in a slightly earlier arrival of the breakthrough curves (by ~10 years) but does not affect the peak concentrations significantly.

It should be noted that no attempt was made to predict the early breakthrough of zinc between today (October 2004) and 2021. This prediction would require a better knowledge of the loading from the tailings impoundments to the aquifer **prior to 2001**.

5.5 Discussion

The model predictions of future loading to Rose Creek suggest that future zinc loading will be of much greater concern to the water quality of Rose Creek than sulphate loading. Sulphate concentrations in Rose Creek (at RC9) are predicted to increase only by a factor of two above current concentrations, still remaining below the CCME guideline of 500 mg/L SO4. In contrast, zinc concentrations in Rose Creek (at RC9) are predicted to increase by 500-700 times above current concentrations, exceeding the CCME guideline for zinc (0.03 mg/L Zn) for freshwater aquatic life by several orders of magnitude, if no remediation measures are implemented. While the interception of Faro Creek seepage (currently allowed to discharge into the Rose Creek Facility) is predicted to reduce the zinc loading significantly, this remediation measure alone is not predicted to achieve acceptable water quality in Rose Creek.

The modeling results further suggest that the uncertainty in pore water propagation rates (i.e. tailings seepage rates), average travel time in the aquifer and degree of retardation generally has only a small influence on the predicted sulphate and zinc concentrations. In all scenarios, sulphate concentrations remain below the CCME guideline for sulphate whereas zinc concentrations are predicted to exceed the CCME guideline for zinc by at least two orders of magnitude.

The predicted zinc concentrations in Rose Creek are generally consistent with earlier predictions provided by Stantec (2002). In this earlier work, a one-dimensional transport model was used to predict future zinc concentrations in Rose Creek downstream of the tailings facility. This study predicted peak sulphate and zinc concentrations in Rose Creek of about 145 mg/L SO4 and 24 mg/L Zn assuming average flow conditions in Rose Creek (2,200 L/s). These estimates compare reasonably well to our range of predicted peak sulphate and zinc concentrations (200-250 mg/L SO4 and 15-25 mg/L Zn, respectively), considering the uncertainty in such model predictions[7]. This general agreement in predicted zinc concentrations using an independent (and different) approach provides some confidence in the modeling predictions.

---

[7] Note that our estimates were calculated assuming low flow conditions in Rose Creek (~500 L/s) whereas Stantec (2003) assumed average flow conditions (2,200 L/s). Hence our loading estimates are about 4 times lower than those obtained by Stantec (2003).

6 FUTURE CONDITIONS WITH REMEDIATION

6.1 Overview

This section summarizes the results for the simulation of future conditions assuming that alternative remediation measures for the Rose Creek tailings facility (i.e. tailings relocation, cover placement etc) are implemented. The majority of these scenarios were simulated assuming our best estimate of tailings seepage rates, i.e. assuming “average” propagation rates. Selected scenarios were also simulated assuming an upper bound of steady-state seepage rates, i.e. assuming “maximum” propagation rates.

Table 6.1 summarizes the proposed remediation scenarios. All remediation scenarios were run using the same flow conditions in Rose Creek used for “current conditions” and “future conditions” (see above). All remediation scenarios were run using our best estimate of transport parameters (K=1.2*10-4 m/s and R=2 for Zinc).

The remediation scenarios evaluated in this study differ in two aspects:

- Remedial activities directly aimed at the source of contamination, i.e. the tailings impoundments (e.g. tailings relocation, cover placement etc.); and
- Collection of impacted groundwater downstream of the tailings facility.

Scenarios R1 and R2 evaluate the benefit of groundwater collection alone (assuming 90% capture efficiency of toe seepage and groundwater at the Cross Valley Dam combined).

Scenarios R4 to R7 evaluate the benefit of alternative remediation measures for the tailings facility without any groundwater collection.

Scenarios R8 to R10 evaluate the benefit of alternative remediation measures for the tailings facility plus groundwater collection (assuming 90% capture efficiency of all groundwater and toe seepage at the Cross Valley Dam combined).

While not specifically stated in Table 6.1, it was assumed that Faro Creek seepage will be collected and treated in all scenarios. Furthermore, the small loading to Rose Creek along the Rose Creek Diversion Canal (via the spilled tailings in Reach 1) is also assumed to be removed.

It should be noted that any remediation measures involving removal of the Polishing Pond and Intermediate Pond (Runs R4/R9 and R7/R10) would result in some decrease in the amount and location of groundwater discharge. In contrast, flooding of the tailings for a water cover is expected to increase the seepage emerging downstream of X Valley Dam. Additional groundwater flow analyses would be required to evaluate these changes in flow in more detail. This work was beyond the scope of this study. For the purpose of this study it was therefore assumed that the groundwater “underflow” flowing in the aquifer beneath station RC9 would remain constant. In practice, the toe seepage at the X Valley Dam and groundwater discharge further downgradient was reduced (or increased) by the amount of seepage eliminated (or produced) by the remediation measures.

Finally, any leakage losses from the Rose Creek Diversion were assumed to remain constant for all remediation scenarios. While these assumptions simplify the future incremental discharge and thus loading pattern to Rose Creek they are not believed to influence the concentrations of COCs in Rose Creek at the downstream end of the model (RC9) significantly.

Table 6.1

Summary of Remediation Scenarios.

Run ID	**Option**	**Description**
Run R1	"Collect & Treat" only	Collect & treat Faro Creek seepage & Toe Seepage at X Valley Dam
Run R2	"Collect, Pump & Treat"	as Run 1a above PLUS pump impacted groundwater immediately downgradient of X Valley Dam; assume combined capture efficiency of 90%
Run R3	"Full Relocation"	Removal of all tailings including dam structures and associated ponds; assume relocation of Original Tailings by 2010, Second Tailings by 2015 and Intermediate Tailings by 2020
Run R4	"Partial Relocation w/ Dry Cover"	Removal of Intermediate Tailings Impoundment only (including dam structures and associated ponds) by end of 2014 & dry cover placed on Original and Second Impoundments by end of 2010
Run R5	"Partial Relocation w/ Water Cover "	Relocation of tailings from all three impoundments above elevation 1042m asl; assume partial relocation of Original Tailings by 2010, Second Tailings by 2014 and Intermediate Tailings by 2018; flooding of all remaining tailings to be completed by 2020
Run R6	"Full Water Cover"	Flooding of all tailings; assume flooding occurs in 2010
Run R7	"Dry Cover"	Placing a "high quality" engineered cover (e.g. capillary barrier); assume net infiltration is reduced to 5mm/yr in 2010
Run R8	"Full Relocation" & "Collect, Pump & Treat"	as for Run 3 **PLUS** collect & treat impacted groundwater immediately downgradient of X Valley Dam (assume 90% capt. efficiency)
Run R9	"Partial Relocation w/ Dry Cover" & "Collect, Pump & Treat"	as for Run 4 **PLUS** collect & treat impacted groundwater immediately downgradient of X Valley Dam (assume 90% capture efficiency)
Run R10	"Dry Cover" & "Collect, Pump & Treat"	as for Run 7 **PLUS** collect & treat impacted groundwater immediately downgradient of X Valley Dam (assume 90% capture efficiency)

For all remediation scenarios, “average” pore water propagation rates with associated “average” seepage rates (16 and 34mm/yr) were assumed for the period until remediation measures dictate a change in those parameters (see section 6.2 below). Selected remediation scenarios were also simulated assuming “maximum” propagation rates with associated high seepage rates (26 & 75mm) as sensitivity runs.

6.2 Contaminant Release from Tailings

For scenarios R1 and R2, the contaminant release model developed for future conditions without remediation (section 5.2) were used without any adjustments. For all other scenarios, adjustments in the timing and/or magnitude of the loading from the tailings were required.

For those scenarios assuming partial or full relocation, the loading from those reaches with relocated tailings was set to zero after completion of tailings relocation in the respective area (see Table 6.1 for assumed dates). The other remediation measures (dry cover or water cover) will affect the propagation rates of the tailings pore water (and seepage rates). The flooding of the tailings is assumed to result in an increased seepage rate of 1038 mm/yr and 290 mm/yr in the coarse and fine tailings, respectively. This seepage rate is equivalent to propagation rates of 2.52m/yr and 0.63m/yr in the saturated coarse and fine tailings, respectively. The placement of a “high quality” dry cover is assumed to reduce the seepage rate to 5 mm/yr in all tailings. This low seepage flux reduces the propagation rate in the coarse tailings to ~0.012 m/yr in the saturated tailings.

The predicted breakthrough of sulphate and zinc to the aquifer for the different tailings remediation options is shown in Figures 6.1 to 6.15 (upper panels). Table 6.2 summarizes the cumulative loading of sulphate and zinc computed for selected time periods for the various tailings remediation options. Table 6.3 shows the % reduction in sulphate and zinc loading to the aquifer relative to the base case of no tailings remediation (i.e. Runs 1a/2a for average propagation rates and Runs 1b/2b for maximum propagation rates).

The influence of different tailings remediation options on the release of sulphate and zinc to the aquifer can be summarized as follows:

- Full relocation of all tailings (by 2020) is predicted to reduce the total sulphate and zinc load entering the groundwater system dramatically (by 98-99%); however, a significant load of sulphate and zinc (6,000 t SO4 and 1,000 t Zn) may still enter the aquifer prior to completion of the relocation project (representing about 40-45% of the potential load for this time period);
- Placement of a “high quality” dry cover (assumed to reduce the rate of net infiltration to 5 mm/year) is predicted to provide the greatest short-term reduction in sulphate and zinc loading (~50% of the potential load between 2001 and 2020); however, this remediation option does not perform as well as full or even partial relocation over the mid-term to long-term;
- Implementation of a full water cover (over all tailings) is predicted to significantly increase the loading of sulphate and zinc to the aquifer, because of the anticipated increase in seepage rates and associated flushing of ARD products currently stored in the unsaturated tailings profile;
- Both partial relocation options are predicted to produce similar loading rates to the aquifer in the short-term (~6,000 t SO4 and 1,000 t Zn between 2001-2020); however, the partial relocation option with a water cover (over all tailings below an elevation of 1042 m asl) is predicted to result in lower long-term loading rates than the partial relocation option with a dry cover (placement of a water cover was assumed to stop future oxidation).

These simulations generally demonstrate that the primary benefit of any tailings remediation option lies in the reduction of sulphate and zinc loading in the medium to long-term (i.e. beyond year 2020). In the short-term, the load reductions that may be achieved are substantially smaller because of the delay in implementing these remediation measures. The predicted zinc loading from the tailings to the aquifer over the next 20 years is significant in all remediation options, suggesting that some form of groundwater collection downstream of the Rose Creek tailings facility may be required, at least in the short to mid-term (see below).

Table 6.2

Cumulative tailings load to aquifer for different tailings remediation options.

Run ID	Tailings Remediation	Porewater Propagation Rate	Cumulative SO4 Load (tonnes)			Cumulative Zinc Load (tonnes)		
			2001-2020	2021-2100	2001-2750	2001-2020	2021-2100	2001-2750
Run R1a & R2a	No tailings remediation	"Average"	10,195	54,335	557,014	1,866	8,413	79,686
Run R1b & R2b		"Maximum"	23,408	150,175	788,010	4,129	23,422	98,403
Run R3a	"Full Relocation"	"Average"	6,203	0	6,203	1,008	0	1,008
Run R3b		"Maximum"	13,507	0	13,507	2,414	0	2,414
Run R4	"Partial Relocation & Dry Cover"	"Average" & modified after cover placement	5,843	5,783	75,470	1,067	1,085	12,379
Run R5	"Partial Relocation & Water Cover "	"Average" & modified after flooding	6,219	20,331	26,550	1,015	1,627	2,642
Run R6	"Full Water Cover"	"Average" & modified after flooding	196,438	375,439	571,878	33,503	60,125	93,625
Run R7	"Dry Cover"	"Average" & modified after cover placement	5,450	6,970	104,752	934	1,224	16,826

Table 6.3

Reduction (or increase) in tailings load to aquifer for different tailings remediation options.

Run ID	Tailings Remediation	Porewater Propagation Rate	Reduction in SO4 Load (% of Potential Source Load)			Reduction in Zinc Load (% of Potential Source Load)		
			2001-2020	2021-2100	2001-2750	2001-2020	2021-2100	2001-2750
Run R1a & R2a	No tailings remediation	"Average"	0%	0%	0%	0%	0%	0%
Run R1b & R2b		"Maximum"	0%	0%	0%	0%	0%	0%
Run R3a	"Full Relocation"	"Average"	39%	100%	99%	46%	100%	99%
Run R3b		"Maximum"	42%	100%	98%	42%	100%	98%
Run R4	"Partial Relocation & Dry Cover"	"Average" & modified after cover placement	43%	89%	86%	43%	87%	84%
Run R5	"Partial Relocation & Water Cover "	"Average" & modified after flooding	39%	63%	95%	46%	81%	97%
Run R6	"Full Water Cover"	"Average" & modified after flooding	(1827)%	(591)%	(3)%	(1695)%	(615)%	(17)%
Run R7	"Dry Cover"	"Average" & modified after cover placement	47%	87%	81%	50%	85%	79%

Notes:
(Brackets) indicate an *increase* in load compared to base case (no reclamation).

6.3 Sulphate Loading to Rose Creek

The predicted breakthrough of sulphate in Rose Creek (at RC9) for the 10 different remediation scenarios is shown in Figures 6.1 to 6.10 (lower left panel). Table 6.4 summarizes the predicted peak breakthrough concentrations and loads of sulphate in Rose Creek (at RC9).

Table 6.4

Predicted peak breakthrough concentrations and loads of sulphate for alternative remediation scenarios in Rose Creek (at RC9).

Run ID	Option	Porewater Propagation Rate	SO4 Peak Load in Rose Creek (at station RC9)		
			Year	mg/L	t/year
Run F1	*"No remediation"*	*"Average"*	*2174*	*202*	*4,332*
Run R1a	"Collect & Treat" only	"Average"	2174	55	1,029
Run R2a	"Collect, pump & Treat"	"Average"	2174	38	711
Run R3a	"Full Relocation"	"Average" until end of removal	2021	52	1,031
Run R4	"Partial Relocation w/ Dry Cover"	"Average" & modified after cover placement	2021	53	1,045
Run R5	"Partial Relocation & Water Cover "	"Average" & modified after flooding	2029	96	2,060
Run R6	"Full Water Cover"	"Average" & modified after flooding	2031	1,004	22,020
Run R7a	"Dry Cover"	"Average" & modified after cover placement	2023	47	942
Run R8a	"Full Relocation" & "Collect, Pump & Treat"	"Average" until end of removal	2027	31	574
Run R9	"Partial Relocation w/ Dry Cover" & "Collect, Pump & Treat"	"Average" & modified after cover placement	2021	31	575
Run R10	"Dry Cover" & "Collect, Pump & Treat"	"Average" & modified after cover placement	2023	31	567

Remediation scenarios R1 and R2 assume that remediation is limited to groundwater collection without any remediation of the Rose Creek tailings facility. The modeling results for those scenarios can be summarized as follows:

- In Option R1, all shallow seepage day-lighting before the confluence of the Rose Creek Diversion and Rose Creek is intercepted, representing a flow of 73 L/s and a sulphate load of 1,540 t/yr at peak breakthrough; this remediation option does not prevent any loading from the tailings to the aquifer; however, this mitigation measure is predicted to substantially reduce the loading to Rose Creek resulting in peak sulphate concentrations of 55 mg/L and peak SO4 loading of ~1,000 t/yr, i.e. comparable and oftentimes lower than other tailings remediation options (without groundwater collection);
- In Option R2, the interception system is upgraded (using a fence of interceptor wells downgradient of the X Valley Dam) to achieve an efficiency of 90% groundwater interception, in this scenario, the combined flow intercepted is 80.5 L/s representing a sulphate load of 1925 t/yr; this improved collection system is predicted to reduce the loading to Rose Creek further (compared to option 1) resulting in peak sulphate concentrations of only about 38 mg/L;

Remediation scenarios R3 to R7 simulate different remediation options for the Rose Creek tailings facility assuming no collection of impacted groundwater downstream of the facility. The modeling results for those scenarios can be summarized as follows:

- In Option R3, all tailings are assumed to be removed between 2008 and 2020; as expected, this option is predicted to result in the lowest overall release of sulphate load to the aquifer (see section 6.2); the removal of the tailings is predicted to reduce the peak sulphate concentrations in Rose Creek to similar levels (~55 mg/L) predicted for options R1 and R2 (groundwater collection only); all residual sulphate loading from the tailings is predicted to be "flushed" from the groundwater system by about 2030;
- In option R4, the tailings of the Intermediate Impoundment are relocated and the tailings of the Original and Second Impoundment are covered to limit infiltration; the very low rate of net infiltration assumed in this scenario reduces both the propagation rates within the tailings profile and the seepage rate, resulting in a large reduction in sulphate loading to the aquifer; as a result the predicted sulphate concentrations Rose Creek show similar trends over time as those predicted for the option of full relocation;
- In option R5, all tailings above an elevation of 1042m amsl are removed and the residual tailings are flooded with a 3m deep water cover; this option is predicted to result in an initial reduction in source loading to the aquifer (primarily because of the removal of the coarse tailings in the Original Impoundment); however, subsequent flooding is predicted to "flush" all of the soluble sulphate inventory stored in the residual tailings into the aquifer over a relatively short period of time; this release is predicted to result in higher sulphate concentrations (~100 mg/L) around year 2029; in the mid- to long-term (.>2060) the system is predicted to return to background conditions as all soluble sulphate is flushed out of the tailings and the underlying aquifer system;
- In Option R6, a water cover is implemented in all three tailings impoundments by the year 2010; this option is predicted to result in the "flushing" of all soluble sulphate in the tailings currently stored in the tailings over a short time period; the predicted sulphate concentrations in Rose Creek for this option would approach ~1,000 mg/L; furthermore, sulphate concentrations in Rose Creek are predicted to remain above the CCEM guideline of 500 mg/L for several tens of years suggesting that groundwater interception would be required for an extended period of time;
- In Option R7, a high quality dry cover is placed over all tailings by the end of 2010; this option is predicted to result in similar loading of sulphate to Rose Creek as predicted for Option R4; those two options only differ in the remediation strategy for the tailings in the Intermediate Impoundment; the sulphate loading from those tailings (after cover placement) is predicted to be relatively small (see section 6.2); hence complete removal of those tailings is predicted to result in very little reduction in sulphate concentrations in Rose Creek, compared to the dry cover option.

Remediation scenarios R8 to R10 simulate selected remediation options for the Rose Creek tailings facility also assuming collection of impacted groundwater downstream of the facility (at the toe of the Cross Valley Dam). The modeling results for those scenarios can be summarized as follows:

- In option R8, the tailings option of “full relocation” (R3) is combined with a groundwater interception system; assuming 90% capture efficiency, the groundwater interception system is predicted to remove about 45 L/s representing a sulphate load of 462 t/yr at peak sulphate breakthrough; this removal of impacted groundwater reduces the peak sulphate concentrations to very low levels (~31 mg/L) representative of “background”;
- In option R9, the tailings option of “partial relocation with dry cover” (R4) is combined with a groundwater interception system; assuming 90% capture efficiency, the groundwater interception system is predicted to remove about 45 L/s representing a sulphate load of 481 t/yr at peak sulphate breakthrough; this removal of impacted groundwater reduces the peak sulphate concentrations to very low levels (~31 mg/L) representative of “background”;
- In option R10, the tailings option of “dry cover” (R7) is combined with a groundwater interception system; assuming 90% capture efficiency, the groundwater interception system is predicted to remove about 45 L/s representing a sulphate load of 384 t/yr at peak sulphate breakthrough; this removal of impacted groundwater reduces the peak sulphate concentrations to very low levels (~31 mg/L) representative of “background”.

In summary, all remediation options considered in this study, except the option of flooding of all tailings (“full water cover”), are predicted to achieve acceptable sulphate concentrations in Rose Creek (<< 500 mg/L). Flooding of all tailings (and in particular the coarse tailings beaches of the Original and Second Impoundments) would induce significant release of sulphate currently stored in the tailings profile resulting in significantly elevated sulphate concentrations in Rose Creek for several decades.

6.4 Zinc Loading to Rose Creek

The predicted breakthrough of zinc in Rose Creek (at RC9) for the 10 different remediation scenarios is shown in Figures 6.1 to 6.10 (lower right panel). Table 6.5 summarizes the predicted peak breakthrough concentrations and loads of zinc in Rose Creek (at RC9).

Remediation scenarios R1 and R2 assume that remediation is limited to groundwater collection without any remediation of the Rose Creek tailings facility. The modeling results for those scenarios can be summarized as follows:

- In Option R1, all shallow seepage day-lighting before the confluence of the Rose Creek Diversion and Rose Creek is intercepted, representing a flow of 73 L/s and a zinc load of 171 t/yr at peak zinc breakthrough; this remediation option does not prevent any loading from the tailings to the aquifer; however, this mitigation measure is predicted to substantially reduce the loading to Rose Creek resulting in peak zinc concentrations of about 3.0 mg/L and loadings comparable and oftentimes lower than other tailings remediation options (without groundwater interception);
- In Option R2, the interception system is upgraded (using a fence of interceptor wells downgradient of the X Valley Dam) to achieve an efficiency of 90% groundwater interception, representing a combined flow of 80.5 L/s and a zinc load of 213 t/yr; this option is predicted to further reduce the loading to Rose Creek (compared to option 1) resulting in peak zinc concentrations of ~1.1 mg/L;

Table 6.5

Predicted peak breakthrough concentrations and loads of zinc for alternative remediation scenarios in Rose Creek (at RC9).

Run ID	**Option**	**Porewater Propagation Rate**	**Zinc Peak Load in Rose Creek (at station RC9)** Year	mg/L	t/year
Run F1	*"No remediation"*	*"Average"*	*2174*	*15.2*	*326*
Run R1a	"Collect & Treat" only	"Average"	2174	3.0	56
Run R2a	"Collect, pump & Treat"	"Average"	2174	1.1	21
Run R3a	"Full Relocation"	"Average" until end of removal	2047	3.3	66
Run R4	"Partial Relocation w/ Dry Cover"	"Average" & modified after cover placement	2047	3.4	67
Run R5	"Partial Relocation & Water Cover "	"Average" & modified after flooding	2047	5.0	108
Run R6	"Full Water Cover"	"Average" & modified after flooding	2052	159	3,444
Run R7a	"Dry Cover"	"Average" & modified after cover placement	2047	3.4	68
Run R8a	"Full Relocation" & "Collect, Pump & Treat"	"Average" until end of removal	2047	0.33	6
Run R9	"Partial Relocation w/ Dry Cover" & "Collect, Pump & Treat"	"Average" & modified after cover placement	2047	0.34	6
Run R10	"Dry Cover" & "Collect, Pump & Treat"	"Average" & modified after cover placement	2047	0.36	7

Remediation scenarios R3 to R7 simulate different remediation options for the Rose Creek tailings facility assuming no collection of impacted groundwater downstream of the facility. The modeling results for those scenarios can be summarized as follows:

- In Option R3, all tailings are assumed to be removed between 2008 and 2020; although this option is predicted to result in the lowest overall release of zinc load to the aquifer (see section 6.2), the small residual load allowed to enter the aquifer prior to the end of remediation in 2020 would still result in significantly elevated zinc concentrations (~ 3 mg/L) over the next 40-60 years; despite the tailings removal, these zinc concentrations are still 2 orders of magnitude above the CCEM guideline for zinc (0.03 mg/L) and some form of groundwater interception system would likely be required over the short- to mid-term (see option R8);
- In option R4, the tailings of the Intermediate Impoundment are relocated and the tailings of the Original and Second Impoundment are covered to limit infiltration; the very low rate of net infiltration assumed in this scenario (5 mm/yr) reduces the rate of zinc loading significantly; however, this option does not eliminate the loading over the mid- to long-term and the zinc

concentrations in Rose Creek are predicted to remain elevated (~0.5-1.0 mg/L) for a very long time (beyond year 2750);

- In option R5, all tailings above an elevation of 1042m amsl are removed and the residual tailings are flooded with a 3m deep water cover; this option is predicted to result in an initial reduction in zinc loading to the aquifer (primarily because of the removal of the coarse tailings in the Original Impoundment); however, subsequent flooding is predicted to “flush” all of the soluble zinc inventory stored in the residual tailings into the aquifer over a relatively short period of time; this release is predicted to result in higher peak zinc concentrations (~5.0 mg/L) around year 2047; in the mid- to long-term (>2060) the system is predicted to return to background conditions as all soluble zinc is flushed out of the tailings and the underlying aquifer system;
- In Option R6, a water cover is implemented in all three tailings impoundments by the year 2010; this option is predicted to result in the “flushing” of all soluble zinc in the tailings currently stored in the tailings over a short time period; the predicted zinc concentrations in Rose Creek for this option would approach 160 mg/L which is clearly unacceptable; flooding of all the tailings would very likely require the interception of significant quantities of toe seepage and groundwater for a period of 80-100 years to prevent the discharge of this “pulse” of contaminants into Rose Creek;
- In Option R7, a high quality dry cover is placed over all tailings by the end of 2010; this option is predicted to reduce the zinc load to the aquifer by about 50% over the net 20 years and by as much as 85% by 2100; however, despite this load reduction, the zinc concentrations are predicted to increase to about 3.4 mg/L over the next forty years and remain elevated (0.5 – 1.5 mg/L) thereafter for a very long time;

In summary, the two remediation scenarios involving flooding of the tailings (partial or full water cover) result in significantly higher zinc concentrations in Rose Creek in the short to mid-term than any other remediation scenarios. On this basis, those remediation scenarios should be rejected as a preferred option.

Nevertheless, the other tailings remediation options (involving either relocation and/or dry cover placement) are also predicted to result in moderately elevated zinc concentrations (>3 mg/L) in the short to mid-term (40-100 years) because of past loading (already in the aquifer) and the future release of tailings seepage prior to the completion of remedial activities. Therefore, it appears likely that some form of groundwater interception downgradient of the tailings facility will be required whichever remediation option is selected.

Remediation scenarios R8 to R10 simulate selected remediation options for the Rose Creek tailings facility also <u>assuming collection of impacted groundwater</u> downstream of the facility (at the toe of the Cross Valley Dam). The modeling results for those scenarios can be summarized as follows:

- In option R8, the tailings option of “full relocation” (R3) is combined with a groundwater interception system; assuming 90% capture efficiency, the groundwater interception system is predicted to remove about 45 L/s representing a zinc load of 61 t/yr at peak zinc breakthrough; this removal of impacted groundwater is predicted to reduce the peak zinc concentrations in Rose Creek by a factor of 10 (from 3.3 mg/L to 0.33 mg/L);

- In option R9, the tailings option of “partial relocation with dry cover” (R4) is combined with a groundwater interception system; assuming 90% capture efficiency, the groundwater interception system is predicted to remove about 45 L/s representing a sulphate load of 62 t/yr at peak sulphate breakthrough; this removal of impacted groundwater is predicted to reduce the peak zinc concentrations in Rose Creek by a factor of 10 (from 3.4 mg/L to 0.34 mg/L);
- In option R10, the tailings option of “dry cover” (R7) is combined with a groundwater interception system; assuming 90% capture efficiency, the groundwater interception system is predicted to remove about 45 L/s representing a sulphate load of 63 t/yr at peak sulphate breakthrough; this removal of impacted groundwater is predicted to reduce the peak zinc concentrations in Rose Creek by a factor of 10 (from 3.4 mg/L to 0.36 mg/L);

In summary, implementation of a groundwater collection system at the toe of the Cross Valley Dam **in addition** to tailings relocation and/or dry cover placement is predicted to reduce the peak zinc concentrations in Rose Creek significantly (by a factor of 10). However, the resulting zinc concentrations in Rose Creek are still predicted to be about one order of magnitude above the CCME guideline of zinc for the protection of freshwater aquatic life (0.03 mg/L Zinc). According to these model calculations, the capture efficiency of the groundwater interception system at the Cross Valley Dam would have to be very high (99% or higher) in order to achieve zinc concentrations in Rose Creek (at RC9) below CCME guidelines, regardless of which tailings remediation option is selected.

The modeling results suggest that the primary advantage of tailings relocation over dry cover placement would be the time period over which groundwater collection would be required. Assuming full relocation, groundwater collection may be required for 40-60 years, whereas in-situ remediation using a dry cover may require collection and treatment of impacted groundwater in perpetuity.

6.5 Sensitivity Analysis

Four remediation scenarios (R1, R2, R3 and R8) were also simulated assuming the maximum propagation rate for contaminant release from the tailings (section 6.2). These results provide a reasonable upper bound of loading from the tailings and hence to Rose Creek for different remediation options. An additional sensitivity run (R7b) was simulated assuming the Intermediate Pond with current (poor) water quality will remain in place after dry cover placement.

The predicted breakthrough of sulphate and zinc in Rose Creek (at RC9) for the five different sensitivity runs (denoted by a suffix “b”) are shown in Figures 6.11 to 6.15 (lower panel). Table 6.6 summarizes the predicted peak breakthrough concentrations and loads of sulphate and zinc in Rose Creek (at RC9). The results for the base case (denoted with the suffix “a”) are also shown in Table 6.6 for ease of comparison.

The results of these sensitivity runs may be summarized as follows:

- The use of maximum propagation rates “accelerates” the migration of the solute front through the tailings profile; as a result the release of sulphate and zinc from the tailings to the aquifer is compressed into a shorter time frame but loading rates more than double;
- The increase in loading rates to the aquifer are predicted to result in a commensurate increase in peak loading and peak concentrations of zinc in Rose Creek for all remediation

scenarios; the increase in peak loading and concentrations of sulphate in Rose Creek is predicted to be significantly smaller (only 12-60% increase compared to average propagation rates depending on remediation scenario);

- The continued presence of the Intermediate Pond after dry cover placement (R7b) is predicted to result in significantly higher sulphate concentrations in Rose Creek at peak breakthrough (75 mg/L compared to 45 mg/L SO4 assuming no pond); however, peak zinc concentrations are predicted to increase only marginally because of the additional pond seepage (3.8 mg/L compared to 3.4 mg/L Zn assuming no pond).

Table 6.6

Predicted peak breakthrough concentrations and loads of sulphate and zinc for alternative remediation scenarios in Rose Creek (at RC9) – Sensitivity Runs.

			SO4 Peak Load in Rose Creek (at station RC9)			**Zinc Peak Load in Rose Creek (at station RC9)**		
Run ID	**Option**	**Porewater Propagation Rate**	Year	mg/L	t/year	Year	mg/L	t/year
Run R1a	"Collect & Treat" only	"Average"	2174	55	1,029	2174	3.0	56
Run R1b		"Maximum"	2101	66	1,248	2101	5.5	103
Run R2a	"Collect, pump & Treat"	"Average"	2174	38	711	2174	1.1	21
Run R2b		"Maximum"	2081	41	761	2101	1.9	35
Run R3a	"Full Relocation"	"Average"	2021	52	1,031	2047	3.3	66
Run R3b		"Maximum"	2027	86	1,710	2047	7.8	155
Run R7a	"Dry Cover"	"Average" & modified after cover placement	2023	47	942	2047	3.4	68
Run R7b[1]			2023	75	1,564	2047	3.8	79
Run R8a	"Full Relocation" & "Collect, Pump & Treat"	"Average"	2027	31	574	2047	0.3	6
Run R8b		"Maximum"	2027	35	638	2047	0.8	15

Notes:

[1] Run 7b assumes that Intermediate Pond remains present after dry cover placement with no improvement in water quality

In summary, uncertainty in the propagation rate of the solute front through the tailings (and associated seepage rate at the base of the tailings) introduces a greater uncertainty in the predicted peak zinc concentrations in Rose Creek than peak sulphate concentrations. The increase in peak zinc concentrations in Rose Creek assuming higher propagation rates is almost directly proportional to the resulting increase in peak loading from the tailings to the aquifer.

6.6 Discussion

One of the key findings of the simulation of alternative remediation scenarios is the prediction that all tailings remediation options (including full relocation of all tailings) will result in moderately elevated zinc concentrations (>3 mg/L) in the short to mid-term (40-100 years) because of past loading (already in the aquifer) and the future release of tailings seepage prior to the completion of remedial activities. These predictions suggest that some form of groundwater interception downgradient of the tailings facility will be required, at least as an interim measure, whichever remediation option is selected.

These predictions are based on two key assumption (i) our estimates of current and future zinc loading from the tailings to the aquifer are reasonable; and (ii) zinc attenuation occurs only in the aquifer (not in the tailings) and can be represented by a retardation factor of R=2. Both assumptions are considered conservative, in that they provide conservative (high) estimates of zinc loading to the aquifer and to Rose Creek. This approach was considered prudent for assessing alternative remediation scenarios in the long-term, considering the lack of reliable field data.

However, this conservative approach may result in overly pessimistic estimates of future zinc concentrations, in particular in the short to mid-term. As discussed in section 4.6, the current zinc load in the aquifer beneath the Original and Second Impoundment is about one to two orders of magnitude **lower** than our estimates of current zinc loading from tailings seepage. This would imply that our predictions of loading to Rose Creek, at least in the short-term, might also be too high by one to two orders of magnitude.

As discussed in sections 4.6 and 4.7, the most likely cause for the discrepancy between modeled and currently observed zinc loads in the aquifer is significant attenuation of zinc along the flow path. The exact mechanism(s) of zinc attenuation are currently not understood thus limiting our ability to predict zinc loading to the aquifer and Rose Creek in the short to mid-term. This has significant implications for evaluating the alternative remediation options. For example, if most (or all) zinc attenuation was occurring in the deeper tailings profile (as opposed to in the natural soils) then full tailings relocation (Options R2 and R8) may be able to prevent a significant increase in future zinc loading to the aquifer and Rose Creek. Clearly, a better understanding of the attenuation processes controlling zinc transport will be required in order to improve our ability to predict zinc concentrations in groundwater and ultimately evaluate the effect of different remediation strategies on stream water quality.

However, even in this “best case” scenario (no future loading and full tailings relocation) some groundwater collection might still be required due to the zinc load already present in the aquifer. Based on our analysis, the current zinc load in the aquifer beneath the Original and Second Impoundment is estimated to range from 0.8 to 4.0 tonnes of zinc per year (section 4.6). Assuming all groundwater discharges to Rose Creek, this zinc load would increase the zinc concentrations in Rose Creek under moderate baseflow conditions (502 L/s) by about 0.05 to 0.25 mg/L. In other words, the CCME guideline for zinc (0.03 mg/L Zn) for the protection of freshwater aquatic life may still be exceeded in the short to mid-term even if all tailings were removed immediately.

Considering the uncertainty in predicting future zinc concentrations, in particular over the short to mid-term, it would be prudent to include provisions in the remediation plan for the Rose Creek tailings facility for an interim groundwater collection system, regardless of which tailings remediation option is selected. However, construction of such a groundwater collection system should be delayed for several years, providing more opportunity to further monitor the zinc concentrations in the tailings pore water and underlying aquifer and to recalibrate, if required, the zinc load balance model. Such an updated model could then be used to re-evaluate the need for a groundwater collection system.

Another key finding of the simulation of alternative remediation scenarios is the prediction that the two remediation scenarios involving flooding of the tailings (partial or full water cover) result in significantly higher zinc concentrations in Rose Creek in the short to mid-term than any other remediation scenarios. This result is intuitive since flooding of the tailings would result in large hydraulic gradients, which would increase the tailings seepage rates significantly, thus flushing the large amount of oxidation products (including zinc) currently stored in the unsaturated tailings profile, into the aquifer and ultimately into Rose Creek. Based on those considerations, a water cover is not considered a preferred option for the Rose Creek tailings facility.

It should be emphasized that no additional loading was assumed in the tailings relocation options during the process of tailings relocation (essentially assuming dry relocation). Other methods of relocation involve re-slurrying of the tailings, which could produce additional seepage during relocation work. The modeling results for the water cover options illustrate the potentially large (temporary) loading that could result from flooding of these oxidized tailings. It follows that flooding of the tailings during any potential relocation works (e.g. using hydraulic monitoring) should be avoided, if at all possible. One potential option would be to relocate the upper layers of the coarse tailings (which carry much of the stored oxidation products) by truck-and-shovel operation, prior to start of hydraulic monitoring.

7 CONCLUSIONS & RECOMMENDATIONS

One of the primary issues in the context of closure planning for the Anvil Range Mining Complex will be the development and assessment of decommissioning options for the Rose Creek Tailings Facility. A comprehensive water and load balance model was developed for the Rose Creek valley (including surface water and groundwater) based on an extensive review of all relevant data, including characterization studies of the tailings and underlying aquifer materials as well as historic monitoring data of surface water and groundwater quality. The primary objectives of this modeling study were to:

(i) Evaluate current and future sources of contaminant loading to the Rose Creek aquifer and Rose Creek itself; and

(ii) Provide order-of-magnitude predictions of SO4 and Zn concentrations in groundwater and Rose Creek for alternative remediation scenarios

The following sections summarize the major findings of this study and provide recommendations for future work.

7.1 Conclusions

7.1.1 Current Conditions

A synoptic field survey consisting of flow measurements and water quality sampling in surface flow and seeps in the Rose Creek valley was carried out in October 2004 under moderate low flow conditions. The key findings from this survey are as follows:

- The seepage discharging at the mouth of the old Faro Creek Canyon is substantial (~10.2 L/s) and represents a large contaminant load (~1,700 t SO4 per year and ~100 t Zn per year) to the Rose Creek valley; most of this seepage flow is lost to the subsurface via leakage before it can reach the Intermediate Pond;
- The Rose Creek Diversion experiences significant leakage (about 200 L/s) between the Intermediate Dam and the end of the diversion; this leakage provides an important source of dilution to the south side of the aquifer;
- The area between the Cross Valley Dam and Rose Creek (X14) represents a major groundwater discharge zone; the combined flow of this “Cross Valley Seepage” was 83 L/s, representing a total load of ~1,400 t SO4 per year but only 0.05 t Zn per year;
- Rose Creek remains a gaining stream downstream of the confluence (where it flows in its natural streambed); flow measurements suggest that as much as 200 L/s of groundwater discharges into the creek between X14 and station RC1 (just upstream of the inflow of Next Creek);

The results of the October 2004 survey were used to calibrate the water and load balance model for current conditions. A unique calibration of the **sulphate** load balance model for current conditions was not possible because of uncertainties in (i) the average solute travel time in the aquifer (influencing the time of loading) and (ii) the historic water quality in tailings seepage. Instead, different scenarios were simulated to bracket the likely range of sources contributing to the loading currently observed (October 2004) in Rose Creek.

The major conclusions from a simulation of current sulphate loading to Rose Creek are as follows:

- Those scenarios assuming loading from Faro Creek seepage (i.e. Scenarios C1 and C2) provided an overall better match with field observations than those scenarios assuming only seepage from the tailings (Scenarios 3 and 4);
- The primary sources contributing to current sulphate loading in Rose Creek (~2,500 t/yr) include:
    - Upstream Sources (591 t/yr or 24%);
    - Faro Creek seepage (644 t/yr or 25%);
    - Historic Tailings Seepage (323-416 t/yr or 12-15%); and
    - Seepage from Intermediate & Polishing Ponds (811 t/yr or 32%)

A calibration of the **zinc** load balance model is even more uncertain because of the added complexity of attenuation which influences the travel time and therefore the time of loading from a given tailings impoundment. Zinc loading calculations were therefore carried out assuming different degrees of retardation along the flow path (R=1, 2 and 7).

The major conclusions from a simulation of current zinc loading to Rose Creek are as follows:

- Assuming no attenuation (R=1), the **simulated** zinc load to Rose Creek ranges from ~30 to 58 t/yr; these estimates are significantly (!) higher than the currently **observed** zinc load in Rose Creek (at RC9) of only about 0.7 t/yr; the large discrepancy between observed and predicted zinc loading may be a result of several factors including:
    - Zinc concentrations in tailings pore water are significantly lower than estimated based on leach extraction data;
    - Zinc is attenuated along the flow path (hence resulting in significantly longer travel times in the aquifer);
- Assuming a retardation factor of R=2, travel times in the aquifer would increase such that only process water from the Second and Intermediate Impoundments would contribute to current loading in Rose Creek; despite this drastic reduction in zinc loading from the tailings this scenario still overpredicts the zinc load to Rose Creek by a factor of ~6;
- A retardation factor of R=7 would increase the average travel time even further, which would imply that the only source of current zinc loading to Rose Creek would be seepage from the Intermediate Pond dating back to 1989 when tailings were still actively discharged into the Intermediate Impoundment and zinc concentrations were very low (0.21 mg/L based on historic water quality data); this scenario provides the best match with the zinc loading and zinc concentrations observed in toe seepage and groundwater discharge downstream of the Cross Valley Dam.
- The zinc load balance modeling convincingly indicates that zinc is attenuated in the system (relative to sulphate); however, the model does not provide insight into the actual mechanism

of zinc attenuation. For example, zinc attenuation may not only occur in the aquifer soils (as was assumed here) but may also occur within the tailings profile or within the unsaturated soils above the water table; the uncertainty in many model input parameters (in particular the nature and magnitude of zinc attenuation) precludes a definitive estimation of the retardation factor.

The primary calibration target for the "current" loading model was the current loading to Rose Creek. However, because of the considerable travel times in the aquifer (5-20 years) the current (2004) loading to Rose Creek is influenced by historic tailings seepage (and loading) that occurred many years ago. As a result the calibration of the "current" load balance model does not provide any validation of our estimates of current loading from the tailings to the aquifer.

In order to provide an independent check on the plausibility of the estimated seepage rates and pore water concentrations used in the load balance model, the loads from tailings seepage estimated for current conditions were compared against sulphate and zinc concentrations currently observed beneath the Original and Second Impoundment. The major findings from this analysis are as follows:

- The current sulphate loading from tailings seepage to the aquifer is estimated to range from 375 t/yr (for average propagation rates) to 741 t/yr (for maximum propagation rates) using leach extraction data (collected in 2001); these estimates agree fairly well with our estimates of the total sulphate load in the aquifer beneath the Original and Second Impoundment based on observed zinc concentrations in groundwater (542 to 780 t/yr);
- The current zinc loading from tailings seepage to the aquifer is estimated to range from 59.6 t/yr (for average propagation rates) to 126 t/yr (for maximum propagation rates) using leach extraction data (collected in 2001); these estimates are about one to two orders of magnitude higher than our estimates of the total zinc load in the aquifer beneath the Original and Second Impoundment (0.8 to 4.0 t/yr);

This discrepancy suggests that significant attenuation of zinc along the flow path (either within the tailings and/or in natural soils) might be occurring. The process of attenuation introduces significant uncertainty into any prediction of future zinc concentrations, in particular the timing of peak breakthrough, in the groundwater and, by extension, in Rose Creek. The predicted maximum concentrations are not significantly affected by this uncertainty in attenuation, provided zinc loading occurs over the long-term (centuries) and zinc uptake is due to finite and linear sorption. A better understanding of the attenuation processes controlling zinc transport will be required in order to improve our ability to predict zinc concentrations in groundwater and Rose Creek for alternative remediation strategies.

7.1.2 Future Conditions (No remediation)

The water and load balance model was used to predict future loading to Rose Creek assuming that no remediation measures for the Rose Creek tailings facility are implemented. These simulations represent the "base case" or "Do Nothing" option and provide a basis for comparison with the simulation of remediation scenarios. A series of sensitivity runs were also carried out in order to evaluate the sensitivity of the model predictions to uncertainty in model input parameters. It should be noted that all simulations of future conditions assumed a 'moderate' base flow in Rose Creek of 502 L/s at X14, or about twice that of the 7-day 2-year base flow in Rose Creek (240 L/s). Extended base flow in Rose Creek would therefore result in an approximate doubling of the modeled ‘peak’ concentrations. All simulations of future conditions further assumed that all contaminant loading from sources other than tailings (e.g. from the Faro waste rock dumps) would not increase in the future.

The main conclusions from these simulations are as follows:

- The sulphate load in Rose Creek (just upstream of the confluence with Next Creek) is predicted to increase by a factor of 2 compared to current loading; the sulphate concentrations in Rose Creek (200-250 mg/L) are predicted to remain below the CCME guideline of sulphate (500 mg/L SO4) for the protection of freshwater aquatic life; however, this guideline may be exceeded at times of extended base flow (not modeled here);
- The total zinc load in Rose Creek (just upstream of the confluence with Next Creek) is predicted to increase to about 320 t/yr (assuming average propagation rates); this load would result in peak zinc concentrations in Rose Creek (under low flow conditions) of about ~15 mg/L, i.e. more than two orders of magnitude higher than the CCME guideline for zinc (0.03 mg/L Zn) for the protection of freshwater aquatic life;
- The assumption of a higher K and retardation generally influences the arrival time of the breakthrough curve but does not change the peak concentrations significantly;
    - A retardation factor of R=2 delays the early breakthrough by some 20 years but has no significant effect on the timing of the **peak** breakthrough;
    - A retardation factor of R=7 delays the entire zinc breakthrough significantly with peak breakthrough predicted to occur in 250-300 years from today;
    - The assumption of a higher permeability in the aquifer results in a slightly earlier arrival of the zinc breakthrough curve (by ~10 years) but does not affect the peak concentrations significantly;
- The assumption of maximum propagation rates “compresses” the zinc loading to Rose Creek into a shorter time period, generally resulting in higher peak concentrations (~24 mg/L) and earlier peak breakthrough (~2080) compared to the case of average propagation rates;
- The model predictions of future loading to Rose Creek suggest that future zinc loading will be of much greater concern to the water quality of Rose Creek than sulphate loading. While the interception of Faro Creek seepage (currently allowed to discharge uncontrolled into the Rose Creek Tailings Facility) is predicted to reduce the zinc loading significantly, this remediation measure alone is not predicted to achieve acceptable water quality in Rose Creek.

7.1.3 Future Conditions with Remediation

The water and load balance model was used to predict the future loading to Rose Creek for alternative remediation scenarios including remediation options for the tailings impoundments and/or collection and treatment of impacted groundwater. As for the base case, all simulations of future conditions with remediation assumed (i) a ‘moderate’ base flow in Rose Creek of 502 L/s and (ii) no increase in contaminant load from sources other than tailings.

Table 7.1 summarizes the predicted zinc loading to the aquifer and Rose Creek for the various alternative remediation scenarios. Note again that the simulated 'peak' zinc concentrations shown in Table 7.1 refer to moderate low flow conditions and extended base flow conditions in Rose Creek could result in doubling of those modeled peak concentrations.

Table 7.1

Summary of predicted zinc loading to aquifer and Rose Creek for alternative remediation options.

Run ID	**Option**	**Zinc Load to Aquifer**		**Zinc Peak Load in Rose Creek[2] (at station RC9)**		
		Duration	**Total Load[1]**	Year	mg/L	t/year
Run F2	*"No remediation"*	*>750 years*	*79,686*	*2174*	*15.2*	*326*
Groundwater Collection only						
Run R1a	"Collect & Treat" only	> 750 years	79,686	2174	3.0	56
Run R2a	"Collect, pump & Treat"	> 750 years	79,686	2174	1.1	21
Tailings Remediation only						
Run R3a	"Full Relocation"	~ 20 years	1,008	2047	3.3	66
Run R4	"Partial Relocation & Dry Cover"	>>750 years	12,379	2047	3.4	67
Run R5	"Partial Relocation & Water Cover "	~ 60 years	2,642	2047	5.0	108
Run R6	"Full Water Cover"	~ 50 years	93,625	2052	159	3,444
Run R7	"Dry Cover"	>> 750 years	16,826	2047	3.4	68
Tailings Remediation plus Groundwater Collection						
Run R8	"Full Relocation" & "Collect, Pump & Treat"	~ 20 years	1,008	2047	0.33	6.1
Run R9	"Partial Relocation w/ Dry Cover" & "Collect, Pump & Treat"	>>750 years	12,379	2047	0.34	6.2
Run R10	"Dry Cover" & "Collect, Pump & Treat"	~ 60 years	2,642	2047	0.36	6.6

Notes:
1) load from 2001 - 2750
2) all runs assume R=2

Remediation scenarios R1 and R2 assume that remediation is limited to groundwater collection without any remediation of the Rose Creek tailings facility. The modeling results for those scenarios can be summarized as follows:

- In Option R1, all shallow seepage day-lighting before the confluence of the Rose Creek Diversion and Rose Creek is intercepted, representing a flow of 73 L/s and a zinc load of 171 t/yr, respectively; this remediation option does not prevent any loading from the tailings to the aquifer; however, this mitigation measure is predicted to substantially reduce the loading to Rose Creek resulting in peak zinc concentrations of about 3.0 mg/L Zn;

- In Option R2, the interception system is upgraded (using a fence of interceptor wells downgradient of the X Valley Dam) to achieve an efficiency of 90% groundwater interception, in this scenario, the combined flow intercepted is 80.5 L/s representing a zinc load of 213 t/yr; this option is predicted to further reduce the loading to Rose Creek (compared to option 1) resulting in peak zinc concentrations of ~1.1 mg/L Zn;

Remediation scenarios R3 to R7 simulate different remediation options for the Rose Creek tailings facility assuming no collection of impacted groundwater downstream of the facility. The modeling results for those scenarios can be summarized as follows:

- In Option R3, all tailings are assumed to be removed between 2008 and 2020; “full relocation” is predicted to reduce the total zinc load entering the groundwater system dramatically (by 98-99%); however, a significant load of zinc (~1,000 tonnes) may still enter the aquifer prior to completion of the relocation project; this residual load is predicted to result in significantly elevated zinc concentrations (~3 mg/L) over the next 40-60 years;
- In option R4, the tailings of the Intermediate Impoundment are relocated and the tailings of the Original and Second Impoundments are covered to limit infiltration; the very low rate of net infiltration assumed in this scenario (5 mm/yr) reduces the rate of zinc loading significantly; however, this option does not eliminate the loading over the mid- to long-term and the zinc concentrations in Rose Creek are predicted to remain elevated (~0.5-1.0 mg/L) for a very long time (beyond year 2750);
- In option R5, all tailings above an elevation of 1042m amsl are removed and the residual tailings are flooded with a 3m deep water cover; this option is predicted to result in an initial reduction in zinc loading to the aquifer (primarily because of the removal of the coarse tailings in the Original Impoundment); however, subsequent flooding is predicted to “flush” all of the soluble zinc inventory stored in the residual tailings into the aquifer over a relatively short period of time; this release is predicted to result in higher peak zinc concentrations (~5.0 mg/L) around year 2047; in the mid- to long-term (>2060) the system is predicted to return to background conditions as all soluble zinc is flushed out of the tailings and the underlying aquifer system;
- In Option R6, a water cover is implemented in all three tailings impoundments by the year 2010; this option is predicted to result in the “flushing” of all soluble zinc in the tailings currently stored in the tailings over a short time period; the predicted zinc concentrations in Rose Creek for this option would approach 160 mg/L which is clearly unacceptable; flooding of all the tailings would very likely require the interception of significant quantities of toe seepage and groundwater for a period of 80-100 years to prevent the discharge of this “pulse” of contaminants into Rose Creek;
- In Option R7, a high quality dry cover is placed over all tailings by the end of 2010; this option is predicted to reduce the zinc load to the aquifer by about 50% over the net 20 years and by as much as 85% by 2100; however, despite this load reduction, the zinc concentrations are

predicted to increase to about 3.4 mg/L over the next 40 years and remain elevated (0.5 – 1.5 mg/L) thereafter for a very long time;

Remediation scenarios R8 to R10 simulate selected remediation options for the Rose Creek tailings facility also assuming collection of impacted groundwater downstream of the facility (at the toe of the Cross Valley Dam). The modeling results for those scenarios can be summarized as follows:

- In option R8, the tailings option of “full relocation” (R3) is combined with a groundwater interception system; assuming 90% capture efficiency, the groundwater interception system is predicted to remove about 45 L/s representing a zinc load of 61 t/yr at peak zinc breakthrough; this removal of impacted groundwater is predicted to reduce the peak zinc concentrations in Rose Creek by a factor of 10 (from 3.3 mg/L to 0.33 mg/L);
- In option R9, the tailings option of “partial relocation with dry cover” (R4) is combined with a groundwater interception system; assuming 90% capture efficiency, the groundwater interception system is predicted to remove about 45 L/s representing a sulphate load of 62 t/yr at peak sulphate breakthrough; this removal of impacted groundwater is predicted to reduce the peak zinc concentrations in Rose Creek by a factor of 10 (from 3.4 mg/L to 0.34 mg/L);
- In option R10, the tailings option of “dry cover” (R7) is combined with a groundwater interception system; assuming 90% capture efficiency, the groundwater interception system is predicted to remove about 45 L/s representing a sulphate load of 63 t/yr at peak sulphate breakthrough; this removal of impacted groundwater is predicted to reduce the peak zinc concentrations in Rose Creek by a factor of 10 (from 3.4 mg/L to 0.36 mg/L);

In summary, implementation of a groundwater collection system at the toe of the Cross Valley Dam **in addition** to tailings relocation and/or dry cover placement is predicted to reduce the peak zinc concentrations in Rose Creek significantly (by a factor of 10). However, the resulting zinc concentrations in Rose Creek are still predicted to be about one order of magnitude above the CCME guideline for zinc (0.03 mg/L Zinc). According to these model calculations, the capture efficiency of the groundwater interception system at the Cross Valley Dam would have to be very high (99% or higher) in order to achieve zinc concentrations in Rose Creek (at RC9) below the CCME guideline for zinc, regardless of which tailings remediation option is selected.

The modeling results suggest that the primary advantage of tailings relocation over dry cover placement would be the time period over which groundwater collection would be required. Assuming full relocation, groundwater collection may be required for 40-60 years, whereas in-situ remediation using a dry cover may require collection and treatment of impacted groundwater in perpetuity.

7.2 Recommendations for Future Work

The following recommendations are provided to improve our ability to predict future contaminant loading to Rose Creek:

- Preliminary results obtained from a bromide injection test carried out by Environment Canada indicate that the travel velocity in the Rose Creek aquifer may be significantly higher (and zinc retardation in the aquifer significantly lower) than assumed in this study. Consideration should be given to carrying out additional bromide (or similar tracer) tests at other locations to assess how representative these preliminary findings are. If it can be shown that average travel velocities are significantly greater (at least 3-5 times higher) than assumed here than consideration should be given to updating this water and load balance model to reflect those updated estimates.

- Consideration should also be given to installing 1-2 additional multi-level piezometers along the north side of the valley between the Secondary and Intermediate Dam. These wells would provide an opportunity to better calibrate the existing sulphate and load balance model and to monitor the predicted increase in zinc concentrations in the Rose Creek aquifer over time. In addition, these wells could be used to monitor the reduction in loading to the Rose Creek aquifer due to interception of the Faro Creek seepage (if and when implemented);
- This study has demonstrated that zinc is attenuated in the system (relative to sulphate); however, there is still significant uncertainty about the actual processes and the magnitude of zinc attenuation in the system. We therefore recommend carrying out additional attenuation studies to better quantify the attenuation potential of zinc along the flow path, including the tailings and unsaturated soils above the water table. The results of these studies should be used to improve predictions of the rate of zinc leaching into the aquifer, the rate of zinc transport through the aquifer, and the level of zinc contamination that is likely to be present in the underlying soils if the tailings are relocated.
- The calibration of the zinc load balance model for current conditions is strongly dependent on the assumed seepage and associated zinc loading from the Intermediate Pond. Yet, the zinc load balance for the Intermediate Pond is poorly constrained. We therefore recommend to carry out an independent water and load balance for the Intermediate Pond; if these results differ significantly from the conditions assumed here, the water and load balance model for the Rose Creek tailings facility should be updated;
- The modeling approach used in this study (assuming complete mixing of loads generated in different reaches) is not well suited for predicting sulphate and zinc loading to Rose Creek over the short-term (i.e. over the next 20-60 years depending on the assumed retardation). In our opinion, a solute transport model would be better suited for such detailed predictions of short-term loading trends. However, this approach would only be warranted if and once a better understanding of zinc attenuation has been developed (see above).
- The calibration of the water and sulphate load balance model has provided significant new insight into the groundwater flow regime along the Rose Creek valley. Among other things, it has illustrated the importance of leakage from the Rose Creek Diversion and provides more realistic estimates of seepage from the Intermediate and Polishing Ponds. These results differ substantially from the most recent version of the groundwater flow model for the Rose Creek tailings, which was used to evaluate alternative groundwater collection scenarios (GLL, 2004). We therefore recommend, that the groundwater flow model be updated (using this “calibrated” water balance as a guide) if required for any additional predictive modeling (e.g. transport modeling, final design of groundwater collection system etc.).

Based on the findings of this study, the following recommendations are provided related to future management of zinc loading to Rose Creek:

- The calibration of the water and sulphate load balance model suggests that leakage from the Faro Creek seepage contributes significantly to current loading to Rose Creek. Consideration should therefore be given to intercepting and treating this seepage as an interim measure even before final closure measures are implemented.
- The surface runoff reaching the Intermediate Pond on the south side of the impoundment (so-called seepage “S6”) represents a significant source of zinc loading (~4-7 t/yr) to the Intermediate Pond and potentially to the aquifer via pond seepage; the source of this seepage and associated zinc load should be studied with the aim at identifying interim remediation measures to minimize this loading;
- Considering the uncertainty in predicting future zinc concentrations, in particular over the short to mid-term, it would be prudent to include provisions in the remediation plan for the Rose Creek tailings facility for an interim groundwater collection system, regardless of which tailings remediation option is selected. However, construction of such a groundwater collection system should be delayed for several years, providing more opportunity to further monitor the zinc concentrations in the tailings pore water and underlying aquifer and to recalibrate, if required, the zinc load balance model. Such an updated model could then be used to re-evaluate the need for a groundwater collection system.
- Consideration should be given to carrying out a pump test in the Rose Creek aquifer to better define the hydraulic properties of the Rose Creek aquifer. The results of this pump test could be used to design a groundwater collection system (for interim and/or long-term pump-and-treat) in the Rose Creek aquifer.
- The two detailed field surveys carried out as part of this study indicate that significant groundwater discharge occurs downstream of the current monitoring station in Rose Creek downstream of the tailings facility (X14). As a result, this station is not well-suited for monitoring the loading from the Rose Creek tailings facility to Rose Creek, in particular in the mid to long-term. Consideration should therefore be given to monitoring stream flow and stream water quality at station “RC1” (model code “RC9”) located just upstream of Next Creek.

8 CLOSURE

This report was prepared by Robertson GeoConsultants Inc., in association with SRK Consulting (Canada) Inc., for Deloitte & Touche Inc. in its capacity as Interim Receiver of Anvil Range Mining Corporation. No third-party engineer or consultant shall rely on any of the information, conclusions, opinions, or any other material contained in this report without the express written consent of deloitte & Touche Inc. and RGC.

We trust that the information provided in this report meets your requirements at this time. Should you have any questions or if we can be of further assistance, please do not hesitate to contact the undersigned.

Respectfully Submitted

Christoph Wels, Ph.D., M.Sc.
Principal & Senior Hydrogeologist

9 REFERENCES

Anvil Range Mining Corporation, 2000. Rose Creek Mass balance for Sulphate ad Total Zinc at Locations X2 and X14. Report prepared by Eric Denholm (ARMC - Interim Receivership), May 2000.

Beak International Inc. 1999. Faro Mine – Down Valley Tailings Contaminant Transport Assessment and Evaluation of the Existing Monitoring Network for Groundwater. Report prepared for Environment Canada, Reference No. 20641.4, March 1999.

Canadian Council of Ministers of the Environment (CCME) 2003. Canadian Water Quality Guidelines for the Protection of Aquatic Life (2003).

Gartner Lee Limited, 2001. Rose Creek Tailings Facility – 2001 Hydrogeological and Geochemical Investigation, Faro Mine, Yukon. Report prepared for Deloitte & Touche Inc., March 2002.

Gartner Lee Limited, 2002. Anvil Range Mine Complex – Preliminary Water Balance and Contaminant Loading Study in Rose and Vangorda Creeks. Appendix A to “2002 Baseline Environmental Information”. Report prepared by Gartner Lee Limited and Patrick Bryan for Deloitte & Touche Inc., May 2002.

Gartner Lee Limited, 2003. 2003 Investigation of Rose Creek Tailings Facility, Faro Mine, Report on Coring and Multi-Level Well Installation, Draft Report prepared for Deloitte & Touche Inc., December 2003.

Anvil Range Mine Complex – Preliminary Water Balance and Contaminant Loading Study in Rose and Vangorda Creeks. Appendix A to “2002 Baseline Environmental Information”. Report prepared by Gartner Lee Limited and Patrick Bryan for Deloitte & Touche Inc., May 2002.

Gartner Lee Limited, 2004. Anvil Range 2003 Project 17b, Assess Requirements for Groundwater Collection”. Report prepared for Deloitte & Touche Inc., July 2004.

Golder Associates 2004. Rose Creek Tailings Impoundment – Site Characterization ad Seismic Stability Assessment Report, Anvil Range Mining Complex, Yukon. DRAFT Report submitted to SRK Consulting Inc, February 9, 2004.

Nicholson R.V., J. Scherer, and E.C.M. Kwong, 1996. Faro Mine – Down Valley Tailings Acid Mine Drainage Modeling with a Focus on Zinc Loadings for Selected Management Options. Final Report prepared for Environment Canada, May 13, 1996.

Robertson GeoConsultants Inc. 1996. Anvil Range Mining Complex – Integrated Comprehensive Abandonment Plan. Report prepared for Anvil Range Mining Corporation, RGC Report No. 033001/3, November 1996.

SRK Consulting 2004a. Waste Rock and Tailings Cover Methods – Anvil Range Mining Complex, Report prepared for Deloitte and Touche Inc., February 2004.

SRK Consulting 2004b. Laboratory Testing of Contaminant Attenuation in Rose Creek Aquifer Soils. DRAFT Report prepared for Deloitte & Touche Inc., November 2004.

Stantec Consulting Ltd. 2003. Faro Mine Groundwater Transport of Zinc from the Tailings to Rose Creek. Appendix 1 to Environment Canada Intervention Statement; Report prepared for Environment Canada, Report No. QZ03-059, September 2004.