Sludge Management Requirements for the Anvil Range Site

Prepared for:

Deloitte and Touche Inc.
Interim Receiver of Anvil Range Mining Corporation
Suite 1900, 79 Wellington Street West
Toronto, ON M5K 1B9

Prepared by:

SRK Consulting
Engineers and Scientists

Project Reference Number
SRK 1CD003.55

December 2005

Sludge Management Requirements for the Anvil Range Site

Deloitte & Touche Inc.

Interim Receiver of Anvil Range Mining Corporation
Suite 1900, 79 Wellington Street West
Toronto, Ontario M5K 1B9

SRK Consulting (Canada) Inc.
Suite 800, 1066 West Hastings Street
Vancouver, B.C. V6E 3X2

Tel: 604.681.4196 Fax: 604.687.5532
E-mail: vancouver@srk.com Web site: www.srk.com

SRK Project Number 1CD003.055

December 2005

Author

John Chapman, P.Eng

Reviewed by

Daryl Hockley, P.Eng

Table of Contents

List of Tables

List of Figures

1 Introduction

Water treatment is likely to be a part of the Anvil Range Site closure plan. Estimates of water treatment requirements were derived for a number of possible closure options (SRK, 2005a). Water treatment will generate sludge that will need to be managed over the long term. Calculation of volumes of sludge that may be generated in the long term was included in the estimation of the water treatment requirements (SRK, 2005a) and those volume estimates were used herein to estimate requirements for sludge disposal over the long term.

This report presents the results of a project to assess long-term sludge management requirements and options. The report is arranged as follows. Estimates of total sludge production that may occur for various treatment scenarios are presented in Section 2. A review of sludge dewatering and concentration methods is provided in Section 3. Based on total sludge production rates, potential disposal sites and methods are identified and discussed in Section 4. Sludge disposal cost estimates are provided in Section 5. Section 6 contains final conclusions and recommendations.

2 Estimates of Sludge Production

As part of the 2004-05 investigations for the Anvil Range Site, a water treatment model was developed to estimate treatment costs. That model incorporated a method for estimating sludge production rates (SRK, 2005a). Assessment of water treatment requirements relied on estimation of water quality and flow rates derived for the waste rock dumps (SRK, 2004a), pit lake (SRK2004b) and the tailings (SRK, 2005b, as reported in RGC2005). The sludge volume production estimates presented in the water treatment report (SRK, 2005a) were used herein to estimate long-term sludge management requirements.

It is considered unlikely that the flows from the Faro site and the Vangorda-Grum site would be treated in a single water treatment system. Therefore, sludge production rates for the two sites were estimated independently, as presented below.

2.1 Faro Site

2.1.1 Base Case Conditions

A summary of the estimated sludge production rates for the Faro site and each of the site components in the absence of any source control methods is presented in Table 2.1. The estimates were derived for current average, current maximum and anticipated future changes in water quality (SRK, 2005a). As shown, at the initial solids density of only 20% solids, the sludge production may vary over time between about 5,700 m^3 per year and 167,000 m^3 per year.

At the final settled density of 50% solids the annual production rate for the site may vary over time from about 1,800 m^3 to about 52,000 m^3. The upper bound production rate would cover an area of about 5.2 ha to a depth of 1 m of sludge each year.

The estimated cumulative productions over a 50-year and a 100-year period are provided in the last two rows of the table. It is apparent from these estimates that substantial sludge storage capacity would be required. For example, assuming sludges are stored to a depth of about 2 m, the storage area to contain the sludges that may be produced during the first 100 years could range between 10 and 110 ha (by comparison, the Rose Creek tailings facility occupies about 190 ha).

Table 2.1: Summary of Estimated Faro Site Sludge Production by Source

Description	Waste Rock		Pit Lake	Tailings		Total Combined	
	Current Average	Future Worst	Current Avg.	Current Avg.	Future Worst	Min.	Max.
Sludge Production (m^3/year) at 20 % Solids							
Year 1 – 20	2,797	2,797	408	2,486	4,756	5,691	7,958
Year 21 – 75	2,797	10,344	408	2,486	41,044	5,691	51,796
Year > 75	2,797	122,428	408	2,486	44,255	5,691	167,088
Sludge Production (m^3/year) at 50 % Solids Final Settled Density							
Year 1 – 20	871	871	127	774	1481	1,772	2,478
Year 21 – 75	871	3,221	127	774	12780	1,772	16,128
Year > 75	871	38,121	127	774	13780	1,772	52,027
Cumulative Production(m^3) at 50 % Solids Final Settled Density							
To Year 50	43,000	113,000	6,000	38,000	412,000	87,000	531,000
To Year 100	86,000	1,147,000	13,000	77,000	1,076,000	175,000	2,235,000

Note: Annual sludge production rates from SRK, 2005a

2.1.2 Source Controlled Production

Because the Faro Site has three different sources (waste rock, tailings and pit walls) and a large number of subsets of sources (sulphide cells, oxide fines, coarse tailings, fine tailings) each producing contaminants at different rates, it is apparent that a large number of combinations of source control methods are possible. Many of these combinations are likely to yield similar sludge production rates. For simplicity, only two source control methods were evaluated for the waste rock (rudimentary covers on all dumps; selective covers on sulphide cells and oxide fines), in combination with two methods for the tailings (low infiltration covers; partial relocation), assuming that the Faro Pit lake will become a clean flow-through system.

Considering only future worst case loadings, the estimated rates of sludge production are summarised in Table 2.2. Comparison with Table 2.1 shows that source control will substantially reduce sludge production rates. For example, the sludge production by treatment of seepage from the Faro waste rock dumps for future worst case conditions would decrease from 122,428 m^3/year (at 20% solids content) to 47,828 m^3/year (at 20 % solids) with the placement of rudimentary covers. Placement of low infiltration covers on the sulphide cells, with rudimentary covers on the balance of the waste rock dumps, would further decrease sludge production to 36,577 m^3/year (at 20 % solids).

Table 2.2: Summary of Estimated Faro Site Sludge Production Rates with Source Control

Description	Units	Waste Rock		Rose Creek Tailings		Combined	
		Rudimentary Covers[1]	Selective Covers[2]	Low Infiltration Cover	Partial Relocation	Min	Max
Initial Density	m^3/year	47,828	36,577	1,761	5,020	38,338	52,848
Final Density	m^3/year	14,897	11,393	549	1,563	11,942	16,460

Notes: [1] Rudimentary covers were assumed to limit infiltration to 20 % of mean annual precipitation.
[2] Low infiltrations covers placed selectively on sulphide cells and balance of waste rock covered by rudimentary covers; low infiltration covers were assumed to limit infiltration to 5 % of mean annual rainfall.
Annual sludge production rates from SRK, 2005a

2.2 Vangorda Grum Site

2.2.1 Base Case Conditions

Estimated sludge production rates for the Vangorda–Grum site without source control measures are summarised in Table 2.3. At the initial solids density of about 20 %, the annual sludge production at the site is estimated to be about 2,600 m^3 for current conditions. The production rate is expected to increase substantially at the onset of net acid generating conditions in the Grum sulphide cell and at the Vangorda waste rock dump. Sludge production rates may increase to 32,000 m^3 per year at that time.

Projected cumulative sludge productions to 50 and 100 years, at a final settled density of 50 %, are provided in the last two rows of the table, assuming the sludge productions change as indicated in the preceding rows. The cumulative sludge production to year 50 is expected to vary between about 40,000 and 147,000 m^3, and that to year 100 to between 80,000 and 644,000 m^3. In the latter case, there would be sufficient sludge to cover an area of 33 ha to a depth of 2 meters.

Table 2.3: Summary of Estimated Vangorda-Grum Site Sludge Production

Description	Waste Rock		Pit Lake	Total Combined	
	Current Average	Future Worst	Current Avg.	Min.	Max.
Annual Production (m^3/year) at Initial Density					
Year 1 – 20	2,129	2,129	462	2,592	2,592
Year 21 – 40	2,129	3,019	462	2,592	3,481
Year > 40	2,129	31,451	462	2,592	31,913
Annual Production (m^3/year) at Final Density					
Year 1 – 20	663	663	144	807	807
Year 21 – 40	663	940	144	807	1,084
Year > 40	663	9,793	144	807	9,937
Cumulative Production (m^3) at Final Density					
To Year 50	32,506	139,945	7,042	39,547	146,986
To Year 100	65,675	629,585	14,227	79,902	643,812

Note: Annual sludge production rates from SRK, 2005a

2.2.2 Source Controlled Production

As discussed for the Faro Site, there are also a large number of sources and source control combinations for the Vangorda-Grum Site. Sludge production estimates were therefore derived only for the site wide cases where i) rudimentary or, ii) rudimentary together with low infiltration covers are placed selectively on the sulphide cells and oxide fines. Backfilling of the Vangorda Pit, for example, will significantly reduce treatment requirements and sludge production and therefore is not discussed further herein.

As shown in Table 2.4, for future worst case conditions, a significant reduction in sludge production will result from rudimentary covers. An even more significant reduction would be expected should low infiltration covers be placed selectively on the high sulphide waste rock.

Table 2.4: Summary of Estimated Site-Wide Sludge Productions for Different Source Controls at Vangorda- Grum

Description	Units	Base Case (no covers)		Rudimentary Covers[1]		Selectively Placed Low Infiltration Covers[2]	
		Current Average	Future Worst	Current Average	Future Worst	Current Average	Future Worst
Initial Density	m^3/year	2,477	30,442	1,341	9,332	1,249	2,681
Final Density	m^3/year	771	9,482	418	2,907	389	835

Notes: [1] Rudimentary covers were assumed to limit infiltration to 20 % of mean annual precipitation.
[2] Low infiltrations covers placed selectively on sulphide cells and balance of waste rock covered by rudimentary covers; low infiltration covers were assumed to limit infiltration to 5 % of mean annual rainfall.
Annual sludge production rates from SRK, 2005a

2.3 Sludge Composition

Table 2.5 summarises estimated compositions (on a dry basis) for sludge produced in the laboratory and that estimated from analyses conducted on sludge samples from the Vangorda-Grum water treatment plant. The Vangorda-Grum sludge represents ‘aged’ sludge as opposed to freshly produced sludge. There are a number of significant differences between ‘aged’ and ‘fresh’ sludge, as described below.

One significant difference between the ‘fresh’ and ‘aged’ sludge is the abundance of carbonate minerals in the latter. This is a result of contact with atmospheric carbon dioxide which reacts with and transforms calcium, magnesium and zinc into carbonates. This phenomenon has been observed elsewhere (MEND, 1997) and generally leads to a more stable sludge, in particular for zinc, since the carbonate form tends to be less soluble and less sensitive to minor changes in pH.

Another difference is the abundance of iron in the sludge. The Vangorda-Grum results represent sludge from water that was collected in the Vangorda Pit and then pumped to the water treatment plant. While in ‘holding’ in the pit, the water is oxidized and iron is precipitated in the pit so that the water that is treated has a lower iron content. The samples treated in the laboratory were collected at sources and generally were acidic so that little or no iron precipitation occurred before treatment, resulting in a higher iron content.

The Vangorda-Grum sludge also exhibited a higher zinc mineral content. This may in part be explained by the lower iron content. However, there is evidence to suggest that the zinc is being preferentially leached from the waste rock. In time, as the zinc is depleted, and the water becomes more acidic, the iron and sulphate concentration in the water will increase relative to the zinc, and the proportion of iron oxy-hydroxides and gypsum present in the sludge will increase.

During 2003, a geochemical characterization study of the Vangorda-Grum water treatment sludges from the water treatment plant sediment pond was completed (SRK, 2003). The purpose of that study was to assess the long-term chemical stability and the potential effects of physico-chemical controls. That study indicated that:

- The majority of the zinc within the water treatment sludge is present as an amorphous hydroxide.
- The porewater pH is effectively buffered by secondary calcite and magnesite that have formed in the sludge.
- The buffered conditions ensure low zinc concentrations in the sludge porewater.
- Under saturated anoxic conditions (i.e. sub-aqueous disposal conditions), the zinc concentrations in the porewater increased, due in part to a decrease in the pH, which may have been a result of the anoxic conditions.
- Sufficient buffering capacity is available in the sludge to ensure carbonate buffering for many pore volume displacements.
- The neutralization potential determination further indicated that if the sludge is acidified to a pH of about 6, most of the zinc would be dissolved.

Conclusions of the study were that, to prevent excessive zinc releases, the sludge should not be disposed of in a location where i) it may be at risk to acidification and/or, ii) the solids to water contact ratio could exceed about 3,500:1.

Table 2.5: Summary of Estimated Sludge Composition

Precipitate	Composition (%)				Vangorda-Grum (%)
	FPO1	X23	FRO1	VG01	
$CaSO_4.H_2O$	<0.1	44	13	34	6.5
$Al(OH)_3$	7	0.01	1	1	0.1
$Cu(OH)_2$	0.40	0.01	0.10	0.20	0.03
$Fe(OH)_3$	4.0	5.0	3.0	21	1.1
$(CaMg)CO_3$	n/a	n/a	n/a	n/a	14
$Mg(OH)_2$	12	19	30	5	8.7
$Mn(OH)_2$	2	2	3	2	11
$Zn(OH)_2$	24	15	35	18	21
$ZnCO_3$	n/a	n/a	n/a	n/a	22
Unreacted Lime	49	15	15	19	15

3 Dewatering and Concentration Methods

A significant reduction in the volume of the sludge is affected if the higher densities can be achieved. The following methods are used for sludge dewatering and concentration:

- Thickening
- Filtration (vacuum, pressure)
- Freezing
- Evaporation/Drying
- Gravity Consolidation

These methods are briefly reviewed in the following sections.

3.1 Thickening

Thickening is an integral part of HDS lime treatment circuits, the preferred treatment technology for future implementation at the Anvil Range Site.

Currently, metal loadings in the Faro Mill and Grum-Vangorda water treatment systems are low and low density sludges are being produced. Even after several seasons of consolidation in the Vangorda-Grum water treatment sludge pond, the solids content of the sludge varied between 15 and 18 % solids (SRK, 2003). Modifications to the existing treatment systems will be required to produce denser sludges and thus reduce the disposal volumes. Nonetheless, sludge density typically achieved in conventional thickeners is in the order of 20 %, so that improved settling will only marginally increase the short-term sludge density.

3.2 Filtration

A number of filtration systems have been used to dewater sludges. The most common dewatering system is pressure filtration using filter presses or disc filters. Filter presses are commonly used in the metal plating industry to concentrate metal sludges prior to offsite disposal. They have also been used at mine sites; in one case to dewater sludges before disposal in an underground mine. Filter presses require power and would increase power demands at the treatment facility. As such, these systems would only likely be considered if rapid sludge volume reduction was required. The capital cost for new filters at the Anvil Range Site plant could be in the range of $10 to $15 million with annual operating costs of about $ 1.0 to 1.5 million (costs scaled from SENES 1994, advanced treatment scenario with pressure filters for high strength ARD wastewater).

3.3 Freezing

The most common application of "freeze dewatering" is to place sludges in thin layers in sludge ponds, and remove them after a winter season. When sludge freezes, water is released from the sludge matrix and forms layers of ice. In spring when the ice melts, the water is released and the sludge density is increased. Dewatering beds or under-drains installed below the sludge beds can further improve the results, as they provide positive drainage and allow further densification of the sludge after it thaws. A typical dewatering bed would comprise a lined basin filled with a sand drainage layer and a series of plastic drainage pipes to decant excess water.

Specific testing of the Anvil Range sludges would be required to determine the expected final density and to optimize the design parameters for the freeze dewatering system. In particular, different sludge compositions would need to be tested to anticipate changes in performance in the future as the sludge properties change.

Dilute sludges are typically projected to undergo concentration by a factor of 10 (from 2 to 20%), while higher density sludges may double in density (from 20 to 40%) in a single winter season. A system would normally consist of at least two cells, one active and one idle. Sludge is applied to the operational cell over one effluent treatment period and removed the following year.

3.4 Evaporation

The most common evaporation method used for sludge densification in a dry climate is to use passive solar evaporation ponds to form a dry sludge for disposal. Evaporation is not likely to be practical at the Anvil Range site because of its short summers and comparatively low evaporation rates.

Sludge driers and other evaporative methods which use fuel (hydrocarbon or electrical) are prohibitively expensive, especially for large volumes such as are anticipated at the Anvil Range site, and would probably be considered only where other options are not available.

3.5 Gravity Consolidation

Gravity dewatering in storage cells is possible where there is sufficient time and adequate drainage. The fine particulate size and colloidal nature of the water treatment sludges will make gravity concentration inefficient as a primary dewatering method. However, it is realistic to consider gravity dewatering as a secondary benefit of under-drainage in either a freeze dewatering cell or a final disposal site.

3.6 Other Methods

Other techniques that have been proposed for sludge dewatering include processes such as centrifuging, flotation, and electro-osmosis. These processes are unproven at the scale that would be required for the Anvil Range site.

4 Final Disposal Location and Methods

Short-term sludge management strategies have been developed and are being implemented for the three water treatment systems at the Anvil Range Site as follows:

- The sludge produced at the Faro Mill Water treatment system will be piped by gravity flow to a cell that has been constructed on the Rose Creek tailings impoundment (SRK, June 2004). The disposal cell comprises a 1.5 m high berm that has been constructed on the tailings in the original tailings impoundment at a location adjacent the old cover test plots.
- Sludges from the Down Valley treatment system that have accumulated in the Cross Valley Pond are to be physically relocated by truck and shovel to the same cell constructed for the containment of the Faro Mill treatment sludges.
- Treatment sludges from the Vangorda-Grum water treatment plant are periodically removed from the settling pond to purpose built cells contained within the Grum Overburden dump.

These short-term strategies are adequate for the interim period, though they will clearly not suffice for long-term sludge disposal. The following options have been proposed for long-term management of water treatment sludges:

- Disposal on the Rose Creek tailings impoundment;
- Disposal on the Main Waste Rock dump and/or other waste rock dumps;
- Disposal in the Faro Pit at the Faro site and/or in the Vangorda Pit at the Vangorda-Grum site;
- Disposal in a purpose-built sludge management area; and
- Recycling

These options are addressed in the sections below.

4.1 Rose Creek Tailings Impoundment

In active operations, tailings ponds are commonly used for sludge management. During operations, sludges are typically slurried with the tailings or pumped directly to the Tailings impoundment. In post-operation conditions, however, it would only be possible to dispose of the sludges on top of the tailings. Sludge disposal on the Rose Creek tailings would require that the tailings impoundment is stable. In order to achieve the necessary stability, upgrades of the Intermediate Dam, Second Dam and the Rose Creek Diversion would, as a minimum, be required.

As noted in Section 2, while the sludges are expected to remain stable under ambient conditions, it is a requirement that the sludges not contact acid generating materials as, over a prolonged time, the buffering capacity of the sludges will be depleted. Alternatively, disposal of the sludge on the tailings is expected to act as a cover which will limit future oxidation. Typically, treatment sludge tend to desiccate and crack in the near surface as moisture evaporates, which may lead to the formation of selective flow paths. However, deposition of sequential layers of sludges tends to fill these cracks so that the effects of cracking would be nullified. Upon decommissioning of a sludge cell, a final soil cover would be placed to retain the integrity of the cover.

As the sludge is first deposited, the rate of exfiltration is expected to be elevated. As subsequent layers of sludge are deposited, the exfiltration rate will slow to very low rates. There is therefore a potential that the rate of displacement of the remaining soluble metals in the tailings porewater to be accelerated during initial sludge deposition, which may impact on water treatment requirements in the short term. However, accelerated removal of the contained acidity will shorten the time to reaching stable conditions in the tailings deposit. As well, porewater released from the sludge will be low in dissolved metals and contain elevated alkalinity. The alkalinity will neutralize some of the acidity contained in tailings. Therefore, while there may be some short-term effects, it is anticipated that in the long term, sludge disposal on the tailings will have a positive effect. This may be verified through monitoring of the sludge that will be deposited in the cell constructed on the Original Impoundment.

The Original Impoundment has a surface area of about 38 ha, the Second Impoundment has an area of about 57 ha, and, the Intermediate Dam tailings area is approximately 94 ha, for a combined surface area of about 190 ha. Based on previous estimates of sludge production, in the event that no source controls are implemented, it is apparent that in order to store in excess of 100 years of sludge production, the sludge would build up to 0.5 to 1 m thick layer across the entire area. This would require that the embankments be raised. At lower sludge production rates, i.e. where source control measures are implemented, smaller containment cells would be established on the tailings surface.

Disadvantages associated with sludge disposal on the tailings include the potential for dust release as the sludge dries and the delay in final reclamation of the tailings surface.

If stabilization measures are implemented, the tailings impoundment appears to be acceptable for long-term sludge disposal at closure (provided chemical interaction between the tailings and the sludge is not significant).

4.2 Waste Rock Dumps

Waste rock stockpiles have been used for sludge disposal at other sites. Concepts employed to date include:

- Co-disposal with waste rock during production/construction;
- Injection into the waste rock dump; and
- Development of sludge disposal cells on top of the flat surfaces of the waste rock dumps.

Co-disposal is most applicable during mine operation, when sludge can be spread and buried within the various dump lifts. Injection is similar in concept but is equally applicable after closure. The potential advantages of co-disposal and injection include the introduction of alkalinity into the waste rock and the increase in moisture content, which may reduce oxygen entry into the pile. Disadvantages include the need to prevent the slurry flowing out the bottom of the pile, remobilization of metals when the slurry contacts acidic rock, and concerns related to the physical stability of the waste rock dumps as a result of the water associated with the sludge.

Sludge disposal in cells on top of a waste rock dump would act as an oxygen barrier and effectively seal the dump surface to oxygen entry. Construction of the cells is cost effective when the cells replace or supplement alternative cover systems such as soil covers or geo-synthetic liners. At closure, the waste rock surfaces at the Faro will occupy an area of more than 300 ha, much of which could be flattened for cell construction. At Vangorda-Grum the Grum Dump covers an area in excess 200 ha that could be flattened for cell construction. Disadvantages of this method are the potential for dust release as the sludge dries and the delay in final reclamation of the waste rock dump surface.

4.3 Pit Lakes

Sludge disposal into pit lakes is a common practice at other sites. Since most deep pits are meromictic (do not mix because of thermal and chemical density gradients), sludges are typically pumped into the bottom of the pit. Therefore, the sludge is effectively isolated from the environment.

An option that is being considered for the Faro Pit Lake is to operate it as a ‘clean’ flow-through system. Under those circumstances, the Faro Pit could be used only if it can be shown that it will become meromictic, and it will remain that way indefinitely. Backfilling of the tailings to the Faro Pit Lake is also being considered. Under those conditions a relatively shallow pit lake will be established that is not likely to sustain meromictic conditions. It may be possible to inject the water sludge into the tailings, but that will lead to porewater and suspended matter displacement into the lake which, depending on the operating strategy for the lake, may not be desirable.

In the case of the Grum Pit Lake, sludge disposal would likely negate the establishment of a ‘clean flow-through’ system. Therefore, sludge disposal in this pit would not be a desirable proposition.

In the case of the Vangorda Pit, the lake would be used as a water storage facility if not backfilled. However, loadings and water quality collected from toe seepage could lead to the acidification of the pit lake. This would consume the buffering capacity of the sludge and result in remobilization of the metals which would overload the water treatment system. In the event that the pit is backfilled with limed waste rock, injection of the sludge into the backfill may be considered. However, the backfill will likely be placed in thin layers and compacted during backfilling which would reduce the available porespace in the backfill and limit the practicality of this option.

Previous testing of the Vangorda-Grum water treatment sludge properties (SRK, 2003) indicated that the zinc concentrations in the porewater of the sludge increased under saturated conditions. This would lead to zinc release to lake water column. The testing further indicated that the buffering capacity of the sludge will be depleted at elevated water to solids contact ratios such as may be encountered for in-lake disposal. Another disadvantage to in-lake disposal is that carbon dioxide is excluded form the sludge which will prevent the formation of more stable zinc carbonate minerals, as discussed in Section 2.3.

Sludge disposal in the pit lakes is, therefore, not desirable.

4.4 Purpose-Built Sludge Management Area

Purpose-built sludge disposal areas are similar to tailings basins. They may be natural basins or purpose-built above ground sludge cells. The primary drawback to these facilities is the need for more land area for the disposal facility. For the Anvil Range site, where waste rock dumps, and possibly the tailings area, are available for disposal, there would be no advantage to the development of an additional area for sludge disposal.

4.5 Recycling for Metals Recovery

Sludges from mine effluent treatment have been sent to smelters for metals recovery, and the economics are, at best, marginal if processed with a concentrate. Generally the economics of recycling sludge are not favourable, due to its high moisture content, impurities and shipping costs. Therefore, recycling does not appear to be a practicable method for long-term sludge management.

5 Sludge Disposal Costs

5.1 Faro Site

In the following sections, the factors that may influence the sludge management costs, and hence sludge disposal strategies, are briefly examined and disposal costs are estimated.

5.1.1 Water Treatment Plant and Sludge Disposal Locations

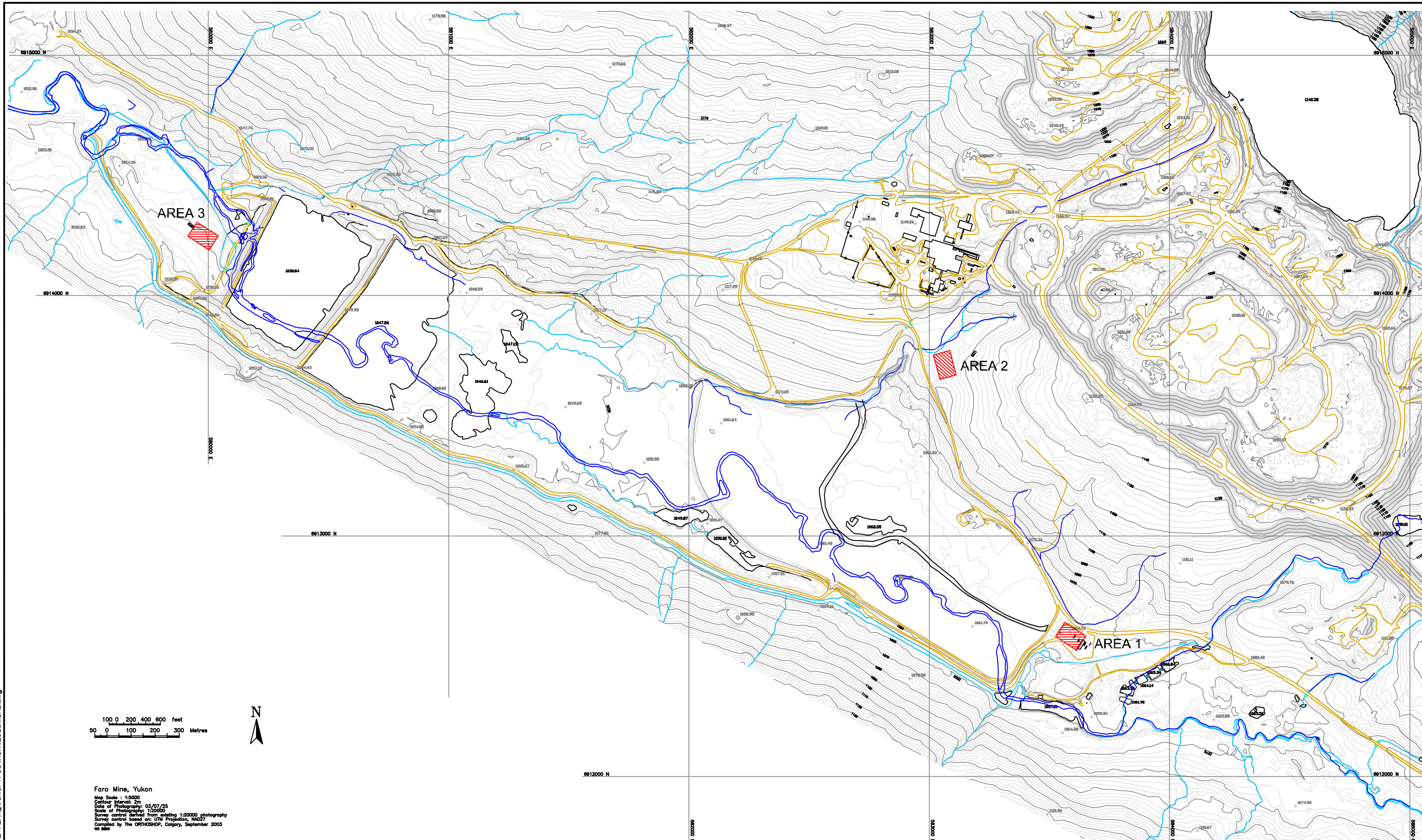
Ideally, the water treatment plant would be located in close proximity to the sludge disposal location. However, because the volume of sludge that will need to be handled is much smaller than the volume of water that is treated, the location of the water treatment plant in almost all cases will be determined by the pumping requirements for the collection system. For example, for the estimated future worst case conditions for the Faro waste rock dumps, the volume of sludge produced will reach a maximum of about 7 percent (by volume) of the volume of water treated.

Overall operating costs will be minimised by locating the treatment system downstream of as many sources as possible, and thereby minimizing the water pumping requirements. Potentially suitable locations are shown on Figure 5.1. Three example plant site areas are identified as follows:

- Area 1, located on a level area upstream of the tailings facility,
- Area 2, located near X23 on a knoll that can be suitably levelled; and,
- Area 3, located downstream of the Cross Valley Dam.

Each of the areas is more appropriate under specific closure scenarios. More importantly for this report, each would lead to different choices for sludge disposal sites. For example:

- Should the tailings remain in place, Area 3 would be a good location for the water treatment plant, and the Intermediate and Secondary Tailings basins would be good locations for sludge disposal;
- Should partial relocation of the tailings occur (i.e. Intermediate Tailings), then Area 1 would be a good location for the water treatment plant, and the Original and Secondary Tailings basins would be good locations for sludge disposal.
- Should the tailings be relocated altogether to the Faro Pit, then Area 2 would be a good location for the water treatment plant, and the top of the waste rock dumps would be a good sludge disposal area.



SRK Consulting
Engineers and Scientists

Deloitte & Touche

FARO MINE SITE

WATER TREATMENT LOCATION AREAS

PROJECT NO.	DATE	APPROVED	FIGURE
1CD003.55	May 2005		5.1

File Ref: Fig5_1FARO SITE PLAN_WaterTreatmentLocations.dwg

5.1.2 Sludge Transfer

The pumping costs to transfer sludge from the water treatment plant location to the sludge densification cells will vary according to the distance and head (elevation difference) over which the sludge has to be transferred. Approximate pumping costs have been estimated, assuming a power cost of about \$0.13/kWh, a pump efficiency of 75 % and a motor efficiency of 85 %. The estimated unit transfer costs are summarised in Table 5.1.

Table 5.1 Estimated Unit Sludge Transfer Costs

Transfer		Approx. Distance	Elevation Difference	Unit Cost
From	To	(km)	(m)	(\$ / m^3)
Area 3	Tailings	2.5	30	\$0.04
Area 1	Waste Rock	1.2	166	\$0.21
Area 2	Waste Rock	1.0	125	\$0.16
Area 3	Waste Rock	4.0	210	\$0.36

5.1.3 Sludge Concentration and Disposal

As discussed in Section 3, freeze densification of the sludges could result in a three-fold reduction of the volume that will need to be stored. Freeze densification would be achieved in two cells that would be operated sequentially; one cell would receive discharge while the other undergoes densification. The densified sludge would be collected and deposited in a permanent disposal area each year.

Assuming sludge is deposited to a maximum depth of 0.6 m in the cell for dewatering, the cell areas that may be required for the minimum and maximum sludge production rates have been estimated from the Faro base case water treatment requirements. The capital costs were derived assuming a bermed containment area with a freeboard of about 1 m would be constructed and a sand filter base of about 0.3 m thick with an underdrain would be placed. The sludge management costs were estimated on the assumption that the densified sludge would be relocated using a truck and shovel operation. The unit operating cost is estimated to be about \$3.70 per m^3 of sludge produced at a density of 50 percent solids. Once a clearer understanding of probable long-term sludge production rates have been established, a cost-benefit analysis should be completed to determine if this cost is reasonable. For the current evaluation, it is assumed that sludge densification will be advantageous.

Table 5.2: Summary of Estimated Costs for Freeze Densification of Sludges at the Faro Site

Faro Site Case	Production at 20 % solids	Area per Cell	Estimated Costs	
	(m^3)	(ha)	Construction (2 cells)	Operating
Current Average	5,691	0.95	\$ 422,000	\$ 7,000
Future Worst	167,088	28	\$ 4,558,000	\$ 195,000

5.1.4 Sludge Disposal Cells

The final disposal of the sludge can be managed in smaller cells that are constructed to contain a limited volume of sludge, or, in much larger cells that can contain many years of sludge production. The benefits of many smaller cells may include more effective management of the sludge, progressive decommissioning and rehabilitation of cells as they are filled, and, minimization of the potential for dusting as sludge dries out. Disadvantages that may be associated with many smaller cells include increased construction costs and less effective utilization of the area (greater proportion covered by berms). Clearly, a cost-benefit analysis will be required for establishing final design and disposal strategies.

Approximate costs for disposing 50 years of sludge production (for base case production rates) in a single cell have been estimated using the following assumptions:

- Final sludge densities of 50 % (w/w) solids will be achieved;
- The disposal containment area would be located on a relatively flat area;
- Waste rock or till would be used to construct the containment berms;
- Containment berms would be constructed to a 2:1 H:V slope for both upstream and downstream slopes;
- Disposal will occur to a maximum depth of 3 m;
- The berm crest would be 4 m wide;
- A freeboard of 1 m would apply; and,
- Berm construction costs will be about $8.00 per m^3 fill placed.

The estimated costs are summarised in Table 5.3.

Table 5.3 Summary of Estimated Construction Costs to Store Faro Site Sludge Production over a 50-Year Period

Case	Sludge Vol. To Year 50 (m^3 @ 50%)	Cell Area (ha)	Approx. Centre line		Embankment Fill Required (m^3)	Construction Cost
			Length (m)	Width (m)		
Current Average	87,000	2.9	178	178	34,232	$ 273,859
Future Worst	531,000	17.7	429	429	82,313	$ 658,504

5.2 Vangorda-Grum Site

5.2.1 Treatment Plant Location

The existing water treatment plant is located above the Grum Pit, at an elevation of about 1,310 m asl. This is approximately the same elevation as the top of the Grum Waste Rock dumps, which, except for the distance, would suite sludge disposal. The elevation difference between the water treatment plant and the toe of the Grum Dump (at 1,115 m asl) is about 195 m. The toe drain of the Vangorda Dump is at an elevation of about 1,118 m, i.e. the elevation difference to the current treatment system is about the same as that of the Grum Dump toe. Collection distances are about 1.8 and 2.2 km, respectively, from the Grum Dump and the Vangorda Dump.

Ultimately, the optimum location will be decided as part of the closure strategy for the site. For example, in the event that the Vangorda pit is backfilled, the need to locate the treatment plant nearer the Vangorda site diminishes. For now, it is assumed that the existing water treatment plant will be retained, and that flow attenuation will be achieved in retention ponds located elsewhere.

5.2.2 Sludge Transfer

Sludge transfer to the top of the Grum dump can be routed one of two ways. First, the transfer pipe could follow the road between the overburden dump and the Grum Pit directly to the Grum Dump. However, by this route the pipe would traverse a significant change in elevation which may affect effective operational performance. The second route would pass around the pit to the north, follow the ore transfer pad and then cross the haul road to the top of the Grum Dump. Although the first route is marginally shorter (by about 0.3 km), the second, which would maintain a steady elevation, would be the preferred route.

By either route, the approximate cost of sludge transfer is estimated (as before) to be in the range of about $0.08 per m^3 of sludge transferred.

5.2.3 Sludge Densification

Estimated costs for a freeze densification system are shown in Table 5.5. The assumptions are the same as in Section 5.1.3.

Table 5.4: Summary of Estimated Cell Size and Costs for Freeze Densification of Treatment Sludges

Vangorda Grum Location	Production at 20 % solids (m^3)	Area per Cell (ha)	Estimated Costs	
			Construction	Operating
Current Average	2,592	0.43	$ 264,000	$ 3,000
Future Worst	31,913	5.3	$ 1,307,000	$ 37,000

5.2.4 Sludge Disposal

The estimated costs for the final sludge disposal site are shown in Table 5.5. The assumptions behind these estimates are the same as in Section 5.1.4.

Table 5.5 Summary of Estimated Construction Costs to Store Vangorda-Grum Site Sludge Production over a 50-Year Period

Case	Sludge Vol. To Year 50 (m^3 @ 50%)	Cell Area (ha)	Approx. Centre line		Embankment Fill Required (m^3)	Construction Cost
			Length (m)	Width (m)		
Current Average	39,547	1.3	123	123	23580	$ 188,643
Future Worst	146,986	4.9	229	229	44035	$ 352,280

5.3 Comparison to Overall Water Treatment Costs

5.3.1 Faro Site

Sludge disposal costs were derived to be directly comparable to the base case (no source control) water treatment requirements reported in SRK 2005. The results are presented in Table 5.6. Only sludge accumulation for the first 50 years is examined as shown in the table. The current average case assumes that there is no appreciable change in sludge production or treatment within the first 50 years. The future intermediate case assumes that sludge production proceeds at current average conditions and then increases as a step function to future intermediate conditions at year 20. The ‘future worst’ case assumes that sludge production commences at the future intermediate production rate and then increases to the future worst rate by year 20. The latter case included only to provide a cost comparison at very high sludge production rates.

The last part of the table provides unit operating cost rate comparisons normalized to the volume of influent water treated. As shown, even at very high sludge production rates, the estimated sludge disposal and handling costs are small in comparison the water treatment costs. It is however important to note that the construction costs, in particular for the freeze densification cells, become significant at the very high sludge production rates.

The relationship between operating costs for sludge disposal and treatment is similar for source control scenarios. Capital costs decrease however as the sludge accumulation rate decreases and therefore the long-term storage requirements.

Table 5.6 Summary of Estimated Treatment and Sludge Disposal Costs at the Faro Site (without source control) over a 50 Year Period

Description	Units	Current Average	Future Intermediate	Future Worst
Annual Treatment	m^3	4,513,000	4,750,000	4,750,000
Quicklime	tonne/year	1,104	6,507	14,482
Sludge Production Initial	m^3/year	5,680	49,244	149,110
Final Density	m^3/year	1,769	15,338	46,444
Treatment Costs				
Capital Cost		$6,359,000	$8,456,000	$10,129,000
Annual Operating Cost				
t o Year 20		$1,266,000	$1,266,000	$3,935,000
to Year 50		$1,266,000	$3,935,000	$7,655,000
Cumulative Sludge (Year 50)				
Initial Density (20 %)	m^3	285,000	1,590,920	5,458,180
Final Density (50 %)	m^3	88,000	495,520	1,700,080
Sludge Disposal Costs				
Construction				
Freeze Densification Cells		$221,000	$1,479,000	$4,200,000
Disposal Cells		$275,000	$637,000	$1,169,000
Total		**$496,000**	**$2,116,000**	**$5,369,000**
Annual Operating Cost				
Area 2 to Waste Rock		$1,000	$8,000	$24,000
Dense Sludge to Final		$7,000	$57,000	$173,000
Total		**$8,000**	**$65,000**	**$197,000**
Unit Operating Costs (Based on influent volume treated)				
Treatment				
to Year 20	$/m^3$	$0.28	$0.27	$0.83
to Year 50	$/m^3$	$0.28	$0.83	$1.61
Sludge Densification / Disposal				
to Year 20	$/m^3$	$0.002	$0.002	$0.014
to Year 50	$/m^3$	$0.002	$0.014	$0.041

5.3.2 Vangorda-Grum Site

As for the Faro Site, sludge disposal costs were derived to be directly comparable to the base case (no source control) water treatment requirements for the Vangorda-Grum site as presented in SRK 2005. The results are presented in Table 5.7. As before, sludge accumulation for the first 50 years is examined. The current average case assumes that there is no appreciable change in sludge production or treatment within the first 50 years. The future intermediate case assumes that sludge production proceeds at current average conditions for 20 years, then increases as a step function to future intermediate conditions for the next 30 years. The ‘future worst’ case assumes that sludge production commences at the current average rates, increases to the future intermediate production rate at year 21, and then increases to the future worst rate by year 41.

Unit operating cost rate comparisons normalized to the volume of influent water treated are presented in the last part of Table 5.7. As before, the estimated sludge disposal and handling costs are small in comparison the water treatment costs. The construction costs, in particular for the freeze densification cells, become significant at the very high sludge production rates.

Table 5.7 Summary of Estimated Treatment and Sludge Disposal Costs at the Faro Site (without source control) over a 50 Year Period

Description	Units	Current Average	Current Maximum	Future Worst
Annual Treatment	m^3	750,000	750,000	750,000
Hydrated Lime	tonne/year	2	85	2,468
Sludge Production Initial	m^3/year	2,043	2,912	31,440
Final Density	m^3/year	636	907	9,793
Water Treatment Costs				
Capital Cost		$2,056,000	$2,156,000	$2,905,000
Operating Cost				
To Year 20		$359,000	$359,000	$359,000
Year 21 to 40		$359,000	$404,000	$404,000
Year 41 and Beyond		$359,000	$404,000	$1,503,000
Cumulative Sludge (Year 50)				
Initial Density (20 %)		102,150	128,220	413,500
Final Density (50 %)		31,800	39,930	128,790
Sludge Disposal				
Construction				
Freeze Densification Cells		$98,000	$129,000	$980,000
Disposal Cells		$170,000	$189,000	$331,000
Total		**$268,000**	**$318,000**	**$1,311,000**
Operating				
Sludge Transfer				
To Waste Rock		$1,000	$1,100	$5,000
Sludge Densification to Final		$2,000	$3,000	$37,000
Total		**$3,000**	**$4,100**	**$42,000**
Unit Operating Costs (Based on influent volume treated)				
Water Treatment				
To Year 20	$/m^3$	$0.48	$0.48	$0.48
Year 21 to 40	$/m^3$	$0.48	$0.54	$0.54
Year 41 and Beyond	$/m^3$	$0.48	$0.54	$2.00
Sludge Densification and Disposal				
To Year 20	$/m^3$	$0.004	$0.004	$0.004
Year 21 to 40	$/m^3$	$0.004	$0.005	$0.005
Year 41 and Beyond	$/m^3$	$0.004	$0.005	$0.056

6 Conclusions and recommendations

6.1 Conclusions

Estimates of sludge production rates for current and future conditions have been prepared. These have been shown to be significant for the cases where there is no source control applied during the remediation.

The properties of sludge produced recently from site waters suggest that sludge stability will be maintained when disposed under ambient conditions. Potential carbonate mineralization due to carbon dioxide uptake from the atmosphere may in fact increase the stability of the zinc contained in the sludge.

Dewatering options to minimize sludge volumes have been reviewed. The most probable technique for use at the Anvil Range Site, should this be required in the future, would be the construction of sludge dewatering beds where freezing would be used to accelerate sludge dewatering. Sludge densification may be beneficial where there are restrictions on available storage area, or where there is a definite benefit to dispose sludge in smaller containment cells. A cost-benefit analysis will be required to determine the appropriate strategy.

Practical locations for sludge storage in the long term include the tailings and waste rock surfaces, and the bottom of pit lakes if they can be shown to be meromictic.

Cost estimates have been derived for sludge handling and disposal in cells constructed on the tailings or waste rock surfaces. These costs can be used to establish overall water treatment costs for the site based on potential future sludge production rates.

Normalized to the influent water, operating costs for sludge handling and disposal are small in comparison to water treatment costs. However, at very high sludge production rates (i.e. no source control) the capital costs, in particular for freeze densification cell construction, may become significant in comparison to water treatment plant capital costs.

6.2 Recommendations

Some uncertainty remains with respect to the benefits for freeze densification of the sludges. It is recommended that freezing trials be undertaken to verify the density that may be achieved by this method, and, to establish practical constraints that may apply to the type of sludge and the site conditions. Once the closure strategies for the site have been defined, these findings can be used to establish a cost-benefit analysis for the inclusion, or not, of sludge densification.

Other uncertainties remain with respect to the management of the disposal cells. In particular, the potential for dusting during dry periods is unknown. There may also be other management requirements such as decanting of excess water on a regular basis. It is recommended that, in order to establish these requirements, rigorous monitoring of the cell that has been established on the Original Impoundment be undertaken during active disposal in 2005. Furthermore, the properties of the sludge contained in the existing cells on the Grum Overburden dump should be determined. This should include porewater quality, sludge density and monitoring of dusting during dry periods.

This report, **"Sludge Management Requirements for the Anvil Range Site"**, has been prepared by SRK Consulting (Canada) Inc.

John Chapman, P.Eng.

Daryl Hockley, P.Eng.

7 References

MEND, 1997. *Characterization and Stability of Acid Mine Drainage Treatment Sludges*, MEND Project 3.42.2a, May 1997.

SENES, 1994. *Acid Mine Drainage - Status of Chemical Treatment and Sludge Management Practices*, MEND Project 3.32.1, June 1994.

SRK, 2003. *Geochemical Assessment Of Vangorda/Grum Water Treatment Sludge.* SRK Project Number 1CG008.00, Report Prepared for Gartner Lee Ltd., October 2003

SRK, 2004a. *Water Quality Estimates for Anvil Range Waste Rock.* SRK Project Number 1CD003.50, Prepared for Deloitte & Touche Inc., November 2004

SRK, 2004b. *Anvil Range Pit Lakes Assessment of Post Closure Condition.* SRK Project Number 1CD003.38, Prepared for Deloitte & Touche Inc., October 2004

SRK, 2005a. *Water Treatment Requirements for the Anvil Range Site.* SRK Report Number 1CD003.054, Prepared for Deloitte & Touche Inc., May 2005

SRK2005b. Technical Memorandum to Christoph Wels (RGC), dated June 14, 2005. Contained in RGC Report *Water and Load Balance Study for Rose Creek Tailings Storage Facility* Appendix B, Report No. 118001/1, 2005