Updated Estimates of Post-closure Water Quality in Faro, Grum, and Vangorda Pit Lakes

Report Prepared for

Deloitte & Touche Inc.

Interim Receiver of Anvil Range Mining Corporation

On behalf of

Faro Mine Closure Planning Office

Report Prepared by

SRK Consulting

Engineers and Scientists

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1 Introduction

1.1 Overview

Biological treatment of the Faro, Grum and/or Vangorda pit lakes has been identified as a potential alternative for removal of metals. An extensive field and laboratory study was initiated in 2004 to further characterize the limnological and chemical characteristics of the pit lakes, characterize sources of metal loading to the pit lakes, determine fertilization requirements, and assess phytoplankton growth and metal removal rates. A more detailed overview of this program is provided in the accompanying report.

Earlier estimates of source concentrations to the pit lakes and therefore long-term water quality in the pits lakes were made as part of the 2003 pit lake assessment (SRK 2004a). Further refinement of these estimates was identified as a priority for the 2004 field program. The source characterization work included the following.

- Collection of additional seepage and runoff samples from the pit walls, particularly for areas that are above the future elevation of flooding. If suitable samples could be collected, the resulting data were intended to replace the current estimates of seepage concentrations based on data from the waste rock seepage sampling programs.
- Ground-truthing existing mapping. Accessible zones within the pits were briefly examined to define the geochemical variations within the zones and to refine the locations of the contacts between the different zones. A limited number of contact tests, sulphur/sulphate analyses, and solids metal analyses were completed to determine how these materials compare to material in the waste rock dumps.
- Improve understanding of current inflows and outflows from each of the pits to allow calibration of load models. Further information on the water management activities in the Faro and Vangorda pits was obtained and used to construct a water and load balance reflecting current conditions in each of the pits.
- Updated water quality estimates, including sensitivity analyses to determine the probable range of loadings to the pits given different closure alternatives in each of the pits.

This report presents results of the additional field studies, a summary of current conditions in each of the pits, and estimates of future water quality. The estimates presented herein supersede those in the 2003 pit lake assessment (SRK 2004a).

1.2 Background Information

There are a number of related studies that were used to improve our understanding of geochemistry and water quality in the pit lakes. A brief description of each of these is as follows.

A number of studies have been completed over the past 20 years to characterize the geochemistry of waste rock at the Anvil Range Mining Complex. A review and compilation of this historical information was completed by SRK in 2002, and supplemental field and laboratory studies were completed in 2002 and 2003 (SRK 2003a and 2004b). These programs included sampling of waste rock and seepage, installation of gas and temperature monitors, and laboratory testing, including static tests, extraction tests, humidity cell tests, and column tests. In 2004, seepage monitoring and gas and temperature monitoring were continued (SRK 2004c). The results of these programs were used to supplement data from the pit lake studies. In particular, data from the seepage surveys were used to supplement the more limited database of pit seep samples, and data from the solids testing programs were used to estimate the long-term weathering behaviour of different types of rock in the pit walls.

Routine monitoring of the pit lake water quality has been completed by site personnel in each of the pits since mining operations ceased and each of the pits were allowed to fill. This has included monthly sampling at Station X22B in Faro Pit Lake since 1996, quarterly sampling at Station V23 in Grum Pit Lake since 1997, and quarterly sampling at Station V22 in Vangorda Pit Lake since 1998.

Detailed studies on Vangorda Pit Lake were completed by SRK in June 2000 (SRK 2000). The study included a pit wall seep survey, sampling of the pit lake at depths of 2 and 12.5 metres, a profile of temperature, pH, conductivity and dissolved oxygen levels, sampling and testing of waste rock and talus, and characterization of secondary minerals found on the pit walls. The study included mass loading estimates, and a preliminary assessment of potential impacts to receiving water quality if untreated water was to be released from the pit.

Estimates of water quality from the waste rock dumps, including the dumps which drain into the Faro pit were made in December 2003 (SRK 2003b). A recent update of those predictions was issued in November 2004 (SRK 2004d). These estimates are the basis for inputs from the waste rock dumps into the pits.

Where relevant, results of the above studies have been incorporated in the summary of current conditions provided in Sections 3 and 4 of the report.

2 Field Investigations

2.1 Methods

2.1.1 Mapping/Ground Truthing

Rough maps of the distribution of lithologies in the current pit walls were produced based on available pit geology maps of existing Faro and Vangorda pits and the design final Grum pit (Brown and McClay 1992; RGI 1996). Limited field mapping and ground truthing of existing maps was undertaken in September of 2003 as part of the initial pit lake assessment (SRK 2004a). Additional field mapping was undertaken in September 2004. Additional mapping consisted of traversing accessible benches and roads within the pits, recording observations of lithology, and photographing pit walls to aid in definition of map units. The mapping included detailed examination of accessible lithologies to assess the degree of uniformity and to define the geochemical variations within each rock type. Additional information on fine scale variations in geology, alteration zones and mineralogy of the units was recorded. For inaccessible sections of pit wall, lithological distribution was verified/ mapped remotely through inspection of visual unit boundaries in pit walls. From the pit rim, the opposite walls were observed, and colour variations in the wall rocks were compared with existing mapped unit boundaries. Where no existing units were defined, colour unit boundaries were mapped and panoramic series of photographs were taken for future reference.

Final map compilation was undertaken by updating existing maps to reflect field observations. Photographs of pit walls were used as a final check on the distribution of lithological units. For Grum Pit, where the available pit geology map was based on the ultimate design pit, photographs were used to define lithological contacts for areas of the pit that were inaccessible. Where lithology of a particular unit could not be verified in the field, unit boundaries were defined based on color variations in pit wall photographs. To apply lithologies to these inaccessible units, the design ultimate pit geology map was consulted and rock units were extrapolated to the current walls. Where these extrapolated units were the same rock type as accessible units, the pit wall photographs were examined to verify visual similarity between these extrapolated units and field-verified units.

A description of rock units and nomenclature at the Anvil Range mines is included in Appendix A.

2.1.2 Waste Rock Seepage

Waste rock seepage within the Faro Pit catchment has been collected in spring and fall since 2002 as part of the waste rock seepage monitoring. Up to 100% of the seepage from each of the Faro Valley North, Faro Valley South, Outer Northeast, Upper Northeast, Lower Northeast, Southwest Pit Wall, Ranch, and Ramp Zone Dumps currently reports to the Faro Pit. Waste rock seepage sampling methods and results are described in a separate report (SRK, 2004c).

2.1.3 Pit Wall Seepage

During spring 2003, six samples were collected of pit wall seepage/ runoff from accessible areas in Grum Pit, in conjunction with the concurrent waste rock seepage sampling.

In spring 2004, a more extensive pit seep sampling effort was undertaken. Pit wall seeps were collected where presented from accessible benches and access roads. At Grum Pit, a total of 13 seeps were sampled. At Faro Pit, samples were collected by accessing the pit walls by boat from the lake; six pit wall seep samples were collected from the pit lake, with one sample subsequently collected from higher up. At Vangorda Pit, seven samples were collected by boat and an additional nine samples were collected from roads and benches.

Where accessible, samples of seepage located within each pit catchment were collected and submitted for analysis of routine parameters (pH, conductivity, acidity, alkalinity, chloride and sulphate), and dissolved metals (dissolved metals by ICP-OES). The samples were filtered and preserved in the field according to standard methods for collection of environmental samples. Field pH, conductivity, redox, temperature measurements were taken at each station using a WTW meter. Flow estimates were made using the bucket and stopwatch method, by estimating the velocity and cross sectional area of the seep, or by visual estimation. Observations of pit wall lithology at sampling stations were recorded to allow correlation of water chemistry and wall rock lithology.

2.1.4 Solids Characterization

Fifteen samples collected during pit traverses were subjected to a distilled water leach extraction to assess the quantity of stored oxidation products in pit wall rock and talus. Samples were collected from talus at the toes of benches and shipped to Canadian Environmental and Metallurgical, Inc. (CEMI) for testing. In the laboratory, as-received samples were screened through a 1 cm mesh sieve. The fines fraction was evaluated for rinse pH and conductivity, using a 1:1 mass ratio of distilled water to solids. Samples were then subjected to a 96-hour distilled water leach at a 3:1 mass ratio of liquid to solids, using 250 g samples. At the end of the extraction, pH and conductivity of the supernatant were measured, and the leachate was filtered and submitted for analysis of acidity, alkalinity, sulphate, and dissolved metals by ICP-OES.

2.2 Results

2.2.1 Mapping/Ground Truthing

Faro Pit

The pre-existing pit geology map for the Faro Pit (RGI, 1996) shows a detailed distribution of rock types, and is based on information from ‘Faro Mine Abandonment Plan’ (Curragh Resources Inc., 1988, referenced in RGI, 1996). Most of the pit walls were inaccessible and prohibited detailed verification of map units; remote visual verification confirmed existing unit boundaries on the basis of color. Where field checking was possible, the existing map was found to be largely representative of existing geological distribution, with a few exceptions described below. The updated Faro Pit map is shown in Figure 2.1.

Field verification led to a change in the lithology assigned to the southwest pit wall, from Unit 2A (ribbon banded graphitic pyritic quartzite) to Unit 3D0 (calc-silicate and related rocks). This change has significant implication for predicted pit water quality, as runoff from Unit 3D0 is expected to be much better quality than runoff from Unit 2A.

Minor changes to two unit boundaries were made on the high northwest pit wall. These included extending Unit 1D4 (quartz muscovite schist) and Unit 10E (hornblende diorite and quartz diorite) to the current pit rim. The pre-existing map had no lithology mapped above Unit 1D4, and thus this change slightly increases estimates of both total pit wall area and area of Unit 1D4. This will increase estimates of loading to the pit lake from the northwest pit wall, as runoff from Unit 1D4 is expected to carry high levels of acidity and metals. The pre-existing map had Unit 1D (biotite schist) mapped from Unit 10E up to the current pit rim; thus, extending Unit 10E to the current pit rim does not change the estimate of total pit wall surface area, but does reduce the exposure of Unit 1D and increases the exposure of Unit 10E. This change will reduce estimates of loading to the pit lake from the northwest pit wall, as runoff from Unit 10E is expected to be better quality than runoff from Unit 1D.

In the southeast pit wall, Unit 1D4 was extended over the pit rim to include a benched area that drains to the pit lake. This will increase estimates of loading to the pit lake due to the poor runoff water quality expected from Unit 1D4.

Active failure of the east wall of Faro Pit results in ongoing changes to the areas of each rock unit exposed at each elevation. Sloughed material covering the pit wall prevents remote updates of pit wall geology, and access to this active failure area for field mapping is dangerous at best. Because this wall largely consists of Unit 1D, the changes in lithological distribution are assumed to be minimal, and for the purposes of pit lake water quality prediction, the pre-existing distribution of rock units (RGI, 1996) is considered to be acceptable.

Grum Pit

The pre-existing Grum Pit geology map was based on the ultimate pit design in the original mine plan, the block model for which was generated from lithological data collected during exploration drilling. Actual mining at Grum followed an updated mine plan that envisioned a modified ultimate pit. This, coupled with the cessation of mining at an intermediate stage of the mine plan, resulted in the current pit shell being substantially different than that depicted in the initial pit geology map. The initial pit geology map provided guidance on the expected distribution of rock types in general, but was not representative of existing geological unit boundaries.

The majority of wall rock exposed in Grum Pit consists of Vangorda Formation phyllites, which make up the entire west wall of the Grum Pit. These phyllites were further divided during operations into a dark grey to black carbonaceous, weakly calcareous member (Unit 5A0) and a silver to dark grey calcareous member (Unit 5B0). Initially, attempts were made to map the distribution of these units separately. However, complex folding has resulted in intimate bench scale mixing of these two units, and it was found to be impractical to differentiate the two units effectively at the pit scale given that large areas of the pit walls are inaccessible. It was decided to map these rocks as a single unit (Unit 5A0/5B0) of undifferentiated Vangorda Formation phyllites, and to define an average runoff water quality for the bulk unit. The new Grum Pit geology map is shown in Figure 2.2.

The second largest component of Grum Pit walls is till, which forms the entire east wall of the pit. A large portion of the east wall is actively failing, which has resulted in a layer of till masking any wall rock that may exist on the east wall above the current pit lake surface. Since the till is expected to dominate runoff quality, this area was mapped as till.

Small areas of undifferentiated sulphides were mapped at the north and south ends of the pit, extending from the current pit lake level (1185 masl) up to approximately 1255 masl. These areas were identified initially through examination of photographs, and subsequently defined following field mapping. Most of the exposed sulphides will be covered when Grum Pit Lake reaches its final spill elevation of 1230 masl, as shown in Figure 2.2. Small areas of Mt. Mye Formation phyllites were defined based on the pre-existing map and the definition of unit boundaries from colour photographs.

Vangorda Pit

The pre-existing pit map was developed during advanced stages of mining at Vangorda as part of a doctoral study of the Vangorda deposit (Brown and McClay, 1992). This simplified map differentiates the Vangorda Pit wall rock into 3 units: Mt. Mye Formation, Vangorda Formation, and massive sulphides.

The boundaries of the geological units observed in the field were found to generally agree with those on the existing map (presented in SRK 2004a). The mapped Mt. Mye Formation was further divided during field mapping to Unit 3G0 (non-calcareous phyllite) and Unit 4L0 (bleached pyritic phyllite).Two small additional sulphide zones were located on the upper part of the north wall internal to the previously mapped Mt. Mye Formation. The mapped Vangorda Formation was inspected where exposed above the Vangorda Creek diversion, and the lithology was identified to be Unit 5A0 (carbonaceous phyllite). Figure 2.3 shows the revised Vangorda Pit geology map.

Southeast of the pit ramp, the previously mapped Mt. Mye Formation wall rock was observed to contain high proportions of sulphides and to have thick coatings of secondary oxidation products. For the purposes of prediction of pit lake water quality, the Mt. Mye Formation here has been lumped with the adjacent undifferentiated sulphides unit. It is expected that runoff water quality of the Mt. Mye wall rock in this area will be dominated by the ongoing oxidation of the contained sulphides, and that loadings from this rock will be more typical of sulphide material.

2.2.2 Waste Rock Seeps

Faro Pit Catchment

Complete results from 2002 through 2004 waste rock seepage monitoring are summarised in the draft report “2004 Waste Rock Seepage Surveys and ARD-related Data Collection” (SRK 2004c).

The largest waste rock seepage input to Faro Pit is water in the former Faro Creek valley that flushes the base of the Faro Valley North and Faro Valley South dumps before flowing over the north pit wall into the lake. This flow can be greater than 1000 L/minute (typically lower), and is sampled at station SRK-FD40. Water quality at SRK-FD40 over the monitoring period has ranged from slightly to strongly acidic (pH 3.0 to 6.2), with zinc concentrations ranging from 47 to 108 mg/L.

Drainage from the Northeast dumps enters the pit at the southern pit ramp. Flow volume can be greater than 1000 L/min (typically lower); this flow is sampled at SRK-FD26, and has neutral pH (6.6 to 7.3) and low zinc concentrations (1.3 to 2.8 mg/L). A number of seeps are collected southeast of the pit (SRK-FD21 through –FD24). These range from neutral to strongly acidic (pH 3.6 to 7.0) and have moderate zinc concentrations (7.2 to 65 mg/L).

The Faro Pit receives occasional waste rock seepage inputs from the low grade ore stockpiles southwest of the pit. These seepage inputs have been present and sampled at SRK-FD38 during two of six sampling events. Flow volumes were low on both occasions (2.5 to 10 L/min), with neutral to acidic pH (pH 3.1 to 7.0) and high zinc concentrations (287 to 595 mg/L). Most loading from the low grade stockpiles to the Faro Pit likely follows a subsurface flowpath, and is rarely available for surface sampling.

There are no waste rock dumps within the catchment of Grum Pit, and therefore all seepage collected within the pit reflects loading from wall rock sources.

Vangorda Pit Catchment

No waste dump toe seepage was collected within the Vangorda Pit catchment. Several seeps were collected that have chemical contributions from both pit walls and in-pit dumps; these are discussed in the following section. In general, all waste rock within the Vangorda Pit catchment is expected to generate acidic seepage with high metal concentrations.

One possible source of seepage to Vangorda Pit could be the Vangorda Dump. The pre-mining topography shows a moderate surface gradient from the location of the dump to the pit. The increase in elevation resulting from placement of the waste rock could theoretically result in the formation of a groundwater mound at this location. This increase in elevation combined with the lowering of the water table adjacent to the pit may have caused a high gradient to develop between the dump and the nearest part of the pit. No seeps have been identified from a waste-dump impacted groundwater source, although the seepage observed on the southwest side of the pit ramp (inside the hairpin) may originate as groundwater.

2.2.3 Pit Wall Seeps

Faro Pit

Faro Pit wall seeps were concentrated along the north and west sides of the pit; seep locations and a summary of water quality results are shown in Figure 2.4. Seep sample locations are also shown on the Faro Pit geology map for reference. Complete pit seep sampling results are provided in Appendix B.1. Faro Pit seeps were collected on June 3, 2004; the area had experienced no precipitation since May 27, and as such the seeps are thought to represent base flow conditions. It should be noted that all seeps wash over wall rock above the point of collection.

Seeps flowing from or over Unit 10E (hornblende diorite and quartz diorite) were neutral to slightly alkaline pH (7.0 to 8.1), with low zinc concentrations (<0.005 to 0.832 mg/L). These flows (seeps 04FP04, -FP05, and -FP07) represent the majority of water entering the pit along the north pit wall. The remainder of the water which enters via the north pit wall flows over Units 1D4 (quartz muscovite schist), 2A (ribbon-banded graphitic pyritic quartzite) and 2E (massive pyritic sulphides). A sample of this water was collected at station 04FP03, and was found to be strongly acidic (pH 3.0) with a high concentration of dissolved zinc (875 mg/L).

Two seeps along the west wall of the Faro Pit (04FP01 and 04FP02) were sampled. This pit wall consists almost entirely of Unit 3D0 (calc-silicate and related rocks) and produces little seepage, as surface and groundwater flow is dominantly driven to the southwest by topography. Sample 04FP02 was collected at the base of the highest section of calc-silicate pit wall. This sample had a slightly alkaline pH (7.5) and a low concentration of dissolved zinc (0.051 mg/L). Sample 04FP01 is adjacent to the west pit ramp, and is likely influenced by upgradient waste rock and low grade ore stockpiles situated near the pit edge. The pH of this sample was slightly acidic (pH 6.5) and the zinc concentration was moderately high (45 mg/L). Due to the likely contamination from low-grade ore and waste rock, this sample was not considered to be representative of Unit 3D0. The water quality measured at 04FP02 was selected to represent runoff from calc-silicate pit walls.

The only pit seep observed originating from the east wall was 04FP06. This water was muddy brown at the time of sampling, with very high total suspended solids derived from the till exposed in the pit wall above. The pH of this water was neutral (pH 7.2) and contained no detectable dissolved zinc. This flow was visually observed to have a similar volume to the seeps on the north pit wall, and likely results from leakage from the Faro Creek diversion.

Grum Pit

Results from 2003 and 2004 Grum Pit seep sampling showed no year-over-year change. Seep locations and water quality results are summarized in Figure 2.5. Seep sample locations are also shown on the Grum Pit geology map for reference. Complete results from pit seep sampling are provided in Appendix B.2. Grum Pit seeps were collected on May 31 and June 1, 2004; the area had experienced no precipitation since May 27, and as such the seeps are thought to represent base flow conditions. It should be noted that all seeps wash over wall rock above the point of collection.

Two seeps were collected from the east wall of the pit, from with the actively failing till unit (04GP04 and 04GP05). A third sample which reflects till runoff water quality was collected from the shallow permanent pond located in the depression in the access ramp that exits the pit to the south (sample 04GP13). All three samples had slightly alkaline pH (pH 7.8 to 8.3) with zinc concentrations ranging from below detection to low levels (<0.005 to 0.031 mg/L).

Four seeps from walls composed of various sulphide materials were sampled. One additional seep (04GP14) within a Vangorda phyllite map unit was sampled, but has water quality that is indicative of a sulphide source. This sample is located midway between two mapped areas of sulphide material, and it is assumed that the seep water contacts similar material upgradient. Abundant iron oxyhydroxide precipitates were observed at 04GP14. This sample also returned the highest zinc concentration (97.5 mg/L) and the lowest pH (6.8) of all Grum Pit seepage samples, and for purposes of pit lake water quality prediction, this sample is assumed to be sourced from sulphide material. Taken together, the five samples had slightly alkaline to slightly acidic pH (pH 6.8 to 8.5) and moderate to high zinc concentrations (6.7 to 98 mg/L).

Fourteen seep samples were collected from benches in mixed Vangorda Formation phyllites along the west wall of Grum Pit (03GP03,-05, -06, 04GP01 through -03, -06 through -08, -11, -12). These samples were characterised by neutral to slightly alkaline pH (pH 7.4 to 8.4) and low zinc concentrations ranging from <0.005 to 0.073 mg/L.

Vangorda Pit

Vangorda Pit seeps were concentrated along the north and east sides of the pit lake, and along the pit access ramp southeast of the pit lake. Seep locations and a summary of water quality results are shown in Figure 2.6. Seep sample locations are also shown on the Vangorda Pit geology map for reference. Complete pit seep sampling results are provided in Appendix B.3. Vangorda Pit seeps were collected on June 1 and 2, 2004; the area had experienced no precipitation since May 27, and as such the seeps are thought to represent base flow conditions. It should be noted that all seeps wash over wall rock above the point of collection.

One seep from Unit 5B0 (Vangorda Formation carbonaceous phyllite) was sampled at the north end of the pit. This seep emerged from the pit wall about 1.5 m above the lake level and had produced a rusty stain on the pit wall below, with local formation of precipitates. Little to no soluble secondary oxidation products were noted in the immediate vicinity; however, abundant salts and secondary copper minerals (green) were observed higher up on the wall within the same unit. This seep had a slightly acidic pH of 6.3 and a high dissolved zinc concentration of 180 mg/L.

Four seeps from Unit 3G0 (Mt. Mye Formation non-calcareous phyllite) were sampled at the north end of the Vangorda Pit. One of these, sample 04VP01, was collected from the wall above the Vangorda Creek Diversion. As this water had contacted at most three metres of pit wall, the water quality is reflective of background conditions with low zinc concentration and neutral pH. The remaining three seeps (04VP11, -12, -13) were collected immediately above the pit lake, and were acidic to neutral pH (pH 3.4 to 7.2) with moderate to high zinc concentrations (2.9 to 42 mg/L). The sources of these seeps had variable amounts of rusty brown staining and bright orange to orangey brown staining. Adjacent rocks and the geological unit as a whole displayed a moderate accumulation of secondary oxidation products. Hard dark grey and occasional tan precipitates were observed on walls that appeared to experience continuous flushing below sources of seepage (04VP12 and -13 only).

One seep was sampled below a till bank along the east wall of the pit south of the pit lake (04VP03). No wall rock was exposed along the flowpath upgradient of this station, and the water quality is assumed to reflect water quality in runoff from exposed till. Where seepage emerged from the till bank, the substrate wais stained a rusty orange; the degree of staining decreased with distance from the seep source. Sample 04VP03 had a neutral pH of 7.6 and no detectable dissolved zinc.

Three seeps from Unit 4L0 (Mt. Mye Formation bleached phyllite) were sampled along the northeast wall of the pit ramp (04VP05 through -07). Unit 4L0 is overlain by siliceous massive sulphides at this location which may be controlling water quality. An undefined amount of sulphide waste was placed on the wide bench above this wall, and seepage may reflect the influence of water acquiring dissolved load as it moves through this waste. However, runoff water quality from Unit 4L0 is expected to be poor, and an average runoff quality defined by these three samples is likely an appropriately conservative approximation.

Seven samples (04VP02, -04, -08, -09, -14, -15, -16) were collected from pit wall runoff and seepage sources draining undifferentiated massive and disseminated sulphides (Figure 2.6). Three of the samples were collected from pit wall runoff immediately above the pit lake surface; these had acidic to neutral pH (pH 3.7 to 7.2) and moderate to high zinc concentrations (19.9 to 238 mg/L). The four samples collected southeast of the pit lake all had acidic pH (2.8 to 5.6) and moderate to very high zinc concentrations (12 to 1550 mg/L). All seepage locations were characterized by orange to rusty brown staining and/ or accumulations of bright reddish orange precipitates. The samples with the highest zinc concentrations (04VP04 and 04VP08) were both downgradient of in-pit sulphide dumps, and seep water quality may reflect dissolved load from these sources. Sample 04VP02 was collected from seepage that had contacted a single bench (~3 m) of blocky siliceous massive sulphide, and the relatively low zinc concentration (12.1 mg/L) is likely reflective of this minimal opportunity for contact.

2.2.4 Solids Characterization

Pit wall talus sample locations are shown on the respective pit geology maps for Faro, Grum, and Vangorda Pits (Figures 2.1 through 2.3). Lithological descriptions of each sample are shown in Table 2.1, along with results from contact testing and leach extraction testing. A brief discussion of the results from each pit follows.

Faro Pit

Seven samples were collected from Faro Pit. Six samples of intrusive, calc-silicate, and biotite schist had neutral to slightly alkaline rinse pH ranging from 7.2 to 8.1, with rinse conductivity ranging from 55 to 1816 µS/cm, as shown in Table 2.1. The lone sample from altered quartz muscovite schist (FP03) had a rinse pH of 2.7 and a rinse conductivity of 2590 µS/cm.

The 96-hour leach extraction testing returned similar pH and conductivity results for all samples, with the altered quartz muscovite schist (FP03) producing acidic leachate (pH 2.6) with higher conductivity (2070 µS/cm) than all other samples. The FP03 leachate had correspondingly high acidity, and elevated concentrations of sulphate and dissolved metals (eg. 19.8 mg/L Zn). The leachate from the remaining Faro Pit talus samples was neutral to slightly alkaline, with low to elevated sulphate and dissolved metal concentrations at or near detection levels.

Grum Pit

Seven samples were collected from Grum Pit, including six samples of mixed Vangorda Formation phyllites and one sample of pyritic quartzite. All phyllite samples had slightly alkaline rinse pH (8.1 to 8.8) and low to elevated rinse conductivity (130 to 1650 µS/cm), as shown in Table 2.1. The pyritic quartzite sample (GP03) returned a slightly acidic rinse pH (6.4) and a somewhat elevated rinse conductivity (620 µS/cm). Extraction leachate from GP03 had high dissolved zinc (55 mg/L) and lead (1.2 mg/L) concentrations, and detectable concentrations of dissolved cadmium, cobalt, copper, and manganese. Extraction leachate from the various phyllite samples contained dissolved metals at or near detection limits; three samples had detectable dissolved zinc with a maximum concentration of 0.0304 mg/L.

Vangorda Pit

Two samples were collected from Vangorda Pit. Sample collection in 2004 was limited as solids testing of Vangorda Pit talus samples had been carried out as part of an earlier study (SRK 2000).

One sample of Vangorda Formation carbonaceous phyllite was collected; rinse pH for this sample was slightly acidic (pH 5.9), with a low rinse conductivity 75 µS/cm. Leach extraction on this sample produced a leachate with slightly alkaline pH and elevated conductivity and sulphate. Dissolved metal concentrations were at or near detection levels, with a dissolved zinc concentration of 0.0089 mg/L.

One sample of Mt. Mye Formation non-calcareous phyllite was collected. This lithology was sampled and tested a number of times during the previous investigation, and was subjected only to contact tests as part of the current program. This sample returned an acidic rinse pH of 3.4, and a moderate rinse conductivity of 570 µS/cm.

A total of nineteen samples were collected in the earlier study (SRK 2000), including talus and waste rock. The results indicated six of the samples had rinse pH below 5, eight samples with rinse pH between 5 and 6, and five samples with rinse pH above 6. Most of the samples contained significant amounts of sulphide, and minimal neutralization potential, and are therefore classified as potentially acid generating. The single exception was a till sample. Concentrations of arsenic, cobalt, copper, lead and zinc were elevated, indicating a strong potential for metal leaching. Leach extraction tests completed at a water to solids ratio of 20:1 indicated soluble zinc loads of 14 to 5580 mg/kg of solids. Several other metals were present at elevated concentrations, particularly in the low pH samples. Secondary minerals were observed at many locations in the pit, and included bianchite (a hydrated zinc sulphate), melanterite (iron sulphate), gypsum and iron hydroxides.

Table 2.1 Sample descriptions, contact test and leach extraction results

		Contact tests		96-hour distilled water extraction															
				Physical Parameters and Anions						Dissolved Metals (mg/L)									
Sample ID	Lithological Unit	Rinse pH	Rinse Conductivity (us/cm)	Final pH	Final Conductivity (uS/cm)	Alkalinity (mg CaCO3/L)	Acidity (pH 4.5) (mg CaCO3/L)	Acidity (pH 8.3) (mg CaCO3/L)	Sulphate (mg/L)	Arsenic	Barium	Cadmium	Cobalt	Copper	Iron	Lead	Manganese	Antimony	Zinc
FP01	10E- Hornblende diorite and quartz diorite	7.72	55	7.46	48	15.75	0	4	8	<0.20	0.06	<0.010	<0.010	<0.010	0.387	<0.050	0.0142	<0.20	<0.0050
FP02	10E- Hornblende diorite and quartz diorite	8.13	1816	7.80	1555	33.5	0	10.5	1818	<0.30	0.037	<0.010	<0.010	<0.010	<0.030	<0.050	<0.0050	<0.20	<0.0050
FP03	1D4- Altered quartz muscovite schist	2.69	2590	2.57	2070	0	520	770	1054	0.58	0.013	0.247	0.546	5.95	128	<0.050	6.77	<0.20	19.8
FP04	1D- Biotite schist	7.24	1278	7.82	1062	36	0	7.75	945	<0.20	0.033	<0.010	<0.010	<0.010	<0.030	<0.050	<0.0050	<0.20	0.0059
FP05	3D0- Calc-silicate	8.53	140	8.15	166	65.5	0	2	21	<0.20	0.035	<0.010	<0.010	0.01	0.036	<0.050	<0.0050	<0.20	<0.0050
FP06	1D- Biotite schist	7.98	91	7.89	108	40.5	0	4.75	12	<0.20	<0.010	<0.010	<0.010	<0.010	<0.030	<0.050	<0.0050	<0.20	<0.0050
FP07	10F- Quartz feldspar porphyry	8.09	128	8.00	191	49.25	0	1.25	36	<0.20	0.061	<0.010	<0.010	<0.010	<0.030	<0.050	<0.0050	<0.20	<0.0050
GP01	5A0/5B0- mixed Vangorda Formation phyllite	8.25	429	8.22	316	72	0	0.5	100	<0.20	0.044	<0.010	<0.010	<0.010	0.099	<0.050	<0.0050	<0.20	<0.0050
GP02	5A0/5B0- mixed Vangorda Formation phyllite	8.10	265	8.14	231	62.75	0	2.25	59	<0.20	0.038	<0.010	<0.010	<0.010	<0.030	<0.050	<0.0050	<0.20	<0.0050
GP03	4C- Pyritic quartzite (mapped as 4EC)	6.37	616	6.75	448	5.5	0	72.75	242	<0.20	0.061	0.112	0.039	0.019	<0.030	1.2	0.195	<0.20	55.3
GP04	5A0/5B0- mixed Vangorda Formation phyllite	8.25	930	8.04	1001	49.75	0	5	559	<0.20	0.02	<0.010	<0.010	<0.010	<0.030	<0.050	<0.0050	<0.20	0.0061
GP05	5A0/5B0- mixed Vangorda Formation phyllite	8.71	193	8.19	197	69	0	1	40	<0.20	0.038	<0.010	<0.010	<0.010	<0.030	<0.050	<0.0050	<0.20	<0.0050
GP06	5A0/5B0- mixed Vangorda Formation phyllite	8.75	337	8.02	269	64	0	2.25	78	<0.20	0.024	<0.010	<0.010	<0.010	<0.030	0.051	<0.0050	<0.20	0.0304
GP07	5A0/5B0- mixed Vangorda Formation phyllite	8.28	1656	7.78	1122	41.25	0	8.75	1017	<0.20	0.024	<0.010	<0.010	<0.010	<0.030	<0.050	<0.0050	<0.20	0.0148
VP01	3G0- Mt. Mye non-calcareous phyllite	5.93	45	7.78	1137	40.5	0	7.25	1029	<0.20	0.027	<0.010	<0.010	<0.010	<0.030	<0.050	<0.0050	<0.20	0.0089
VP02	5A0- Carbonaceous phyllite	3.36	357	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Note: Sample VP02 was not subjected to to leaching extraction testing

3 Current Conditions

3.1 Faro Pit Lake

3.1.1 Routine Monitoring

Faro Pit Lake water quality is currently sampled as part of the routine monitoring required by the site water license. Samples are collected by site environmental staff from the pit lake surface at station X22B. Sulphate and zinc concentrations at station X22B for the period of 1998 to present are shown in Figure 3.1; dissolved concentrations are plotted where available, and total concentrations were substituted where necessary to complete the record. Complete monitoring results for the 1998-2004 period are provided in Appendix C.1.

The results indicate the pit lake surface water currently has neutral to slightly alkaline pH's (ranging from 6.7 to 7.8), moderate alkalinity levels and sulphate concentrations of approximately 600 mg/L. Calcium and magnesium are the dominant cations. Concentrations of cadmium (0.012 mg/L)[1], cobalt (0.036 mg/L), copper (0.039 mg/L), and zinc (12 mg/L) are elevated. As shown in Figure 3.1, sulphate concentrations indicated some short-term variability, but have typically been in the range of 600 mg/L since the start of monitoring in 1996. Zinc concentrations were typically less than 5 mg/L from 1996 to 2000. From August 2000 to November 2000, there was a brief spike in surface water concentrations. The cause of this temporary increase in surface zinc concentrations is not known, but may be related to high zinc inflows due to site water management. This increase is unlikely to be related to fall turn-over of the lake, as Figure 3.1 shows the bottom water to have a lower zinc concentration. Following the Fall 2002 spike, concentrations then stabilized in the range of 10 to 15 mg/L. However, periodic spikes were observed in March 2002, 2003 and 2004.

3.1.2 Depth Profiles

In April 2003 Gartner Lee Limited (GLL) carried out a program of sampling and analysis to characterize water quality in Faro Pit Lake. A similar program was carried out in June 2004 by Lebarge Environmental Services (Lorax, 2004). Complete results are presented in Appendix D.1.

The results shown in Figure 3.2 indicate that the Faro Pit has two haloclines: one at 3-5 metres depth, and the other at 15 to 20 metres depth, with conductivity increasing in two distinct steps. The uppermost layer is characterized by higher pH (7.9), lower conductivity (1070 uS/cm), and generally higher metal concentrations (eg. 11 mg/L zinc), the middle layer shows a slight decrease in pH (7.5 to 7.8), increase in conductivity (1200 uS/cm) and decrease in metal concentrations (eg. 8.4 to 10 mg/L zinc), while the lower layer has the lowest pH (6.9 to 7.3), highest conductivity (1350 uS/cm) and lowest metal concentrations (eg. 1.4 to 3 mg/L zinc).

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[1] Values represent the average of the 2003 and 2004 data.

Suboxic conditions were also observed at depth, and corresponded to a substantial increase in redox sensitive metals such as iron and manganese. As discussed previously, tailings were deposited in the Faro pit. Sulphate reduction may be occurring at depth, which could be acting as a sink for metals in this system.

3.2 Grum Pit Lake

3.2.1 Routine Monitoring Data

Routine monitoring of Grum Pit Lake water quality is currently completed to fulfil the requirements of the site water license. Samples are collected from the surface of the pit lake at station V23, which is located at the bottom of the ramp. Sulphate and zinc concentrations from 1997 to present are shown in Figure 3.3. Complete monitoring results are provided in Appendix C.2.

The pit lake currently has a slightly alkaline pH (approximately 7.8), elevated alkalinity levels and sulphate concentrations of approximately 420 mg/L. Calcium and magnesium are the dominant cations. Concentrations of cadmium (0.012 mg/L)[2], cobalt (0.041 mg/L), copper (0.021 mg/L), and zinc (7.0 mg/L) are somewhat elevated. As shown in Figure 3.3, sulphate concentrations increased over the first two years of filling, and there are no clear trends in zinc concentrations. In general, concentrations of most metals were highly variable, and had the highest concentrations in 2000/2001. For example, zinc concentrations in 2000/2001 ranged from less than detection to 14 mg/L, while more recent concentrations were in the range of 4 to 8 mg/L. It should be noted that the last sample, collected in July 2004 is influenced by the pit lake study.

3.2.2 2003/2004 Depth Profiles

Depth profiling was completed in August 2003 by Gartner Lee Limited (GLL 2003) and from July through September 2004 by Lebarge and Lorax (Lorax 2004). Results from both programs indicated the pit lake was thermally stratified during the summer season, with a warm surface layer extending to depths of 2 to 5 metres; the complete set of data is included in Appendix D.2 and summarised in Figure 3.4. The warmer surface layer had consistently lower conductivity, sulphate and metal concentrations compared to samples collected at depth (for example, zinc concentrations were 3 to 4 mg/L at surface and approximately 9 to 12 mg/L at depth). Possible reasons for this include dilution by melting ice, incident precipitation, clean runoff from the pit walls, and partial removal of zinc due to inherent biological activity present in the lake. The stratification is maintained during the summer months due to the strong thermal gradient; further monitoring is being completed to determine fall and winter conditions when the thermal gradient is reversed.

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[2] Values represent the average of the 2003 and 2004 data, excluding the July 2004 data which was influenced by the treatment studies in the pit.

3.3 Vangorda Pit Lake

3.3.1 Routine Monitoring Data

Routine monitoring of Vangorda Pit Lake water quality is currently completed to fulfil the requirements of the site water license. Samples are collected by site environmental staff from the surface of the pit lake at station V22, which is currently located on the barge. Sulphate and zinc concentrations at station V22 from 1998 to present are shown in Figure 3.5. Complete monitoring results are provided in Appendix C.3.

The results indicate the pit lake currently has a neutral pH, moderate alkalinity levels and sulphate concentrations of approximately 1000 mg/L. Calcium, magnesium and zinc are the dominant cations. Concentrations of cadmium (0.069 mg/L), cobalt (0.44 mg/L), copper (0.045 mg/L), iron (0.81 mg/L), manganese (22 mg/L), nickel (0.38 mg/L) and zinc (66 mg/L) are elevated. As shown in Figure 3.5, sulphate and zinc concentrations increased significantly between 2001 and 2003. This was coupled with a slight decrease in pH (from 7.5 prior to 2001 to less than 7 in the more recent data), and increases in cobalt, manganese and nickel concentrations.

3.3.2 2003/2004 Depth Profiles

Depth profiling was completed in September 2003 by SRK (SRK 2004a) and in July 2004 by Lebarge and Lorax (Lorax 2004). A partial profile was also completed in June 2000 by SRK (SRK 2000). Results are provided in Figure 3.6, and Appendix D.3. The results indicated that there was a strong thermocline at a depth of 2 to 3 metres. Results from all three sampling periods indicated that conductivity, sulphate and metal concentrations increased with depth. The differences were more strongly pronounced in the June 2000 and September 2004 results, indicating there is more variability in concentrations in this system. For example, zinc concentrations were 6.3 mg/L in the surface layer and 70 mg/L at depth in June 2000, 92 mg/L at surface and 110 mg/L at depth in August 2003, and 56 mg/L at surface and 131 mg/L at depth in September 2004. The latter results may have been influenced by a short but severe period of fresh water inflow from Vangorda Creek during the large storm event of June 8, 2004.

4 Water Quality Estimates

4.1 Overview

Water quality estimates for each of the pits were estimated using simple mass balance calculations which considered geometry, water balance, limnology, and specific sources of contaminant loading to each pit lake.

Input assumptions and resulting water quality estimates for each of the pits are presented and discussed in the following sections.

4.2 Faro Pit

4.2.1 Modelled Scenarios

Three scenarios were considered in the water quality estimates for Faro Pit Lake. In the base case, it was assumed that the Faro Creek diversion would be breached and allowed to spill into the pit. Two additional scenarios were also evaluated to show the effects of: 1) maintaining the diversion, and 2) removing the Faro Valley Dump.

All three scenarios took the ‘Current Average’ waste rock drainage quality (SRK 2004d) as the estimate for waste rock loading to the pit. To examine the sensitivity of each scenario to waste rock loadings, each scenario was also evaluated with the ‘Future Worst Case’ dump drainage prediction (SRK 2004d) providing the waste rock loading estimate.

Any closure alternative which includes in-pit treatment will also include some form of remediation of waste dumps that contribute load to the pit. In the waste rock seepage prediction (SRK 2004d), it was assumed that 45% of incident precipitation leaves uncovered waste rock dumps as either runoff or seepage. For the estimates herein, it was assumed that simple soil covers would be in place on all contributing dumps, and that infiltration (and seepage) would be limited to 25% of incident precipitation.

Assumptions common to all scenarios were that the ore stockpiles would be removed from the pit catchment and that the Zone II pit discharges would be directed to the water treatment plant. In addition, a plug dam would be constructed across the southeast pit ramp, to increase the flood elevation and thus the residence time in the pit. This would result in an ultimate pit lake elevation of 1173.5 masl. The water and load balances assumed that pit filling began on January 1, 2004.

4.2.2 Geometry, Flow Conditions and Stratification

The volume-capacity curve for the Faro pit was re-assessed using the topography generated from the 2003 aerial photography. To include the volume of water below the current pit lake level, the new curve was ‘meshed’ with the new pit bathymetry acquired in 2004. The complete volume-capacity curve is provided in Figure 4.1.

The overall water balance for Faro Pit Lake is summarised in Tables 4.1 and 4.2. Estimates of discharge would apply only after the lake reached the spill elevation. Table 4.1 shows conditions for the scenario where Faro Creek is routed through the pit lake, making the total catchment about 17.1 km^2. The mean annual runoff is estimated to be 341 mm and mean annual precipitation 400 mm. The evaporative losses are estimated for a fixed pit lake surface area of about 0.78 km^2 using lake evaporation rates provided in the ICAP (RGI, 1996). The pit lake area adopted in the calculations represents the pit lake at fully flooded conditions. It should however be noted that during the flooding period the pit lake will be smaller and the actual evaporative losses will be lower. The net implication is that the time to flooding will be marginally overestimated and, as a result of the longer time to flooding, the contaminant concentrations at the time of spilling will also be slightly overestimated. Table 4.2 shows the Faro Pit annual water balance for the scenario where Faro Creek is diverted around the pit using the proposed East Interceptor and East Interceptor Extension (Golder, 2004). The catchment reporting to the pit in this case would have an area of 1.7 km^2.

The pit lake stability assessment (Lawrence, 2004) indicated that if Faro Creek is allowed to flow into the pit lake, the kinetic energy introduced will likely result in a completely mixed system having uniform contaminant concentrations.

Table 4.1 Summary of Pit Lake Water balance with Faro Creek Flow-through

Month	Days in month	INFLOWS		OUTFLOWS				
		Runoff	Direct Precipitation on Lake Surface	Groundwater Recharge	Lake Evap	Lake Evaporation	Discharge at Pit Outlet	
		(1000 m^3)	(1000 m^3)	(1000 m^3)	(mm)	(1000 m^3)	(1000 m^3)	(m^3/s)
Jan	31	123	7	1	0	0	128	0.05
Feb	28.25	91	5	1	0	0	95	0.04
Mar	31	88	5	1	8	6	78	0.03
Apr	30	116	6	1	53	41	27	0.01
May	31	1085	58	1	90	70	982	0.37
Jun	30	1873	100	1	112	87	1772	0.68
Jul	31	858	46	1	108	84	710	0.27
Aug	31	427	23	1	81	63	304	0.11
Sep	30	414	22	1	31	24	380	0.15
Oct	31	392	21	1	10	8	393	0.15
Nov	30	207	11	1	0	0	217	0.08
Dec	31	164	9	1	0	0	171	0.06
Annual	365.25	5838	312	16	493	385	5257	0.17

Table 4.2 Summary of Faro Pit water balance with Faro Creek diverted

		INFLOWS		OUTFLOWS				
Month	**Days in month**	**Runoff** (1000 m^3)	**Direct Precipitation on Lake Surface** (1000 m^3)	**Groundwater Recharge** (1000 m^3)	**Lake Evap** (mm)	**Lake Evaporation** (1000 m^3)	**Discharge at Pit Outlet** (1000 m^3)	(m^3/s)
Jan	31	12	7	1	0	0	18	0.01
Feb	28.25	9	5	1	0	0	13	0.01
Mar	31	9	5	1	8	6	6	0.00
Apr	30	12	6	1	53	41	-25	-0.01
May	31	109	58	1	90	70	96	0.04
Jun	30	188	100	1	112	87	200	0.08
Jul	31	86	46	1	108	84	46	0.02
Aug	31	43	23	1	81	63	1	0.00
Sep	30	42	22	1	31	24	38	0.01
Oct	31	39	21	1	10	8	51	0.02
Nov	30	21	11	1	0	0	31	0.01
Dec	31	16	9	1	0	0	24	0.01
Annual	365.25	587	312	16	493	385	498	0.02

4.2.3 Contaminant Inventory and Sources

Pit water quality will be determined by the inventory of contaminants currently present in the pit lake and by the future influx of contaminants. Potential contaminant sources to Faro Pit Lake include seepage and runoff from the wall rock, talus, and in-pit dumps, dissolution of secondary minerals from sheltered areas of the pit walls during flooding, and releases from material at the bottom of the lake, such as tailings and tailings porewater, and any secondary minerals that have precipitated.

Current Pit Inventory

The contaminant mass currently resident in Faro Pit Lake determines the current pit water quality and provides the starting point for calculating future pit water quality. Resident contaminant mass was calculated from results of depth profiling conducted in June 2004, as discussed in Section 3.1.2. Table 4.3 summarizes the mass of contaminants currently resident in the pit lake.

Table 4.3 Current contaminant inventory in Faro Pit

Parameter	Current mass in pit lake (kg)
Cl	37000
SO4	18000000
Ca	4600000
Mg	1700000
K	370000
Na	850000
Al	1400
Cd	110
Co	970
Cu	240
Fe	350000
Pb	27
Mn	99000
Ni	2100
Zn	150000

Wall Rock

Maps and descriptions of the pit wall rock are provided in Section 2.2.1. The relative areas of each rock for current and future flooding levels are presented in Figure 4.2. As indicated in Figure 2.1, the dominant rock type is biotite schist (Unit 1D), with somewhat smaller exposures of calc-silicate (Unit 3D0), hornblende diorite and quartz diorite (Unit 10E), and altered quartz muscovite schist (Unit 1D4). Minor exposures of quartz feldspar porphyry (Unit 10F), graphitic pyritic quartzite (Unit 2A), and massive sulphides (Unit 2E) are also present.

The geochemical characteristics of each of the above rock types are described in *“Geochemical Studies of Waste Rock at the Anvil Range Mining Complex”* (SRK 2004b). This report included an overall classification of the long-term geochemical behaviour based on acid base accounting tests and kinetic tests. In brief:

- Unaltered biotite schist (Unit 1D) unit has been classified as non-acid generating unless it is mixed with sulphides from other rock types
- Calc-silicates (Unit 3DO) are classified as acid consuming
- Intrusives (Unit 10E and 10F), are theoretically acid generating, but are expected to take several decades before acid generation occurs
- Altered quartz muscovite schists (Unit 1D4) and sulphides (Unit 2) are acid generating, and likely already producing acidic seepage.

Given the advanced state of weathering observed in the Faro pit, and the limited amount of material which is expected to change in the longer term, loading from the wall rock is not expected to change significantly over time.

As discussed in Section 2.2.4, the results of the limited wall rock and talus testing indicated that these samples contained relatively little soluble oxidation products. However, a single sample from Unit 1D4 (altered quartz muscovite schist) generated acidic rinse water and contained a high soluble zinc load. Once the pit reaches its ultimate lake elevation (Figure 4.2), this unit will occupy approximately 80,000 m^2 of the high northwest wall of the Faro Pit, and will therefore remain a major source of loading to the pit lake in the long term.

Seepage data from the 2004 pit seep surveys (Section 2.2.3) provides the most representative means of estimating source concentrations associated with each of the above rock types. Wall rock runoff quality was assumed to be the average of that in seep/runoff samples collected from within each rock unit. Where seeps were not available for a given rock unit, a water type was selected from the available database of waste rock seepage types. In some cases, results of the leach extraction tests (Section 2.2.4) were helpful in selecting these seepage types. Table 4.4 summarizes the water types used to characterize runoff each of the above rock units. A complete set of parameters for each water type is attached in Appendix E.1.

The total contaminant load from the wall rocks was estimated by multiplying the relative areas of each of the rock types (m^2) by the source concentrations in Table 4.4 (mg/L). This was then multiplied by the site runoff ($L/(m^2.year)$) to yield mg/year, and corrected to kg per year. The estimates of total wall rock load are provided in Table 4.5.

Secondary mineral salts such as zinc and iron sulphates observed on the pit walls could also be a source of contaminant loading to the pit lake during the flooding period. Scoping level calculations indicate that this source is insignificant in relation to other sources of load.

Table 4.4 Water types for used to estimate wall rock loadings to Faro Pit Lake

Water type	Unit	Lithology	pH (s.u.)	Alk (mg/L)	SO4 (mg/L)	Cu (mg/L)	Zn (mg/L)	Exposed rock above final spill elev. (m^2)
FT1	1D	Biotite schist	7.3	185	720	0.010	2.5	257,000
FT4	1D4	Altered quartz muscovite schist	3.9	16	1600	2.1	109	76,000
FT5	2E	Barren massive sulphides	3.4	6	17000	92	4260	8,000
FT11	2A	Ribbon-banded graphitic pyritic quartzite	4.3	10	390	0.37	35	18,000
FT12	3DO	Calc-silicate	7.5	139	430	0.010	0.051	81,000
FT13	10E	Hornblende diorite and quartz diorite	7.5	242	140	0.010	0.28	102,000
FT13	10F	Quartz feldspar porphyry	7.5	242	140	0.010	0.28	32,000

Table 4.5 Summary of wall rock contaminant loadings to Faro Pit

	Initial Loading	After spill elevation reached
Parameter	**Loading (kg/year)**	**Loading (kg/year)**
Cl	970	610
SO4	259,000	173,000
Ca	32,000	23,000
Mg	25,000	18,000
K	1,500	1,100
Na	14,000	7,800
Al	1,500	1,000
Cd	39	24
Co	36	24
Cu	510	310
Fe	16,000	9,600
Pb	32	23
Mn	2,200	1,300
Ni	49	34
Zn	24,000	15,000

Waste Rock

Several waste dumps are within or partially within the Faro Pit Catchment. They will be an ongoing source of loading to Faro Pit Lake. Loadings from low grade ore stockpiles within the dump catchment were not considered, as these stockpiles will likely be removed or covered by a very low infiltration cover in the near future.

A list of waste dumps partially or fully inside the Faro Pit catchment is shown in Table 4.6, along with an estimate of the proportion of seepage from each dump that will report to the pit. Table 4.6 also includes the water quality estimates presented in the waste dump water quality estimates report (SRK 2004d). The estimated contaminant concentrations were multiplied by the net annual infiltration to each waste rock dump to obtain the total annual loading for that dump. Each waste rock dump load was then multiplied by the proportion of seepage reporting to the pit catchment to estimate the corresponding contaminant loads to the pit lake.

The resulting annual load estimates to Faro Pit from waste rock are summarised in Table 4.7. Loadings to Faro Pit are shown for both the base case, with Faro Valley Dump in place, and for the case where the Faro Valley Dump is removed. Zinc loadings and copper loadings are estimated to be reduced by over 1500 kg/year, and 29 kg/year, respectively, through dump relocation.

Table 4.6 Faro Pit catchment: Waste Rock Dumps and Applied Seepage Quality

Waste Rock Dump	Proportion in Pit Lake Catchment	Acidity	Alk	Cl	SO4	Ca	Mg	K	Na	Al	Cd	Co	Cu	Fe	Pb	Mn	Ni	Zn
Faro Valley North	100%	11215	182	35.6	18697	2006	1870	74	87	171	1.8	3.5	24	884	4.2	116	6.5	1268
Faro Valley South	100%	2691	44	8.6	4487	481	449	18	21	41	0.4	0.8	5.7	212	1.0	28	1.6	304
Southwest Pit Wall Dump	70%	6463	105	20.5	10774	1156	1077	43	50	99	1.1	2.0	14	509	2.4	67	3.7	731
Ranch Dump	20%	117	581	5.9	4371	796	624	26	81	0.8	0.1	0.1	0.1	3.5	0.2	9.1	0.4	51
Ramp Zone Dump	20%	80	572	3.9	10532	1082	1452	92	622	1.0	0.1	0.1	0.1	1.6	0.3	0.7	0.4	31
Outer Northeast Dump	100%	35	176	1.8	1321	241	188	8	24	0.3	0.0	0.0	0.0	1.0	0.1	2.8	0.1	15
Lower Northeast Dump	30%	289	4749	43.9	10758	3083	2212	90	160	4.7	0.2	0.2	0.2	0.7	1.2	1.0	1.2	50
Upper Northeast Dump	40%	269	4426	40.9	10025	2873	2061	84	149	4.3	0.2	0.2	0.2	0.7	1.1	0.9	1.1	47

All units are loadings in kg / year

Table 4.7 Summary of Estimated Annual Contaminant Loadings to Faro Pit from Waste Rock

Parameter	Faro Valley Dump in place	Faro Valley Dump removed
	Loading (kg/year)	Loading (kg/year)
Cl	92	48
SO4	42000	19000
Ca	6000	3500
Mg	5200	2800
K	210	120
Na	420	310
Al	290	73
Cd	3.2	0.95
Co	5.9	1.6
Cu	39	9.8
Fe	1500	340
Pb	7.9	2.6
Mn	200	52
Ni	12	3.7
Zn	2100	580

4.2.4 Water Quality Estimates

A calculation spreadsheet was used to estimate changes in concentrations that could occur once the plug dam is constructed, the pit is allowed to fill to its final level of 1173.5 masl, and the resident load is flushed from the system. No in-pit removal of contaminants through sorption, particulate settling, biological removal, or sulphate reduction was considered. The calculations also assume that no contaminants will enter the pit water from in-pit tailings or from wall rock below the present lake surface, and that no further contaminant removal will occur through water treatment. Steady-state concentrations are assumed to be reached once the amount of load entering the pit is equal to the amount of load leaving the pit.

In the base case estimates, it was assumed that the Faro creek diversion would be breached and allowed to spill into the pit. In this case, the water level is expected to reach the 1173.5 masl spill elevation in August 2007 (Figure 4.3). Results of the pit lake water quality calculations are presented in Figure 4.4.

The most notable feature of the estimates is the decrease in acidity and zinc concentrations due to the influx of clean water. The modelling suggests that, at the time when the pit would first spill, the acidity would be about 34 mg $CaCO_3$ eq/L, the zinc about 5 mg/L, and the copper about 0.04 mg/L. Zinc would then continue to decrease to a long-term steady-state concentration of about 3 mg/L, and acidity would decrease to about 12 mg/L. However, copper would continue to increase to a long-term average of about 0.06 mg/L. Copper estimates are likely very conservative, as detection limit values were substituted for samples where concentrations were less than detection. This apparent accumulation of copper may be a function of the analytical limitations, and may not be representative of actual copper loadings to the pit.

Two additional scenarios were evaluated to show 1) the effects of continuing to divert Faro Creek flows and 2) the effects of removing the Faro Valley Dump. In the case of diversion, pit filling would occur much slower, with the first predicted discharge occurring in 2047 (Figure 4.5). At this time, modelling suggests that the pit lake water would have an acidity of 101 mg $CaCO_3$ eq/L, a zinc concentration of 22 mg/L, and a copper concentration of 0.39 mg/L. The model predicts that acidity and metal concentrations will continue to increase for at least 200 years under these conditions, and that after 200 years, the pit lake would have an acidity of 127 mg $CaCO_3$ eq/L, a zinc concentration of 32 mg/L, and a copper concentration of 0.64 mg/L (Figure 4.6).

Removing the Faro Valley Dump and allowing Faro Creek to flow into the pit results in little change from the base case predictions. When the pit first discharges (August 2007- Figure 4.3), the pit lake water is predicted to have an acidity concentration of 33 mg $CaCO_3$ eq/L, a zinc concentration of 4.6 mg/L, and a copper concentration of 0.04 mg/L. In the long term, the pit lake water is predicted to have acidity of 11 mg $CaCO_3$ eq/L, zinc concentrations of 2.7 mg/L, and a copper concentration of 0.06 mg/L (Figure 4.7).

A summary of results for the three scenarios modelled is presented in Table 4.8.

Table 4.8 Estimated Faro Pit water quality with 'Current Average' waste rock inputs

Parameter	Base Case		Faro Creek Diverted		Faro Valley Dump Removed	
	At spill (Aug. 2007)	Long term (~ yr. 2040)	At spill (yr. 2047)	Long term (yr. 2204)	At spill (Aug. 2007)	Long term (~ yr. 2040)
Acidity (mg CaCO3eq /L)	34	12	101	127	33	11
Zinc (mg/L)	4.7	3.0	22	32	4.6	2.7
Copper (mg/L)	0.04	0.06	0.39	0.64	0.04	0.06

Sensitivity to increased waste rock load

It is conceivable that waste dump seepage quality within the Faro Pit catchment could degrade in the future such that waste rock loads to the pit would increase over the loads assumed in the 'Current Average' predictions. As a check on the sensitivity of the water quality predictions to waste rock load inputs, the 'Future Worst' seepage quality estimated in the dump water quality prediction (SRK 2004d) was used as an input. Table 4.9 summarizes the key results of this sensitivity analysis for the three scenarios modelled. Long term concentrations of acidity, zinc, and copper are higher by a factor of 15 to 20 for the Base Case scenario under conditions of 'Future Worst' waste rock loading. The other two scenarios have similar increases in acidity, zinc, and copper concentrations. Clearly, Faro Pit Lake water quality predictions are sensitive to increased loadings from waste rock currently located within the pit catchment.

Table 4.9 Estimated Faro Pit water quality with 'Future Worst' waste rock inputs

Parameter	Base Case		Faro Creek Diverted		Faro Valley Dump Removed	
	At spill (Aug. 2007)	Long term (~ yr. 2040)	At spill (yr. 2047)	Long term (yr. 2204)	At spill (Aug. 2007)	Long term (~ yr. 2040)
Acidity (mg CaCO3eq /L)	126	218	1153	2256	63	76
Zinc (mg/L)	24	46	243	478	11	17
Copper (mg/L)	0.54	1.2	6.1	12	0.19	0.40

4.3 Grum Pit

4.3.1 Modelled Scenario

Since there is no substantial diversion of water away from Grum Pit, and since there is no waste rock within the pit catchment, a single scenario was considered in the water quality estimate for Grum Pit Lake. The water and load balance assumed that pit filling began on January 1, 2004.

4.3.2 Geometry, Flow Conditions and Stratification

The volume-capacity curve for the Grum pit was re-assessed using the topography generated from the 2003 aerial photography. To include the volume of water below the current pit lake level, the new curve was ‘meshed’ with that presented in the ICAP (RGI 1996). The complete volume capacity curve is provided in Figure 4.8.

The overall water balance for Grum Pit Lake is summarised in Table 4.10. The table shows conditions whereby the Grum interceptor ditch is breached and surface runoff within the pit lake catchment is routed through the pit lake, making the total catchment about 1.22 km^2. The mean annual runoff is estimated to be 270 mm and mean annual precipitation 450 mm. The evaporation rate is based on a fixed pit lake surface area of about 0.28 km^2. As noted for Faro Pit Lake calculations, the calculations represent the pit lake at fully flooded conditions. The net implication is that the time to flooding will be marginally overestimated and, as a result of the longer time to flooding, the contaminant concentrations at the time of spilling will also be slightly overestimated.

Table 4.10 Summary of Grum Pit water balance with Grum interceptor breached

Month	Days in month	INFLOWS		OUTFLOWS				
		Runoff	Direct Precipitation on Lake Surface	Groundwater Recharge	Lake Evaporation	Lake Evaporation	Discharge at Pit Outlet	
		(1000 m^3)	(1000 m^3)	(1000 m^3)	(mm)	(1000 m^3)	(1000 m^3)	(m^3/s)
Jan	31	5	2	0	0	0	8	0.003
Feb	28.25	4	2	0	0	0	6	0.002
Mar	31	4	2	0	6	2	2	0.001
Apr	30	8	3	0	38	11	-10	-0.004
May	31	68	26	0	64	18	58	0.021
Jun	30	70	27	0	80	22	51	0.020
Jul	31	49	19	0	77	22	24	0.009
Aug	31	34	13	0	58	16	15	0.005
Sep	30	46	17	0	22	6	51	0.020
Oct	31	24	9	0	7	2	29	0.011
Nov	30	11	4	0	0	0	15	0.006
Dec	31	8	3	0	0	0	11	0.004
Annual	365.25	329	126	0	352	99	258	0.008

4.3.3 Contaminant Inventory and Sources

Pit water quality will be determined by the inventory of contaminants currently present in the pit lake and by the future influx of contaminants. Potential contaminant sources to Grum Pit Lake include seepage and runoff from the wall rock and talus, dissolution of secondary minerals from sheltered areas of the pit walls during flooding, and releases from any secondary minerals that have precipitated at the bottom of the lake.

Current Pit Inventory

The contaminant mass currently resident in Grum Pit Lake determines the current pit water quality and provides the starting point for calculating future pit water quality. The resident contaminant mass was calculated from results of depth profiling conducted in June 2004, as discussed in Section 3.2.2. Table 4.11 summarizes the mass of contaminants currently resident in the pit lake.

Table 4.11 Current contaminant inventory in Grum Pit

Parameter	Current mass in pit lake (kg)
Cl	1100
SO4	990000
Ca	270000
Mg	160000
K	7900
Na	25000
Al	99
Cd	21
Co	65
Cu	2.1
Fe	170
Pb	1.9
Mn	1100
Ni	490
Zn	20000

Wall Rock

Maps and descriptions of the pit wall rock are provided in Section 2.2.1. The relative areas of each rock for current and future flooding levels are presented in Figure 4.9. As indicated in Figure 2.2, the dominant rock types are mixed calcareous and carbonaceous Vangorda Formation phyllite (Unit 5A0/5B0), non-calcareous Mt. Mye Formation phyllite (Unit 3G0), and undifferentiated massive and disseminated sulphides (Unit 4EC). In addition, a large portion of the pit wall surface consists of glacial till (Unit T).

The expected long-term geochemical behaviour of each of the above rock types (SRK 2004b) are summarized as follows:

- Carbonaceous phyllites (Unit 5A) are potentially acid generating, but are expected to react slowly, and may not develop acidic conditions for several decades. Calcareous phyllites (Unit 5B) are net acid consuming. Contaminant loads from the carbonaceous phyllites may therefore increase over time. However, calcareous phyllites are likely to neutralize any acidity and limit loading from this mixed unit.
- Non-calcareous phyllites from the Mt. Mye formation (Unit 3GO) have been classified as acid consuming unless they are mixed with sulphides.

- Sulphides (Unit 4EC) are potentially acid generating, and contaminant loading from this unit may increase slightly with time.

In general, any changes in loading due to further weathering and oxidation of the wall rocks are not expected to significantly effect water quality in the pit lake due to the relatively large amount of alkalinity contributed by the till and the calcareous phyllites.

The results of the limited wall rock and talus testing indicated that the majority of the wall rock contains very little soluble oxidation products, as discussed in Section 2.2.4. Moderate zinc concentrations in the leachate from the sulphide rich samples (Unit 4EC) indicate that that these wall rocks are currently a source of metal loading. This unit largely occurs below the expected 1230 masl flood elevation (Figure 2.2), and as such will not be a major source of loading to the pit lake in the long term.

Seepage data from the 2004 pit seep surveys (Section 2.2.3) provides the most representative means of estimating source concentrations associated with each of the above rock types. Wall rock runoff quality was assumed to be the average of that in seep/runoff samples collected from within each rock unit. Table 4.12 summarizes the water types used to characterize runoff each of the above rock units. A complete set of parameters for each water type is attached in Appendix E.2.

The total contaminant load from the wall rocks was estimated by multiplying the relative areas of each of the rock types by the source concentrations in Table 4.12. The estimates of total wall rock load are provided in Table 4.13.

Secondary mineral salts were rarely observed in the Grum Pit walls. However, solids testing described in section 2.2.4 showed that release of soluble products, primarily from sulphide wall rock (Unit 4EC), could contribute loading to the pit during flooding. Scoping level calculations suggest that dissolution of stored products will contribute a minor incremental load compared to the current contaminant inventory in the pit lake.

Table 4.12 Water types for used to estimate wall rock loadings to Grum Pit Lake

Water type	Unit	Lithology	pH (s.u.)	Alk (mg/L)	SO4 (mg/L)	Cu (mg/L)	Zn (mg/L)	Exposed rock above final spill elev. (m^2)
VG7	5A0/5B0, 3G0	calcareous, carbonaceous, and non-calcareous phyllite	8.0	240	630	0.0040	0.020	228,000
VG8	4EC	Massive and disseminated sulphides	7.6	220	830	0.010	28	11,000
VG9	T	Till	8.0	110	330	0.010	0.014	197,000

Table 4.13 Summary of wall rock contaminant loadings to Grum Pit

	Initial Loading	**After spill elevation reached**
Parameter	**Loading (kg/year)**	**Loading (kg/year)**
Cl	83	58
SO4	65 000	41 000
Ca	14 000	8 800
Mg	12 000	7 800
K	350	230
Na	420	260
Al	7	5
Cd	0.6	0.3
Co	3	1
Cu	0.5	0.3
Fe	180	42
Pb	2	1
Mn	45	11
Ni	16	7
Zn	350	80

4.3.4 Water Quality Estimates

The calculation spreadsheet was used to estimate changes in contaminant concentrations that occur while Grum Pit Lake fills to its final level of 1230 masl, and as the resident load is flushed from the system. No in-pit removal of contaminants through sorption, particulate settling, biological removal, or sulphate reduction was considered. The calculations also assume that no contaminants will enter the pit water from wall rock below the present lake surface, and that no contaminant removal will occur through water treatment. Steady-state concentrations are assumed to be reached once the amount of load entering the pit is equal to the amount of load leaving the pit. The biological treatment assessment will evaluate whether it is possible to achieve sufficient contaminant removal rates during filling such that pit lake surface water is acceptable for discharge to the environment at the time the spill elevation is reached.

With the Grum interceptor ditch breached, Grum Pit Lake is expected to reach the 1230 masl spill elevation in year 2030 (Figure 4.10). Results of the pit lake water quality calculations are presented in Figure 4.11 and summarized in Table 4.14. The modelling suggests that, at the time when the pit would first spill, the acidity would be about 6.1 mg $CaCO_3$ eq/L, the zinc about 2.9 mg/L, and the copper about 0.0014 mg/L. In the long term, zinc and copper would continue to decrease to concentrations of about 0.33 mg/L and 0.0011 mg/L, respectively. Acidity is estimated to decrease to about 1.4 mg/L. As in the case for Faro Pit Lake, copper estimates are likely very conservative, as detection limit values were substituted into water types where sample concentrations were less than detection. This apparent accumulation of copper may be a function of analytical limitations, and may not be representative of actual copper loadings to the pit.

The most notable feature of Grum Pit Lake water quality estimate is that equilibrium conditions require the entire period modelled (200 years) to develop (Figure 4.11). The relatively rapid decline in acidity and zinc concentration over the period of filling (to year 2030) indicates that inflows have lower concentrations than the current pit water. The majority of zinc and acidity expected in the lake when it reaches the 1230 masl level are contained within the current lake inventory.

Over the period of filling, the exposed surface area of sulphide rocks (Unit 4EC) will be greatly reduced (Figure 4.9), thus limiting loading from this unit. This is illustrated in the behaviour of copper as shown in Figure 4.11. In this figure, copper concentrations in Grum Pit Lake peak prior to the estimated spill date, indicating that the decrease in copper loadings due to reduction in exposed Unit 4EC surface area is sufficient to reverse the trend of increasing copper concentration.

Table 4.14 Estimated Grum Pit water quality

Parameter	Base Case	
	At spill (yr. 2030)	Long term (yr. 2204)
Acidity (mg CaCO3eq /L)	6.1	1.4
Zinc (mg/L)	2.9	0.33
Copper (mg/L)	0.0014	0.0011

4.4 Vangorda Pit

4.4.1 Scenarios

Three scenarios were considered in the water quality estimates for Faro Pit Lake. In the base case, it was assumed that the Vangorda Creek diversion would be breached and allowed to spill into the pit. Sensitivity runs were also completed to show 1) the effects of maintaining the diversion and 2) the effects of removing the Southeast (SE) Ramp Dump and the Hairpin Dump.

As discussed in section 4.2.1, any closure alternative which includes in-pit treatment will also include some form of remediation of waste dumps that contribute load to the pit. For the purposes of this exercise, it was assumed that simple soil covers are in place on all contributing dumps, and that infiltration (and seepage) is limited to 25% of incident precipitation.

All three cases assumed that the pit will ultimately overflow the northwest side of the pit at the approximate plan location of the original Vangorda Creek channel. This would result in an ultimate pit lake elevation of 1130 masl. The water and load balances assumed that pit filling began on January 1, 2004.

4.4.2 Geometry, Flow Conditions and Stratification

The volume-capacity curve for the Vangorda pit estimated using the topography generated from the 2003 aerial photography. To include the volume of water below the current pit lake level, the new curve was ‘meshed’ with that presented in the ICAP (1996). The complete volume capacity curve is provided in Figure 4.12.

The overall water balance for Vangorda Pit Lake is summarised in Table 4.15. The table shows conditions whereby the Vangorda Creek diversion is breached and routed through the pit lake. The total pit lake catchment becomes about 21.7 km2. Losses to groundwater are assumed to be negligible. The mean annual runoff is estimated to be 362 mm and mean annual precipitation 380 mm. The evaporation rate is based on a fixed pit lake surface area of about 0.17 km^2. As noted before, the calculations adopted a lake surface area corresponding to fully flooded conditions. Because of the short time to flooding, this assumption has little effect on the calculation results.

Table 4.16 shows the Vangorda Pit water balance for the scenario where Vangorda Creek is permanently diverted. In this case, the total pit lake catchment has an approximate area of 0.67 km^2. This catchment assumes that a surface water interception ditch is constructed above the east edge of the pit south of Vangorda Creek, and that only the catchment below this proposed ditch (SRK 2003c) reports to the Vangorda Pit.

Table 4.15 Summary of Vangorda Pit water balance with Vangorda Creek diversion breached

		INFLOWS		OUTFLOWS				
Month	Days in month	Runoff	Direct Precipitation on Lake Surface	Groundwater Recharge	Lake Evaporation	Lake Evaporation	Discharge at Pit Outlet	
		(1000 m^3)	(1000 m^3)	(1000 m^3)	(mm)	(1000 m^3)	(1000 m^3)	(m^3/s)
Jan	31	123	1	0	0	0	124	0.05
Feb	28.25	123	1	0	0	0	124	0.05
Mar	31	119	1	0	8	1	119	0.04
Apr	30	157	1	0	53	9	149	0.06
May	31	1462	12	0	90	15	1459	0.54
Jun	30	2523	21	0	112	19	2524	0.97
Jul	31	1155	10	0	108	18	1146	0.43
Aug	31	575	5	0	81	14	566	0.21
Sep	30	558	5	0	31	5	558	0.22
Oct	31	528	4	0	10	2	530	0.20
Nov	30	279	2	0	0	0	281	0.11
Dec	31	221	2	0	0	0	222	0.08
Annual	365.25	7823	65	0	493	84	7804	0.25

Table 4.16 Summary of Vangorda Pit water balance with Vangorda Creek diverted

		INFLOWS		OUTFLOWS				
Month	Days in month	Runoff	Direct Precipitation on Lake Surface	Groundwater Recharge	Lake Evaporation	Lake Evaporation	Discharge at Pit Outlet	
		(1000 m^3)	(1000 m^3)	(1000 m^3)	(mm)	(1000 m^3)	(1000 m^3)	(m^3/s)
Jan	31	4	1	0	0	0	5	0.00
Feb	28.25	4	1	0	0	0	5	0.00
Mar	31	4	1	0	8	1	3	0.00
Apr	30	5	1	0	53	9	-3	0.00
May	31	45	12	0	90	15	42	0.02
Jun	30	78	21	0	112	19	80	0.03
Jul	31	36	10	0	108	18	27	0.01
Aug	31	18	5	0	81	14	9	0.00
Sep	30	17	5	0	31	5	17	0.01
Oct	31	16	4	0	10	2	19	0.01
Nov	30	9	2	0	0	0	11	0.00
Dec	31	7	2	0	0	0	9	0.00
Annual	365.25	243	65	0	493	84	223	0.01

4.4.3 Contaminant Inventory and Sources

Pit water quality will be determined by the inventory of contaminants currently present in the pit lake and by the future influx of contaminants. Potential contaminant sources to Vangorda Pit Lake include seepage and runoff from the wall rock, talus, and in-pit dumps, dissolution of secondary minerals from sheltered areas of the pit walls during flooding, and releases from treatment plant sludges deposited in the lake and/or any secondary minerals that have precipitated in the bottom of the pit lake.

Current Pit Inventory

The contaminant mass currently resident in Vangorda Pit Lake determines the current pit water quality and provides the starting point for calculating future pit water quality. Resident contaminant mass was calculated from results of depth profiling conducted in June 2004, as discussed in Section 3.3.2. Table 4.17 summarizes the mass of contaminants currently resident in the pit lake.

Table 4.17 Current contaminant inventory in Vangorda Pit

Parameter	Current mass in pit lake (kg)
Cl	750
SO4	1800000
Ca	360000
Mg	140000
K	5500
Na	8300
Al	74
Cd	150
Co	1100
Cu	350
Fe	25000
Pb	13
Mn	60000
Ni	990
Zn	180000

Wall Rock

Maps and descriptions of the pit wall rock are provided in Section 2.2.1. The relative areas of each rock for current and future flooding levels are presented in Figure 4.13. As indicated in Figure 2.3, the dominant rock types are massive and disseminated sulphides (Unit 4EC) and till, with moderate exposures of non-calcareous phyllite (Unit 3G0), and minor amounts of carbonaceous phyllite (Unit 5A0), and bleached phyllite (Unit 4L0).

As discussed in Section 2.2.4, wall rock and talus from the Vangorda pit was characterized in an earlier study (SRK 2000). The results indicated that several of the samples had acidic pH’s or were potentially acid generating, indicating that seepage quality is likely to worsen over time, potentially to the point where neutral conditions could not be maintained in the pit. However, for the scenario where the Vangorda Creek diversion would be breached and allowed to flow through the pit, there should be sufficient alkalinity to offset any acidic seepage from the pit walls.

Seepage data from the 2004 pit seep surveys (Section 2.2.3) provides the most representative means of estimating source concentrations associated with each of the above rock types. Where insufficient data is available, data from the waste rock seep surveys was used to supplement this data. Table 4.18 summarizes the seepage data used to represent each of the above rock units. A complete set of parameters for each water type is attached in Appendix E.3.

The total contaminant load from the wall rocks was estimated by multiplying the relative areas of each of the rock types by the source concentrations in Table 4.18. The estimates of total wall rock load are provided in Table 4.19.

The results of the wall rock and talus testing also indicated that several samples contained high soluble zinc loads. These and secondary mineral salts such as zinc and iron sulphates observed on the pit walls could also be a major source of contaminant loading to the pit lake during the flooding period (SRK 2000). These sources have not been included in the wall rock load calculations.

Table 4.18 Water types used to estimate wall rock loadings to Vangorda Pit Lake

Water type	Unit	Lithology	pH (s.u.)	Alk (mg/L)	SO4 (mg/L)	Cu (mg/L)	Zn (mg/L)	Exposed rock above final spill elev. (m^2)
VG10	3G0, 5A0	Carbonaceous phyllite and non-calcareous phyllite	6.2	88	620	0.32	46	29,000
VG11	4EC	Undifferentiated massive and disseminated sulphides	5.0	17	2500	6.5	450	71,000
VG12	4L0	Bleached pyritic phyllite	3.8	4	6100	6.9	780	2,000
VG13	Till	Till	7.6	200	25	0.010	0.0050	48,000

Table 4.19 Summary of wall rock contaminant loadings to Vangorda Pit

	Initial Loading	After spill elevation reached
Parameter	Loading (kg/year)	Loading (kg/year)
Cl	47	36
SO4	111 000	77 000
Ca	10 000	7 500
Mg	7 500	5 100
K	340	240
Na	430	330
Al	580	420
Cd	24	18
Co	63	42
Cu	240	180
Fe	11 000	8 200
Pb	30	23
Mn	5 100	3 200
Ni	51	37
Zn	18 000	13 000

Waste Rock

Waste rock has been placed within the Vangorda pit ramp area that leads down to the pit lake. Two waste rock piles are located in this area on either side of the access road. The smaller dump is located within the hairpin of the access road (hairpin dump) and the second comprises waste rock that has been placed along the road to the south of the bend and to the east of the road as it descends to the pit lake (SE ramp dump). The hairpin dump represents an area of about 15,000 m^2 and the SE ramp dump an area of about 20,000 m^2. To be consistent with the assumptions for the wall rock runoff, it was assumed that all of the runoff (i.e. surface overflow and infiltration) would be contaminated. Table 4.20 shows the waste rock seepage quality used in the model to characterize dump loadings to Vangorda Pit Lake.

Previous characterization of the waste rock in these dumps (SRK 2000) indicated that this material was consistently net acid generating, with high concentrations of soluble metals.

The water quality estimates derived in the waste dump and load balances (SRK 2003b) were used directly to estimate the corresponding contaminant loads to the pit lake. The hairpin dump is expected to remain above the water level; however, a layer of about 10 m of waste rock in the second pile would remain below the ultimate lake level. Some reduction in the loadings may result from this which was not accounted for in the calculations.

The in-pit dumps at Vangorda represent a significant source of loading to the pit (Table 4.21). However, if a flow-through pit system is implemented, these dumps would be removed or isolated from the main section of the pit to minimize contaminant loading. The prediction for the case where these dumps are removed provides the best available estimate of the long term water quality facing biological treatment.

Sludges and Precipitates

The Vangorda pit was reportedly used for a short period to store sludges from the water treatment plant. The quantity of sludges is not known. Under reducing and/or acidic pH conditions, it is possible that these sludges could become remobilized, resulting in increased loading to the pit lake.

Equilibrium modelling of the pit water quality completed in the 2000 pit lake study (SRK 2000) indicated that water in the lower portions of the pit were close to equilibrium with the minerals smithsonite ($ZnCO_3.H_2O$) and rhodochrosite (manganese carbonate). This suggests that these minerals could be present in the bottom sediments. Decreasing zinc concentrations in the water column resulting from changes to the water balance (such as breaching the Vangorda Creek diversion), or changes in the pH could lead to short-term remobilization of these precipitates into the water column.

Table 4.20 Vangorda Pit catchment: Waste rock dumps and applied seepage quality

Waste Rock Dump	Proportion in Pit Lake Catchment	Acidity	Alk	Cl	SO4	Ca	Mg	K	Na	Al	Cd	Co	Cu	Fe	Pb	Mn	Ni	Zn
SE Ramp Dump	100%	4088	638	3.7	10950	607	1233	14	15	26	2.3	6.2	19	457	0.74	645	5.5	1911
Hairpin Dump	100%	84	228	2.7	2819	477	383	13	26	0.45	0.050	0.086	0.074	3.1	0.11	8.2	0.27	43

All units are loadings in kg / year

Table 4.21 Summary of Estimated Annual Contaminant Loadings to Vangorda Pit From Waste Rock

Parameter	In-pit dumps in place	In-pit dumps removed
	Loading (kg/year)	Loading (kg/year)
Cl	6	0
SO4	14 000	0
Ca	1 100	0
Mg	1 600	0
K	27	0
Na	41	0
Al	27	0
Cd	2	0
Co	6	0
Cu	19	0
Fe	460	0
Pb	1	0
Mn	650	0
Ni	6	0
Zn	2000	0

4.4.4 Water Quality Estimates

The calculation spreadsheet was used to estimate changes in contaminant concentrations that occur while Vangorda Pit Lake fills to its final level of 1130 masl, and as the resident load is flushed from the system. No in-pit removal of contaminants through sorption, particulate settling, biological removal, or sulphate reduction was considered. The calculations also assume that:

- no contaminants will enter the pit water from treatment sludges stored within the pit;
- no contaminants will enter the pit water from the wall rock below the present lake surface;
- no contaminants will enter the pit water from the stored oxidation products present on the pit walls and within the pit talus;
- no further contaminant additions will occur via pumping of contaminated water to the pit;
- no further contaminant removal will occur through treatment of pit water.

Steady-state concentrations are assumed to be reached once the amount of load entering the pit is equal to the amount of load leaving the pit.

With the Vangorda Creek diversion breached, Vangorda Pit Lake is expected to reach the 1130 masl spill elevation within a single year (Figure 4.14). Results of the base case pit lake water quality calculations are presented in Figure 4.15 and summarized in Table 4.22. The modelling suggests that, at the time when the pit would first spill, the acidity would be about 86 mg$CaCO_3$ eq/L, the zinc about 33 mg/L, and the copper about 0.091 mg/L. In the long term, zinc and copper would continue to decrease to concentrations of about 1.5 mg/L and 0.020 mg/L, respectively. Acidity is estimated to decrease to about 5.8 mg/L. Copper concentrations in Vangorda Pit seeps were at measurable levels, and copper estimates are likely more reflective of field conditions than at the estimates for both Faro and Grum.

Two additional scenarios were evaluated to show 1) the effects of continuing to divert Vangorda Creek flows and 2) the effects of removing the in-pit dumps. In the case of diversion, pit filling would occur much slower, with the first predicted discharge occurring in 2023 (Figure 4.16). At this time, modelling suggests that the pit lake water would have an acidity of 349 mg $CaCO_3$ eq/L, a zinc concentration of 102 mg/L, and a copper concentration of 0.97 mg/L. The model predicts that acidity and metal concentrations will continue to increase for at least 200 years under these conditions, and that after 200 years, the pit lake would have an acidity of 251 mg $CaCO_3$ eq/L, a zinc concentration of 67 mg/L, and a copper concentration of 0.87 mg/L (Figure 4.17).

Removing the Vangorda in-pit dumps and allowing Vangorda Creek to flow into the pit results in little change from base case predictions. When the pit first discharges (July 2004- Figure 4.14), pit lake water is predicted to have an acidity level of 85 mg $CaCO_3$ eq/L, a zinc concentration of 33 mg/L, and a copper concentration of 0.89 mg/L. In the long term, pit lake water is predicted to have acidity of 5.1 mg $CaCO_3$ eq/L, zinc concentrations of 1.3 mg/L, and a copper concentration of 0.018 mg/L (Figure 4.18).

A summary of results for the three scenarios modelled is presented in Table 4.22. A sensitivity analysis for conditions of increased waste rock loading to the Vangorda Pit was not warranted due to the high concentrations of contaminants in pit lake water under 'Current Average' loading conditions.

Table 4.22 Estimated Vangorda Pit water quality

Parameter	Base Case		Vangorda Creek diverted		In-Pit Dumps removed	
	At spill (Jul. 2004)	Long term (~ yr. 2014)	At spill (yr. 2023)	Long term (~ yr. 2104)	At spill (Jul. 2004)	Long term (~ yr. 2014)
Acidity (mg $CaCO_3$eq /L)	86	5.8	350	250	85	5.1
Zinc (mg/L)	33	1.5	100	67	33	1.3
Copper (mg/L)	0.091	0.020	0.97	0.87	0.89	0.018

5 Conclusions

This project has developed revised estimates of contaminant concentrations in the Faro, Grum, and Vangorda Pit lakes. These estimates are based on the following assumptions.

- January 1, 2004 is the beginning of the modelled water balance.
- All diversions will be breached.
- Summer 2004 contaminant concentrations in each lake provide the starting point for estimates of future concentrations.
- Pit walls and waste rock provide the only significant sources of contaminant loading to each pit lake.
- In-pit removal of contaminants through biological and geochemical processes will be insignificant.
- Influx and outflow of contaminants due to site water management and water treatment will not occur going forward.

Under conditions where Faro Creek is routed through the pit, Faro Pit Lake is estimated to have a zinc concentration of approximately 5 mg/L at the time of first discharge in 2007. Long term water quality in Faro Pit Lake is estimated to be characterized by zinc concentrations of 3 mg/L.

Discharge from Grum Pit Lake is estimated to have zinc a concentration of about 3 mg/L when it first overflows. Zinc concentration is projected to decline slowly over the long term, reaching a concentration of 0.33 mg/L after 200 years.

Under conditions where Vangorda Creek is routed through the pit, Vangorda Pit Lake is estimated to have a zinc concentration of 33 mg/L at the time of first discharge, and to have a long term zinc concentration of 1.5 mg/L.

Additional calculations were completed to examine two remediation options, which consist of permanent diversion of creeks and relocation of contributing waste rock. These estimates indicate that permanent diversion of Vangorda and Faro Creeks will result in higher zinc concentrations and longer periods before the respective pits discharge to surface water. Removal of waste rock from the Vangorda and Faro Pit catchments was estimated to have little impact on pit lake zinc concentrations in both the short and the long term.

This report, **1CD003.046 - Updated Estimates of Post-closure Water Quality in Faro, Grum, and Vangorda Pit Lakes,** was prepared by SRK Consulting (Canada) Inc.

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6 References

Brown, Dennis, and McClay, Ken. 1992. The Vangorda Deposit. In Yukon Exploration and Geology 1992. Exploration and Geological Services Division, Yukon Region, Department of Indian and Northern Affairs Canada. pp. 25-32.

Golder Associates, 2004. Detailed Comparison of Alternatives for the Remediation of the Faro Creek Diversion, Faro YT. Report 022-1497/4000.

Lawrence, G., 2004. Preliminary Evaluation of the Physical Stability of the Faro, Grum and Vangorda Pit Lakes. In SRK Consulting, 2004a, Anvil Range Pit Lakes, Assessment of Post Closure Conditions. Prepared for Deloitte and Touche, January 2004.

Lorax, 2004. Assessment of the biological treatment of Faro, Grum, and Vangorda Pit Lakes. Prepared for SRK Consulting, November 2004.

Robertson Geoconsultants Inc (RGI). 1996. Anvil Range Mining Complex, Integrated Comprehensive Abandonment Plan. Report no. 033001/3, prepared for Anvil Range Mining Corporation. November, 1996.

SRK Consulting, 2000. Interim Report on the Feasibility of Reclaiming Vangorda Pit as a Clean Water System. Prepared for Deloitte and Touche, October 2000.

SRK Consulting, 2003a. Geochemical Studies of Waste Rock at the Anvil Range Mining Complex – Phase 1 and 2 Report. Prepared for Deloitte and Touche, April 2003.

SRK Consulting 2003b. Dump Water Quality Estimates for Anvil Range Mining Complex. Prepared for Deloitte and Touche, December 2003.

SRK Consulting 2003c. Alternatives Assessment for the Vangorda Creek Diversion. Prepared for Deloitte and Touche, April 2003.

SRK Consulting, 2004a, Anvil Range Pit Lakes, Assessment of Post Closure Conditions. Prepared for Deloitte and Touche, January 2004.

SRK Consulting, 2004b. Geochemical Studies of Waste Rock at the Anvil Range Mining Complex – Phase 3 Report. Prepared for Deloitte and Touche, June 2004.

SRK Consulting, 2004c. 2004 Waste Rock Seepage Surveys and ARD-related Data Collection. Prepared for Deloitte and Touche, December 2004.

SRK Consulting 2004d. Water Quality Estimates for Anvil Range Waste Rock. Prepared for Deloitte and Touche, November 2004.

Figures

Appendix A

Description and Nomenclature of Anvil Range Rock Types

Appendix B

Pit Wall Seep Sampling Results

Appendix B.1

Faro Pit Seeps

Appendix B.2

Grum Pit Seeps

Appendix B.3

Vangorda Pit Seeps

Appendix C

Pit Lake Routine Monitoring Results

Appendix C.1

Faro Pit

Appendix C.2

Grum Pit

Appendix C.3

Vangorda Pit

Appendix D

Pit Lake Vertical Profiling Results

Appendix D.1

Faro Pit

Appendix D.2

Grum Pit

Appendix D.3

Vangorda Pit

Appendix E

Characteristics of Water Types
Used In Predicting Wall Rock Loadings

Appendix E.1

Faro Pit

Appendix E.2

Grum Pit

Appendix E.3

Vangorda Pit