Water Treatment Requirements for the Anvil Range Site

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Report Prepared for

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Interim Receiver of Anvil Range Mining Corporation

Report Prepared by

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1 Introduction

1.1 Terms of Reference

In the long term, water treatment is expected to be an integral part of the Anvil Range site closure plan. As part of the 2004/05 planning meetings, two projects to address water treatment and related components were identified as follows:

14. Develop Faro / Grum / Vangorda Decommissioning Methods

e) Test Water Treatment Changes

Carry out testing of any new water treatment and sludge management testing systems required for closure and include any effects of any changes to Faro and Vangorda water treatment and sludge handling systems. Prepare preliminary engineering designs and cost estimates.

16. Develop Tailings Decommissioning Methods

h) Test Surface and Ground Water Treatment Methods

Carry out testing of any new water treatment and sludge handling system required for closure including, if needed, a treatment system for contaminated groundwater and surface water collected during the project described in 16 f) and g). Prepare preliminary engineering designs and cost estimates.

The two projects represent parallel assessments of water treatment requirements with the only difference in the volumes and water quality that will be treated. The programs were therefore carried out together as a single project. This report presents the results, including results from the laboratory programs and development of a model for estimating water treatment costs. Using the cost model, example estimates for specific areas are presented.

2 Treatment Method Evaluation

An evaluation of treatment technology or methods amenable to current and estimated future water quality at the Anvil Range Site was completed by Senes Consultants. For the purpose of the evaluation, the water quality that was treated in the Faro, Vangorda/Grum and Down Valley treatment systems during 2003 were assumed to be representative of the water quality that may be treated at the site in the near to intermediate term. The evaluation is provided in Appendix A, and the results are summarised below.

2.1 Treatment Methods

The water treatment processes considered in the methods evaluation can be subdivided into six broad categories. The categories and example processes are summarized in Table 2.1

As shown in the table, while a number of alkali's are available for neutralization and metal precipitation, lime (CaO) or hydrated lime ($Ca(OH)_2$) are the preferred methods from a reagent cost perspective and given there are no offsetting benefits for using any of the other alkalis. Typically conventional lime treatment (such as already in use at the Grum /Vangorda treatment system) or high density sludge (HDS) treatment systems are utilized. The latter option produces a more dense – lower volume of sludge than the former process.

Sulphide precipitation and co-precipitation processes are designed to target very specific elements. Therefore, neither process is considered stand alone and would require additional treatment to achieve acceptable discharge concentrations. Similar to sulphide precipitation and co-precipitation, chemical reduction removes only specific contaminants and also is not a standalone process.

Membrane processes are distinguished on the size of molecules rejected by the membrane. Reverse osmosis (RO) removes molecules or solutes down to mono-valent salts whereas nano-filtration removes solutes down to divalent salts. Consequently, only reverse osmosis would be considered applicable at the Anvil Range Site. However, RO is rarely used in a mining environment due to the fouling nature of the water (fine particles and secondary mineralization) that requires treatment. Treatment costs using RO for water with a quality similar to that of the Anvil Range Site generally are about 2 to 4 times higher than lime precipitation. Reverse osmosis also produces a brine that would require further treatment which adds to the treatment costs.

Ion exchange can, in theory, be applied to remove any dissolved solids related to mining. While natural materials such as zeolites exhibit ion exchange properties, many synthetic ion exchange resins have been developed that tend to be more efficient than the natural substrates, and, are more selective. Resins have been developed for removal of heavy metals, calcium, magnesium, radionuclides, sulphate and ammonia. However, in general ion exchange is not economically attractive for treating large volumes of water and treatment systems are complex, requiring skilled operators. Similar to membrane processes, ion exchange also generates a concentrated brine that requires further treatment.

Solar evaporation requires large shallow ponds to maximize evaporative losses and is most effective where evaporation greatly exceeds precipitation. The climate at the site does not support such systems. Mechanical or thermal evaporation on the other hand relies on various heat exchange equipment to achieve the heat transfer necessary for evaporation and is usually only applied to small but concentrated streams. Both methods produce soluble salts that are difficult to dispose off.

Biological processes that were considered herein were limited to sulphate reduction in bioreactors and constructed wetlands. Biological sulphate reduction produces hydrogen sulphide in solution which then reacts with dissolved metals to form a corresponding insoluble metal sulphide, similar to chemical sulphide precipitation. Like sulphide precipitation, low metal concentrations result and it is possible to produce saleable products. However, biological sulphate reduction demands large quantities of a suitable organic substrate, and is ineffective in cold temperatures due to reduced biological activity. Such systems are also slow to start-up and prone to upsets due to changes in inflow conditions.

Table 2.1 Summary of Water Treatment Methods

Category	Objective	Method	Comments
Chemical Treatment	Remove contaminants from solution as metal precipitates	Alkali (lime, quicklime, soda ash, limestone, caustic)	Lime/quicklime most economical
		Sulphide Precipitation (NaHS; Na_2S)	Can produce saleable product; not a standalone process – only removes metals that form insoluble sulphides
		Co-precipitation ($FeSO_4$)	Suitable for very specific elements (As, Mo, Cd); not a standalone process
		Chemical reduction	Suitable for very specific elements (Se; Cr(VI)); not a standalone process
Membrane Processes	Concentrate metals by physical separation into a reduced volume brine	Reverse Osmosis (removes down to mono –valent salts Nano-filtration (removes down to divalent salts) –	Only Reverse Osmosis would be considered Susceptible to fouling; requires pre-treatment; produces high concentration brine; costly process;
Ion Exchange	Reversible contaminant transfer to a solid phase and removed to produce a concentrated brine	Ion exchange resins	Produces brine; high capital and operating costs; not economic for treating large volumes
		Zeolites	Less efficient; (as above for resins)
Evaporation / Distillation	Removal of pure solvent (water)	Solar	Evaporation rates low in a northern climate
		Mechanical	Very costly
Biological	Re-mineralize metals as a sulphide mineral	Bio-reactor Process	H_2S emissions; requires large quantities of carbon source; susceptible to fluctuations in flow and feed concentrations; winter operation would require heating; uneconomic
		Constructed Wetland	Not suitable due to climate, flows and requirement for large land areas
Other Physical Processes	Physical separation of solvent	Freeze-thaw	Requires large areas for freezing; brine requires further treatment; 'clean' water will require polishing

Due to the cold climate, high flows requiring large land areas, and the range of flow variability, wetlands are not likely to perform consistently to meet water quality objectives at the Anvil Range Site.

Freeze-thaw processes depend on the phenomenon that when water freezes, the ice that is formed low in salt content and the salts are excluded to form a brine. However, the process has not proven to be practical, particularly for very large scale applications. Similar to wetlands, large areas would be required to contain the contaminated solutions in shallow ponds for freezing. A treatment plant to manage the resulting brine would also be required. Since not all salts are excluded from the ice that is formed it is likely that additional treatment will be required to ‘polish’ the effluent.

2.2 Conclusion

A range of treatment alternatives that could be considered at the Anvil Range site were identified. Chemical treatment, and in particular alkali amendment using either lime or hydrated lime, is the most appropriate treatment technology for the site. Lime treatment processes are simple, can be automated readily and have commonly and successfully been implemented at remote sites.

3 Bench Scale Treatability Testing

3.1 Objectives and Scope

The primary objectives of the testing program were to:

- Evaluate effects of elevated contaminant concentrations on lime treatability of site water;
- Estimate lime demand for waters containing various solute concentrations; and,
- Correlate sludge production rates to influent water quality.

To meet these objectives, a series of water samples were collected at various locations on the Anvil Range site. The sample locations were selected to represent the range of water quality that may need to be treated at present and in the future. These water samples were submitted for laboratory scale treatability tests which simulated HDS treatment.

The sampling and testing programs and the results from the laboratory testing are presented and discussed in the following sections.

3.2 Sampling

A series of four samples were obtained by SRK on June 24, 2004, as follows:

- FP01 – Seepage from Faro Creek and Faro Valley Dump flowing into the Faro Pit (coincides approximately with SRK seepage monitoring station A30)
- X23 – Sampled at weir in Faro Creek below waste rock dumps
- FRO1 – Seepage from Faro Main Dump to inner haul road (coincides approximately with SRK seepage monitoring station FD13)
- VG01 – Seepage from Vangorda in-pit oxide fines sampled at hairpin bend in Vangorda Pit haul road (coincides approximately with SRK seepage monitoring station VP04)

Approximately 20 litres of water were obtained at each sample location, sealed in PVC containers and shipped to CEMI's laboratory in Vancouver for analysis and testing.

3.3 Testing

All samples were submitted for detailed analysis before the treatability testing was initiated. Bench scale laboratory testing was then undertaken to assess the treatability of the water samples for HDS treatment. The testing for each water sample was carried out as follows.

First, a 100 g $Ca(OH)_2$ /L milk of lime solution was prepared for neutralization testing. A volume of 1 liter of the water sample to be tested was then placed in a 2 liter stirred reactor. The pH of the water was adjusted to 9.5 with the milk of lime, while recording the volume of lime solution added. Once a stable pH of 9.5 was achieved, the solids were allowed to settle, and the clear supernatant was decanted while retaining the solids in the reactor. An additional 1 liter of the untreated water was added to the retained sludges, and the neutralization process was repeated to an endpoint pH of 9.5. While retaining the sludges formed for each step, this process was repeated ten times. The sludges from the final step were allowed to settle, and were then recovered by filtration. The cumulative mass of sludge formed was dried and weighed to estimate the overall mass produced. Similarly, the cumulative volume of lime added at each step was summed to estimate the overall lime demand. The final decant solution from the 10th cycle was analyzed for metals by ICP-OES and compared to the initial water analysis to determine the treatment efficiency.

3.4 Results

3.4.1 Treatability

Selected parameters for the initial and treated water samples are summarized in Table 3.1. Complete results are provided in Appendix B. As shown in the table below, zinc concentrations in the four samples selected for testing ranged from 96 mg/L to 1,560 mg/L. The total acidity (by titration) ranged from 340 to 4,762 mg $CaCO_3$ eq/L and sulphate ranged from 887 to 6,705 mg/L. Therefore, as required, these samples represent a wide range of conditions. It is also important to note that the magnesium concentrations in the initial water samples also varied significantly.

Zinc in the treated water was removed to as low as 0.023 mg/L. The variability in the treated effluent concentrations are likely a results of the small scale testing. The results nonetheless show that zinc removal can be achieved consistently. It is also noted that where initially present at elevated concentrations, both sulphate and magnesium are removed from solution. While the sulphate removal occurs as a result of gypsum formation, it has no impact on the lime demand. However, magnesium removal has a direct bearing on lime consumption since the magnesium is removed as hydroxide precipitate and, consequently, its removal should be factored into estimating lime utilization as discussed in the next section.

Similar to zinc, other metals that were effectively removed from solution by lime treatment included aluminium, cadmium, copper, iron, lead, manganese and nickel.

Table 3.1 Summary of Initial and Treated Water Analyses

Parameter	Units	FPO1		X23		FRO1		VG01	
		Feed	Effluent	Feed	Effluent	Feed	Effluent	Feed	Effluent
pH		3.02	9.51	5.46	9.49	2.99	9.50	3.19	9.52
Acidity*	(pH 4.5)	107	-	0.0	-	157.5	-	177.5	-
	(pH 8.3)	340	-	873	-	775	-	4762	-
Alkalinity*		0.0	18.8	5.0	21.8	0.0	17.8	0.0	11.8
Sulphate	mg/L	887	923	5985	3355	3532	2635	6705	1638
Metals									
Aluminum	mg/L	13.6	<0.20	<0.60	<0.20	7.29	<0.20	42.4	<0.20
Cadmium	mg/L	0.141	<0.010	0.194	<0.010	0.362	<0.010	3.04	<0.010
Calcium	mg/L	56.1	236	535	520	243	641	250	478
Cobalt	mg/L	0.298	<0.010	1.17	<0.010	0.810	<0.010	4.80	<0.010
Copper	mg/L	1.75	<0.010	0.213	<0.010	0.911	<0.010	18.5	<0.010
Iron	mg/L	11.5	<0.030	162	<0.030	27.6	<0.030	1460	<0.030
Lead	mg/L	0.303	<0.050	<0.15	<0.050	1.14	<0.050	3.11	<0.050
Magnesium	mg/L	97.1	66.7	922	469	459	247	270	15.8
Manganese	mg/L	7.65	0.085	85.5	0.013	36.0	0.0059	178	0.041
Nickel	mg/L	0.25	<0.050	1.52	<0.050	1.96	<0.050	2.31	<0.050
Silicon	mg/L	9.14	0.94	7.71	0.086	6.83	0.201	17.7	0.077
Strontium	mg/L	0.257	0.575	4.04	2.86	0.926	1.53	0.298	2.02
Zinc	mg/L	96.3	0.031	588	0.074	380	0.092	1560	0.023

* Alkalinity and acidity in units of mg $CaCO_3$ eq./L

3.4.2 Lime Consumption and Utilization

The lime consumed for each stage and the average for the combined ten cycles are summarised in Table 3.2. As shown in the table, the lime demand across all samples varied by a factor of ten, ranging from 0.61 kg $Ca(OH)_2/m^3$ to 6.2 kg $Ca(OH)_2/m^3$.

Table 3.2 Lime Consumption Results for Bench Scale HDS Simulations

Conditions	FPO1	X23	FRO01	VG01
Initial pH	3.09	5.85	3.09	3.25
Target pH	9.50	9.50	9.50	9.50
Stage	**Dosage ($kgCa(OH)_2/m^3$)**	**Dosage ($kgCa(OH)_2/m^3$)**	**Dosage ($kgCa(OH)_2/m^3$)**	**Dosage ($kgCa(OH)_2/m^3$)**
Cycle 1	0.63	2.06	1.08	6.15
Cycle 2	0.60	2.40	1.30	5.40
Cycle 3	0.63	2.83	1.48	6.31
Cycle 4	0.66	3.25	1.55	6.30
Cycle 5	0.63	3.28	1.53	6.86
Cycle 6	0.66	3.50	1.56	6.60
Cycle 7	0.67	3.50	1.65	6.50
Cycle 8	0.64	3.00	1.53	5.81
Cycle 9	0.53	2.15	1.43	6.00
Cycle 10	0.50	2.55	1.34	6.24
Average	**0.61**	**2.85**	**1.44**	**6.21**

The lime availability or utilization was estimated from the above results by two methods. First, the lime demand was calculated from the total acidity in the feed water obtained by titration (corrected for stoichiometry to units of lime equivalency), which was divided by the actual lime addition rate and multiplied by 100 to indicate the percent lime utilized. However, since the total acidity titration endpoint pH is only 8.3, it is unlikely that all of the zinc was precipitated from solution, nor would magnesium removal have occurred to the extent observed in the HDS simulation tests. Therefore, in the second method, the theoretical lime demand was calculated stoichiometrically from the change in pH and the actual metal removal, inclusive of magnesium, that was observed in the tests. The calculated theoretical lime demand was then divided by the lime consumption and multiplied by 100 to indicate the percent utilization.

The results are shown in Table 3.3. The difference between the two sets of estimates is a result of the acidity titration underestimating the actual lime demand and indicates, therefore, that the standard total acidity titration method is not a suitable indicator of total lime demand for the Anvil Range water types. The results furthermore indicate lime utilizations between 81 and 85 % for the more contaminated - high lime demand water samples. However, the lime utilization is somewhat lower for the less contaminated sample, which is consistent with the lime utilization factors observed for the water treatment systems on site.

Table 3.3 Estimated Lime Utilization

Method	Lime Utilization			
	FPO1	X23	FRO1	VG01
Acidity Titration	41%	23%	40%	57%
Theoretical (Inclusive of Mg removal)	51%	85%	85%	81%

3.4.3 Sludge Generation

The measured weight of sludge generated from each test is provided in Table 3.4. Sludge densities of 18.5 % solids and 24.1 % solids were achieved for samples X23 and VG01 respectively, indicating that high sludge densities can be achieved. However, due to the lower contaminant concentrations in these water samples, insufficient sludge build-up had occurred in the remaining two tests to establish high sludge densities. Nonetheless, given a sufficient number of cycles, it is anticipated that elevated sludge densities would also have been achieved for Samples FP01 and FR01 because the sludge composition from the four samples are not dissimilar. Sludge compositions were estimated based on the metal removals observed and are summarised in Table 3.5. The calculations assume that the metal precipitates that were formed are predominantly metal hydroxides.

The last row in the table represents the ratio of the calculated weight of the sludge to the measured dry weight of the sludge. All but FP01 show that the calculated (theoretical) weight of the sludge exceeds the measured dry weights. It is possible that either some of the metal hydroxides were converted to metal oxides, due to the heating of the samples during the drying process which would have resulted in a lower dry weight, or that not all of the sludge was captured during the tests.

Therefore, simple mass balance calculations were completed to estimate the net mass removed from solution during the tests. The results are shown in Table 3.6. The last row of the table expresses the mass removed from solution as a percentage of the measured dry weight of the sludge from each test. As shown, the actual mass removed from solution exceeds the dry weight of the samples, which suggests that not all of the sludge that was generated is accounted for in the measured dry weight. Furthermore, these ratios correspond reasonably to those given in the last row of Table 3.5. It is therefore concluded that it is reasonable to estimate sludge production from the mass of the gypsum and metal hydroxides produced.

Table 3.4 Measured Sludge Generation Rates and Properties

Sample	Sludge Weight (g)		Moisture Content	Solids Content	Sludge Production
	Wet	Dry	(%)	(%)	(g/L)
FP 01	70.7	6.0	91.5	8.5	**0.60**
X 23	315	58	81.5	18.5	**5.8**
FR 01	185	17	90.9	9.1	**1.7**
VG 01	556	134	75.9	24.1	**13**

Table 3.5 Summary of Estimated Sludge Composition

Precipitate	Calculated Composition			
	FPO1	X23	FRO1	VG01
$CaSO_4^*$	<0.1%	64%	76%	53%
$Al(OH)_3$	7%	0.0%	1%	1%
$Cu(OH)_2$	0.4%	0.0%	0.1%	0.2%
$Fe(OH)_3$	4%	5%	3%	21%
$Mg(OH)_2$	12%	19%	30%	5%
$Mn(OH)_2$	2%	2%	3%	2%
$Zn(OH)_2$	24%	15%	35%	18%
Unreacted Lime	49%	15%	15%	19%
Total**	**99%**	**121%**	**164%**	**119%**

Notes: * assumed to be anhydrous because sludge products were heated during drying process.
** Calculated mass as a percentage of measured dry weight.

Table 3.6 Comparison of Sludge Production Estimated from Mass Balance Calculations and Measured dry Weight

Method	Sludge Production (g/L)			
	FPO1	X23	FRO1	VG01
Mass Balance	0.56	6.80	2.62	14.59
Actual Dry Weight	0.60	5.82	1.67	13.42
Ratio	**94%**	**117%**	**157%**	**109%**

3.5 Conclusions

The bench scale tests confirmed that effective metal removals, in particular for zinc, can be achieved by conventional lime treatment for a wide range of water types from the Anvil Range Site. The also show that high density sludges can be generated in an HDS system configuration. The results further provide a basis for estimating lime demand for a known water quality and provide a basis for estimating lime utilization. Finally, the results provide a basis for estimating sludge production rates from solute concentrations.

4 HDS Treatment Calculations

4.1 Introduction

Preliminary HDS system simulations were carried out by CEMI as reported in SRK (2004). That preliminary model formed the basis for developing a more site specific model applicable to the range of water quality conditions likely to be encountered at the Anvil Range site. In addition, a cost model was developed based on the process flow diagram for an HDS treatment system and utilizing cost estimates obtained from suppliers, previously reported cost estimates and a cost model developed by Senes Consultants for the MEND program (MEND 1996, INAC, 2002).

The following sections briefly present and discuss the development of the HDS treatment process and cost model developed for the Anvil Range Site.

4.2 Process Simulation Calculations

4.2.1 Process Description

The process flowsheet that was adopted for the HDS treatment system is illustrated in Figure 4.1. As shown in the process diagram, the HDS treatment differs from conventional lime treatment systems in that sludge is continuously recycled to the neutralization reactor to promote precipitate growth and densification of the sludge. The process can be described as follows.

The feed water to the plant is collected in a surge pond and pumped to the primary neutralization reactor on a continuous basis. Lime slurry is prepared in a lime slaking plant using quicklime. (At higher lime consumption rates quicklime will be more cost effective and on-site lime slaking is therefore the only option considered.) The slaked lime is contained in a lime slurry storage tank which feeds a continuous lime loop to maintain flow in the lime slurry feed line. The lime dosed to the sludge recycle mixing tank is controlled by a pH controller that maintains the target pH in the primary neutralization reactor. The solids formed in the neutralization process settle out in the clarifier to produce a clear treated effluent. The sludge, or treatment solids, is recycled to the sludge lime mixed tank on a continuous basis. To total inventory of sludge is managed by periodically purging a fraction of the sludge generated to maintain a steady inventory. Settling of the precipitates in the thickener is enhanced through the addition of a flocculating agent. Flocculent, prepared in the flocculent mixing system and blended with recycled water, is dosed to the neutralized discharge which flows from the primary neutralization reactor to the clarifier by gravity.

A list showing the primary equipment including back-up equipment is provided in Table 4.1.

Primary design considerations for equipment sizing are also noted in Table 4.1. Additional assumptions include:

- All the iron in the influent is assumed to be present as ferrous iron for the purpose of calculating airflow requirements to oxidize the ferrous to ferric to facilitate iron removal;
- An overall aspect ratio of 1:1, after the inclusion of freeboard as appropriate, is assumed for determining dimensions of reactor vessels and storage tanks; and,
- A clarifier underflow density of 20 % will be achieved.

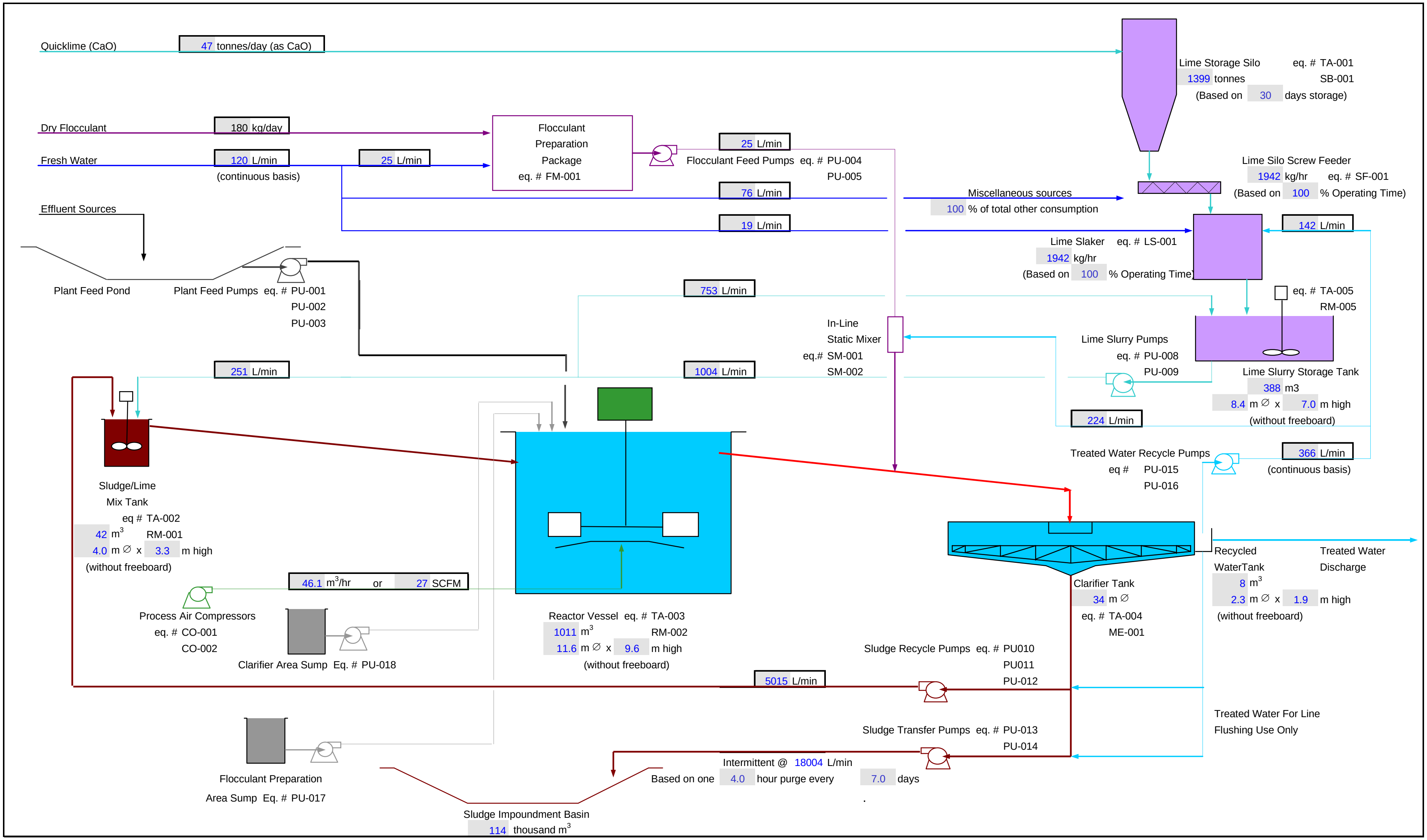

Figure 4.1 HDS Treatment System Process Flow Diagram

Table 4.1 Major Equipment List

Equipment Number	Description	Design Consideration
	Feed Pumps	
PU-001	Plant Feed Pump #1 V.S.D.	Feed flow rate
PU-002	Plant Feed Pump #2 V.S.D.	
PU-003	Plant Feed Pump #3 V.S.D.	
	Flocculent System	
FM-001	Flocculent Preparation System	Solids production rate
SM-001	Flocculent Static Mixer	
SM-002	Flocculent Static Mixer	
PU-004	Flocculent Feed Pump #1	
PU-005	Flocculent Feed Pump #2	
	Lime System	
TA-001	Lime Storage Silo	Feed flow rate and lime demand
SB-001	Lime Silo Baghouse	
SF-001	Lime Silo Screw Feeder	
LS-001	Lime Slaker	
TA-005	Lime Slurry Storage Tank	24 storage capacity
RM-005	Lime Slurry Storage Tank Agitator	
PU-008	Lime Slurry Pump #1	
PU-009	Lime Slurry Pump #2	
	Compressors	
CO-001	Process Air Compressor #1	Iron concentration in influent water
CO-002	Process Air Compressor #2	
CO-003	Instrumentation and Service Compressor	
	Clarifier	
TA-004	Clarifier Tank	Upflow ratio of 1 $(m^3/hr)/m^2$
ME-001	Clarifier Rake Mechanism	
PU010	Sludge Recycle Pump #1 V.S.D.	Solids production rate
PU011	Sludge Recycle Pump #2 V.S.D.	
PU-012	Sludge Recycle Pump #3 V.S.D.	
PU-013	Sludge Transfer Pump #1	Solids production rate
PU-014	Sludge Transfer Pump #2	
	Sump and Recycle Pumps	
PU-015	Treated Water Recycle Pump #1	Reagent make-up water demand
PU-016	Treated Water Recycle Pump #2	
PU-017	Flocculent Preparation Area Sump Pump	
PU-018	Clarifier Area Sump Pump	
	Reactor and Mix Tanks	
TA-006	Water Recycle Tank (no agitator)	30 second retention time
TA-002	Sludge/Lime Mix tank	8 minute retention time
RM-001	Sludge/Lime Mix Tank Agitator	
TA-003	Lime Reactor Tank	60 minute retention time
RM-002	Lime Reactor #2 Tank Agitator	

4.2.2 Mass Balance Calculations

Lime Demand

Lime demand is calculated from the calcium equivalent demand and from the hydroxide equivalent demand. The calcium equivalent lime demand was calculated as follows:

$$CELD = ([SO_4]_{initial} - [SO_4]_{Gypsum} - [SO_4]_{(Na+K)} - [SO_4]_{Mg}) * (56/96) / R$$

Where:

$CELD$ = Calcium Equivalent Lime Demand of the influent as mg CaO /L
$[SO_4]_{initial}$ = sulphate concentration in the feed solution (mg/L)
$[SO_4]_{gypsum}$ = sulphate in the treated effluent in equilibrium with gypsum (mg/L)
$[SO_4]_{(Na+K)}$ = sulphate concentration equivalent to sodium and potassium concentrations in the influent (mg/L)
$[SO_4]_{Mg}$ = sulphate concentration in equivalent to free magnesium concentration in equilibrium with magnesium hydroxide (mg/L)
(56/96) = stoichiometric conversion factor
R = availability of lime (assumed to be 85 %)

The hydroxide equivalent lime demand was calculated as follows:

$$HELD = \{\sum([Me] /MM* V) + [Mg(OH)_2] /MM + (10^{-pH})*1000\} *(56/2)/R$$

Where:

$HELD$ = Hydroxide Equivalent Lime Demand of the influent as mg CaO /L
$[Me]$ = metal concentration in the feed solution (summed for Al, Cu, Cd, Fe, Pb, Mn, Ni, and Zn) (mg/L)
MM = molecular weight of the metal in solution
V = valency of the metal in solution
$[Mg(OH)_2]$ = mass of magnesium that would be precipitated from solution as $Mg(OH)_2$ (mg/L)
1000 and (56/2) conversion factors
R = availability of lime (assumed to be 85 %)

A K_{sp} of 5.6×10^{-12} for $Mg(OH)_2$ was used for calculating the equilibrium magnesium concentration in the treated solution.

These two methods in general yielded very similar results and an average of the two values were used in the mass balance calculations.

Flocculent Demand

The flocculent addition rate is an input variable which was fixed between 50 and 100 mg flocculent per kilogram of solids entering the clarifier. The calculated rate was then verified against a typical operating dosage rate of between 1 and 10 mg flocculent per litre of influent.

Sludge Production

The sludge production is calculated assuming that the hydroxide precipitates shown in Table 4.2 are formed. The mass of precipitate formed is calculated stoichiometrically from the metal present in solution as follows:

$$MP)_{Me} = [Me] * MM_{PPT} / MM_{Me}$$

Where:

$MP)_{Me}$ = mass of metal precipitate formed (mg/L)
$[Me]$ = concentration of metal Me removed from solution (mg/L)
MM_{PPT} = molecular weight of the metal precipitate formed (mg/mmol)
MM_{Me} = molecular weight of the metal (mg/mmol)

The total mass is calculated by summing all the precipitates generated.

Table 4.2 Products Assumed to be Generated by Lime Precipitation

Parameter	Precipitate Formula	Molecular Weight (g/mol)
Al	$Al(OH)_3$	78.01
Ag	AgOH	124.88
As	$As(OH)_3$	125.95
Bi	$Bi(OH)_3$	260.01
Cd	$Cd(OH)_2$	146.43
Cu	$Cu(OH)_2$	97.57
Fe	$Fe(OH)_3$	106.88
Pb	$Pb(OH)_2$	241.22
Mg	$Mg(OH)_2$	58.33
Mn	MnO_2	86.94
Ni	$Ni(OH)_2$	92.73
Sb	$Sb(OH)_3$	172.78
Se	$Se(OH)_4$	147
Si	$Si(OH)_2$	62.11
Zn	$Zn(OH)_2$	99.4
Na	n/a	-
K	n/a	-
SO_4^{2-}	$CaSO_4.2H_2O$	172.18

Sludge Recycle

The sludge recycle ratio is determined from the specific sludge generation rate for the influent water. The correlation presented in Figure 4.2 (after CEMI as reported in SRK 2004) is then used to estimate the optimum rate of sludge recycle.

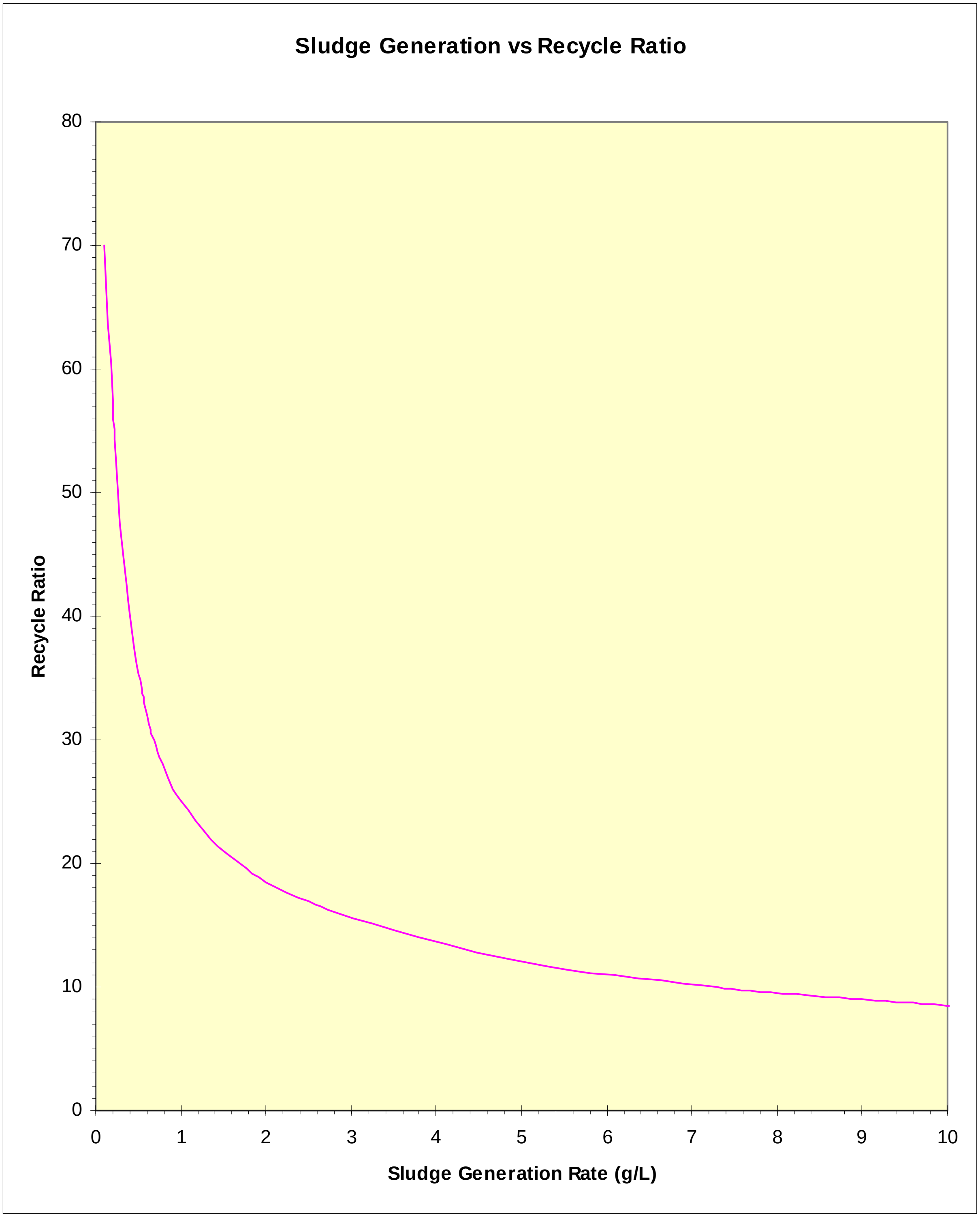

Figure 4.2 Sludge Recycle Ratio (after CEMI as reported in SRK 2004)

4.2.3 Mass Balance Model Inputs

The model inputs were selected to maximise flexibility and thus enable rapid evaluation of multiple options for various treatment scenarios. For this reason, input variables were subdivided into primary and secondary categories. The difference between the two categories in essence is defined by their uniqueness to any one scenario. For example, water quality, a primary variable, will change from scenario to scenario, whereas design variables such as reactor retention time (considered a secondary variable in this context) will in essence remain constant for many scenarios and does not require modification, even though it can be varied as an input variable.

Primary variables include:

- Water quality (dissolved metals, pH and sulphate)
- Annual operating period
- Peak flow
- Average annual flow
- Surge capacity
- Lime utilization

From these inputs the model calculates the design flowrate and reagent demand.

Secondary variables include:

- Target pH (normally fixed at 9.5)
- Lime slurry solids content
- Lime storage requirement
- Neutralization reactor retention
- Sludge – Lime mixing tank retention time
- Clarifier upflow ratio

These, together with the primary variables, are then used to determine equipment size for the mechanical equipment listed in Table 4.1. The equipment sizes, together with reagent demand, are then used in the cost model to estimate capital and operating costs as discussed in Section 4.3.

4.2.4 Model Verification

Germaine to the mass balance model are estimations of the lime demand and the sludge production for different water qualities. Therefore, to verify the calculations, the water quality tested in the bench scale tests were input to the model and the calculated results compared to the measured values. This comparison is provided in Table 4.3.

The calculated lime demand is also compared to the measured lime demand in Figure 4.3. While the lime utilization was fixed at 85 % for all the calculations, it should be noted that the actual lime utilization varied somewhat in the tests. Nonetheless, the correlation between the calculated and measured lime confirms that the model provides a reasonable estimate of lime demand for different water quality conditions.

Table 4.3 Measured and Modelled Lime Demand and Sludge Production Rates

Parameter	Method	FPO1	X23	FRO1	VG01
Lime Demand (g $Ca(OH)_2$ /L)	Calculated	0.31	3.8	2.0	5.7
	Actual	0.61	2.9	1.4	6.2
Sludge Production (g/L)	Calculated	0.58	11	5.3	16
	Actual	0.60	5.8	1.7	13

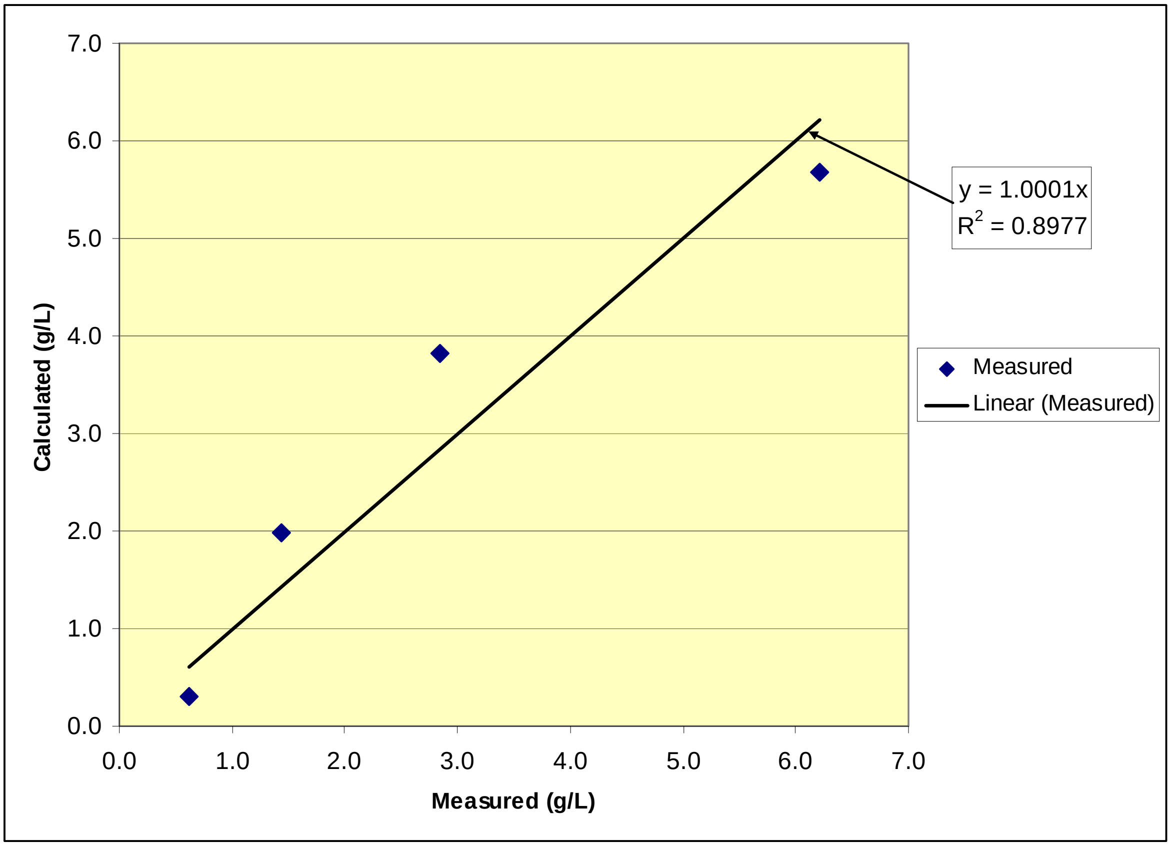

Figure 4.3 Comparison between Calculated and Measured Lime Demand

The calculated sludge production generally exceeds the measured sludge production. However, as discussed in Section 3.4.3, it is likely that not all of the sludge was recovered during bench scale testing. In addition, excessive heating of the sludge during the drying process could have led to weight loss (due to crystal lattice water loss and conversion to metal oxide) which would not occur under sludge management and disposal conditions. Therefore, the measured sludge production rates likely underestimate actual sludge production. Nonetheless, the results suggest that the modelled estimates are likely to be conservative.

4.3 Cost Model

4.3.1 Equipment Cost Estimation

The general approach adopted for estimating the equipment costs was to develop regressions relating equipment cost to equipment size or flow rate, as appropriate. The equipment costs were obtained from vendor supplied quotes obtained in November 2004 for equipment at a specific size and capacity. These were then used to adjust published data (Mend 1996, INAC 2003, AMDTreat 2004) for inflation to current (November 2004) values.

The reference equipment ratings and costs that were used to develop the regressions are provided in Appendix C. The lime slaking system, together with the lime dry lime storage bin feed hopper, is supplied as a package unit, with fixed production rates. As such, the cost estimation for the lime system is a step function completed by selecting a unit with a production capacity nearest but exceeding the plant lime demand. Similarly, the flocculent preparation system also is produced as a unit package, and the same approach was adopted.

4.3.2 Capital Cost Model

The cost model adopted for estimating total capital costs is illustrated in Table 4.4. The calculation of the equipment costs are, as noted above, by regression method. Building costs are estimated from the floor area (to enclosed major equipment) and a building cost factor of $430/m^2. The factors for estimating installation of equipment, process piping, electrical and instrumentation were obtained from The Chemical Engineer's Handbook (Perry and Green 2002). These factors are typical for chemical processing plants. Similarly, the factors for construction overheads and engineering and procurement were also obtained from the Chemical Engineers Handbook. A contingency of 25 % is applied to accommodate potential uncertainty in the regression calculations.

Table 4.4 Capital Cost Estimation Model

Component	Calculation		
Major Equipment			
Plant Feed, Sump and Recylce Pumps			Regression
Package Flocculent Preparation and Dosage			Regression
Lime storage, slaker and dosage			Regression
Process and Instrument Control Compressors			Regression
Clarifier			Regression
Reactor and Rapid Mix Tanks complete with agitators			Regression
Polishing Pond			Calculated
Buildings and services			Factored
Equipment total			Equipment total
Equipment Installation	10	%	Of Equipment total
Process Piping	30	%	Of Equipment total
Electrical	20	%	Of Equipment total
Instrumentation	16	%	Of Equipment total
Total Direct Costs			Total Direct Costs
Construction Overheads	13	%	Of Total Direct Costs
Engineering and Procurement	15	%	Of Total Direct Costs
Total Indirect Costs			Total Indirect Costs
Total Direct and Indirect			Direct + Indirect
Contingency	25	%	Of (Direct + Indirect)
TOTAL ESTIMATED CAPITAL COSTS			Contingency + Direct + Indirect

4.3.3 Operating Cost Estimation

The operating cost estimation includes reagent costs (lime and flocculent), power and labour. An annual allowance for operating maintenance and capital replacement is also included as a percentage of the plant capital cost.

The input variables for operating costs include unit rates for:

- Lime and quicklime
- Flocculent
- Labour costs
- Power costs

In addition, labour overheads and operating and capital replacement costs are input as percentages.

The unit rates adopted for further evaluation of treatment costs at the Anvil Range Site are summarised in Table 4.5. Although the current cost of hydrated lime delivered to site is about $320 per tonne (during 2004), recent quotations obtained from suppliers suggest a rise in prices. Therefore, the higher unit rates as shown in the table were adopted. Price estimates for lime, quicklime and flocculent are F.O.B. the site.

Table 4.5 Summary of Operating Costs Assumptions

Description	Units	Rate
Power costs	$ / kWh	0.13
Flocculent	$ / tonne	6 000
Lime ($Ca(OH)_2$)	$ / tonne	420
Quicklime (CaO)	$ / tonne	373
Labour costs	$ / hour	30.00
Labour overheads	% of hourly rate	30 %
Capital Replacement	% of Capital Cost	3 %

4.3.4 Net Present Value

For simplicity, net present value calculations assume that plant installation occurs in year one. Operating costs are assumed to remain constant for 100 years into the future. The operating maintenance and capital cost replacement allowance of 3 % of capital costs should allow complete plant replacement in 20 to 25 years. The discount rate for net present value calculations is an input variable but is assumed to remain constant at 3 % in all the calculations presented herein.

4.3.5 Cost Model Verification

Figure 4.4 shows a plot of the logs of the ratio of capital cost estimate against the corresponding flow ratios derived from the cost model for a series of flow conditions. Flow conditions were varied from about 0.05 m^3/s to 0.5 m^3/s and the resultant estimated capital costs ranged from about $2.6 million to about $9.7 million. The data points shown in Figure 4.4 were developed using the low flow results as the point of reference, i.e. the low flow conditions were the common denominator for all the ratios shown.

A standard method generally used in the chemical processing industry to scale cost estimates of chemical processing plants from one rate of production to another is the capacity-ratio exponent method as follows:

$$C_2 = C_1 (q_2/q_1)^n$$

Where C_1 is the capital cost at production rate q_1 and C_2 the capital cost at production rate q_2. The exponent n generally depends on the type of equipment. Typically, for chemical processing plants similar in configuration to the HDS treatment system, the exponent n varies between 0.48 and 0.70, with an average of about 0.6. The slope of the line shown in Figure 4.4 represents the exponent of the above equation. The slope of 0.6065 obtained from the curve fitted to the results indicates that the scaling function of the cost model, within the range of conditions assessed, falls within the range adopted elsewhere in industry.

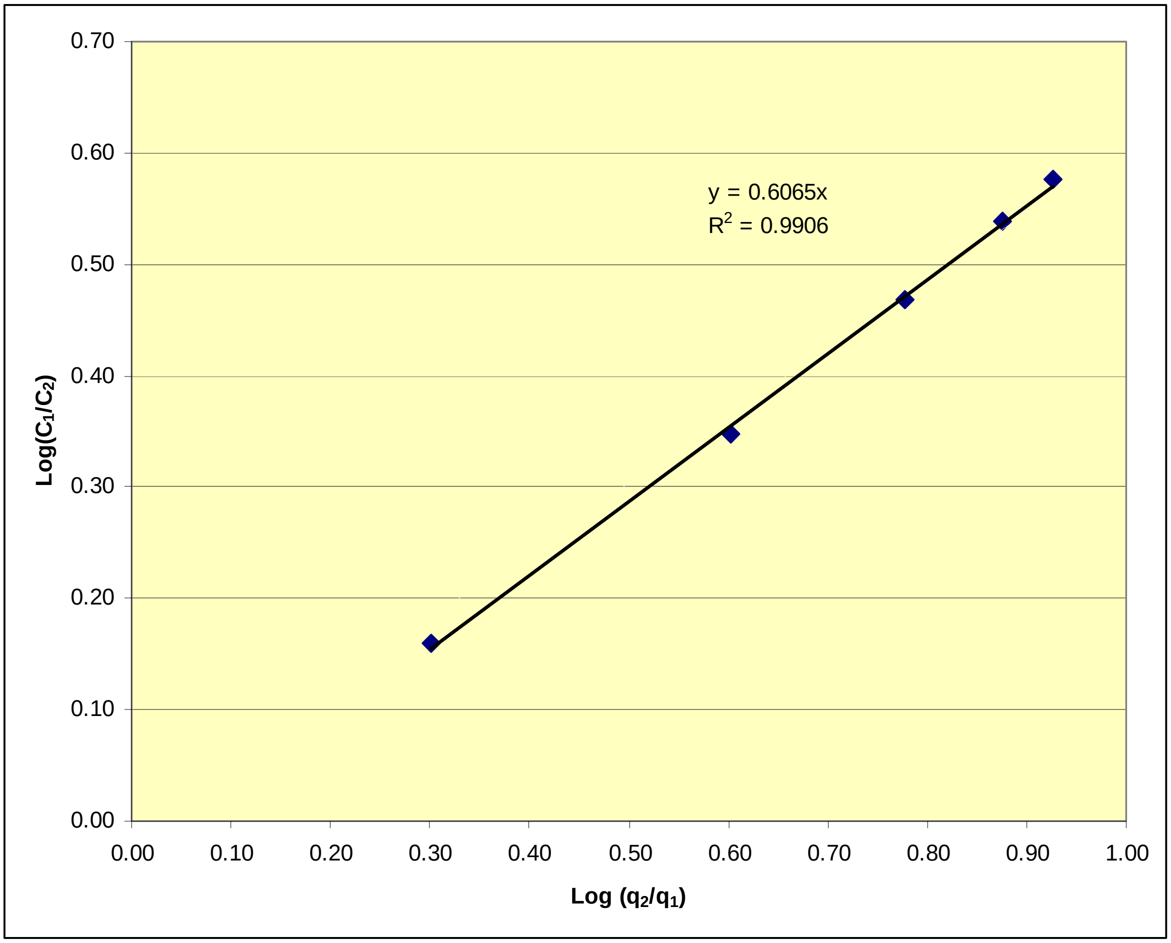

Figure 4.4 Cost Model Scaling Exponent

5 Baseline Water Treatment Requirements

5.1 Approach

Adverse water quality that will require treatment is expected to occur from the waste rock, pit wall rocks and from the tailings at the Anvil Range Site.

Water quality predictions for the waste rock dumps at the Anvil Range Site (SRK 2004) were prepared for current average conditions, current maximum conditions and for future worst case conditions.

Water quality predictions for the pit wall rocks (SRK 2005) were prepared using conservative assumptions for both flow through and isolated pit configurations. Water treatment in the event of a flow through configuration would likely be by biological methods and not by chemical treatment, whereas an isolated pit system would require chemical treatment. Therefore only the latter configuration is considered herein.

Water quality predictions were prepared for the tailings for current conditions and for various in situ remediation scenarios (SRK, 2005; RGC, 2005). By necessity, treatment of seepage from the tailings would require a series of interception wells to collect contaminated groundwater. Rates of pumping have been estimated by RGC and are adopted herein.

These estimates from the above investigations were used to prepare various scenarios for the Faro and Grum-Vangorda sites respectively as described below.

5.2 Faro Site

5.2.1 Cases

The water quality and flow rates estimated in previous studies were used to estimate water treatment requirements for the Faro mine and tailings areas under the following conditions:

1. Faro waste rock dumps
    a. Current average
    b. Current maximum
    c. Future maximum
2. Faro Pit lake
    a. Isolated current conditions
3. Rose Creek Tailings
    a. Future intermediate conditions
    b. Future maximum conditions
4. Faro site (Baseline)
    a. Current average conditions (waste rock – current average, isolated pit – current, and tailings current)
    b. Future intermediate conditions (waste rock – current maximum; isolated pit current conditions and tailings – future intermediate)
    c. Future maximum conditions (waste rock – future maximum; isolated pit current conditions and tailings – future maximum)

A similar series of evaluations were also identified for the Grum – Vangorda site. The basic assumptions and conditions used in the evaluations are presented in the next section.

5.2.2 Flows and Loadings

Table 5.1 provides a summary of the conditions that were used as inputs. As noted before, these estimates were extracted from the water quality predictions (SRK 2004) and loading calculations completed for the pit lakes (SRK 2005). Estimates for tailings water quality were derived fom the load calculations presented in RGC (2005). Additional assumptions that were adopted to provide reasonable inputs for estimating water treatment requirements included:

- Waste rock dump run-off was included in the volume of water to be treated;
- The catchment of the waste rock dumps were increased by about 50 percent to allow for runoff and other flows that cannot be diverted away;

- Since only sulphate and zinc concentrations were estimated for the Rose Creek tailings deposit, concentrations in the aquifer intercepted at or below the Cross Valley dam were estimated from the sulphate loadings and the ratio of the dissolved metals to dissolved suphate encountered in the pore water of the tailings as follows:

$$[Me]_{aq} = [So_4]_{aq} * ([Me]_{PW}/[SO_4]_{PW})$$

Where $[Me]_{aq}$ = concentration of the metal Me in the aquifer;
$[SO_4]_{aq}$ = concentration of sulphate in the aquifer (from modeled results)
$[Me]_{PW}$ = concentration of metal ME in the tailings porewater;
$[SO_4]_{PW}$ = concentration of sulphate in the tailings porewater
(with concentrations in consistent units)

- Wall rock loadings to the pit lake were assumed to remain constant with time.

Table 5.1 Summary of Conditions Evaluated

		Faro Waste Rock Dumps			**Tailings**			
Parameter	**Units**	**Current Avg**	**Current Max**	**Future Worst**	**Current Max.**	**Future (2021)**	**Future Worst (2074)**	**Faro Pit Lake**
Flow	m^3/year	1,711,260	1,711,260	1,711,260	2,540,387	2,540,387	2,540,387	498,201
Water Quality								
pH	s.u	6.0	4.0	2.0	3.51	2.7	2.7	6.0
SO_4^{2-}	mg/L	723	1,712	7,073	356	1,842	1,940	556
Al	mg/L	4.5	15.9	97.1	9.32	48.2	50.8	3.3
Ca	mg/L	76	139	162	10.6	55	58	68
Cd	mg/L	0.14	0.28	1.78	0.011	0.06	0.06	0.09
Co	mg/L	0.11	0.35	2.05	0.051	0.26	0.28	0.08
Cu	mg/L	1.9	6.6	37.5	2.56	13.2	13.9	1.1
Fe	mg/L	51	190	1,289	172	888	936	35
K	mg/L	3	6	15	-	-	-	3
Mg	mg/L	70	177	400	2.61	13	14	53
Mn	mg/L	7.6	31.0	185.0	1.54	8.0	8.4	4.9
Na	mg/L	7	29	28	-	-	-	31
Ni	mg/L	0.14	0.48	1.71	0.033	0.17	0.18	0.11
Pb	mg/L	0.06	0.19	0.51	0.011	0.06	0.06	0.07
Zn	mg/L	90	200	1,284	11.4	59	62	55

5.2.3 Treatment costs

Site Components

A series of tables summarising the estimated capital and operating costs have been prepared to show water treatment requirements for the seepage or discharge from the waste rock dumps (Table 5.2), the Rose Creek Tailings (Table 5.3) and the Pit Lake (Table 5.4) respectively. For consistency it was assumed in all cases that the water treatment plant would be operated 365 days a year because seepage from the waste rock dumps would be expected to continue throughout winter, as would flow within the Rose Creek aquifer. Assuming year-round operations yields the lowest capital cost. Lower operating costs may be achieved if the treatment plant was operated for only 4 to 6 months per year, however, this would require significant surge capacity to equalize flows to the treatment plant. Inherently, the pit lake has a large surge capacity and year round treatment is not required. Therefore, treatment costs for summer operation have been included in Table 5.4.

Three scenarios are presented for the waste rock dumps in Table 5.2 to determine the effects of changes in future water quality on treatment requirements. In the first scenario it is assumed that water quality does not change but remains at current concentrations. In the second scenario, it is assumed that at some time in the future the water quality will changed to estimated current maximum concentrations, and in the third it is assumed that the future worst water quality occurs at some later date. Neutralization potential depletion calculations suggest that the worst water quality may not occur for many years. In all cases, the capital costs were derived for the applicable worst water quality.

As shown in Table 5.2, for the current average conditions, treatment of the waste rock dump seepage would require a capital cost of about $3.4 million dollars, and an average annual operating cost of about $665 000. In the second scenario presented in the table, it was assumed that treatment would commence with current average water quality, but that the water quality would change to reflect estimated current maximum water quality. The operating costs would therefore escalate to about $1.1 million. In the last case presented in the table, treating the estimated future worst quality would incur a capital costs increase to about $5.9 million and the annual treatment costs would escalate to about $5.3 million.

Table 5.2 Summary of Faro Waste Rock Dump Water Treatment Requirements

Description	Units	Current Average	Current Maximum	Future Worst
Operating	days/year	365	365	365
Design Flow	m^3/s	0.106	0.106	0.106
Surge Capacity Required	m^3	274,000	274,000	274,000
Annual Treatment	m^3	1,711,000	1,711,000	1,711,000
Lime	tonne/year	417	1,411	10,383
	g/L	0.244	0.825	6.068
Sludge Production initial	m^3/year	2,796	10,340	122,388
Final Density	m^3/year	871	3,221	38,121
Costs				
Capital Cost		$ 3,406,000	$ 3,826,000	$ 5,864,000
Annual Operating Cost	Stage 1	$ 665,000	$ 665,000	$ 665,000
	Stage 2	$ 665,000	$ 1,142,000	$ 1,142,000
	Stage 3	$ 665,000	$ 1,142,000	$ 5,275,000

As shown in Table 5.3, water treatment requirements for the Rose Creek Tailings Facility were estimated for three cases. The water quality predictions suggest an initial breakthrough is likely to occur at about year 2021, and peak loadings are likely to occur in at about 2074.

The water treatment requirements for current maximum conditions, assuming no changes in the future, indicates a capital cost of about $4.6 million and an annual operating cost of about $1,034,000. Accounting for the effect of the predicted initial breakthrough increases the water treatment requirements substantially, with an estimated capital cost of about $6.1 million. The estimated operating costs are shown to increase to about $3.0 million. In the third case, should the estimated future worst case conditions develop, the capital and operating costs would increase marginally. The latter case likely most accurately reflects anticipated future conditions for the Rose Creek Tailings.

Table 5.3 Estimated Treatment Requirements for the Rose Creek Tailings

Description	Units	Current Maximum	Future (2021)	Future Worst (2074)
Operating	days/year	365	365	365
Design Flow	m^3/s	0.158	0.158	0.158
Annual Treatment	m^3	2,540,000	2,540,000	2,540,000
Lime	tonne/year	978	5,069	5,339
Sludge Production initial	m^3/year	4,755	41,032	44,242
Final Density	m^3/year	1,481	12,780	13,780
Costs				
Capital Cost		$ 4,617,000	$ 6,114,000	$ 6,199,000
Annual Operating Cost	Stage 1	$ 1,034,000	$ 1,034,000	$ 1,034,000
	Stage 2	$ 1,034,000	$ 3,044,000	$ 3,044,000
	Stage 3	$ 1,034,000	$ 3,044,000	$ 3,167,000

The estimated water treatment requirements for the Faro Pit Lake, with the Faro Creek Diversion maintained, are shown in Table 5.4. The calculations assume that the loadings from the wall rocks will not change in time. The estimated capital cost for a system treating water year round is estimated to be about $1.8 million. A slightly larger treatment system is required if treatment occurred only over a 120 day period each year, with a capital cost of about $2.2 million. However, the shorter treatment period would result in a significantly lower annual treatment cost of about $195,000 compared to $359,000 for year round treatment.

Table 5.4 Summary of Estimated Treatment Requirements for the Faro Pit Lake

Description	Units	All Year Treatment	Summer Treatment
Loading Conditions		Current Average	Current Average
Operating	days/year	365	120
Design Flow	m^3/s	0.031	0.048
Annual Treatment	m^3	498,000	498,000
Lime	tonne/year	68	68
Sludge Production initial	m^3/year	406	406
Final Density	m^3/year	127	127
Costs			
Capital Cost		$ 1,837,000	$ 2,202,000
Annual Operating Cost		$ 359,000	$ 195,000

Combined Treatment Scenarios

When compared to stand alone treatment systems dedicated to treating specific sources, combining flows from different components and treating it in one or two water treatment plant systems will result in significant operating cost savings.

Two possible scenarios were evaluated. The first considers treatment of the pit lake water with the waste rock dumps because of their proximity and the potential for utilizing the open pit as a water storage facility. Tailings groundwater treatment is not included in the first scenario to represent a case where, the tailings are relocated without contamination of the Rose Creek aquifer. The second scenario considers treating water from all the site components in a single water treatment plant. Both scenarios assume year-round treatment. The results are summarised in Table 5.55.5 and 5.6.
A comparison of the results presented in Table 5.5 with those presented in Table 5.2 and Table 5.4 demonstrates that by treating the combined mine area flows in a single water treatment plant could lead to a capital cost savings of about $1.1 million and a operating cost savings of about $300,000 per annum. Associated water management costs are not included in the estimates presented in the table. The pit lake will provide a substantial storage capacity which will enable summer treatment only. However, it will be necessary to maintain seepage collection and pumping systems year round to capture winter seepage and discharge it to the pit lake.

A similar comparison using Table 5.6 shows that a single treatment plant treating all of the site water would lead to a capital cost savings of about $3.5 million, and an operating cost savings of between $750,000 and $1.1 million per year. Additional water collection and pumping costs are not included.

Table 5.5 Summary of Estimated Treatment Costs for Treating the Pit Lake and Waste Rock Dump Loadings in a Single Water Treatment Facility

Description	Units	Case 1	Case 2	Case 3
Waste Rock Loadings		Current Average	Current Maximum	Future Worst
Pit Lake Loadings		Current Average	Current Average	Current Average
Operating	days/year	365	365	365
Design Flow	m^3/s	0.137	0.137	0.137
Surge Capacity Required	m^3	354,000	354,000	354,000
Annual Treatment	m^3	2,209,000	2,209,000	2,209,000
Quicklime	tonne/year	485	1,333	10,412
Sludge Production initial	m^3/year	3,202	8,280	118,401
Final Density	m^3/year	997	2,579	36,879
Costs				
Capital Cost		$ 3,920,000	$ 4,308,000	$ 6,344,000
Annual Operating Cost	Stage 1	$ 746,000	$ 746,000	$ 746,000
	Stage 2	$ 746,000	$ 1,154,000	$ 1,154,000
	Stage 3	$ 746,000	$ 1,154,000	$ 5,344,000

Table 5.6 Estimated Treatment Costs for Treating Contaminated Seepage from the Faro Pit, Faro Waste Rock Dump and Rose Creek Tailings in a Single Water Treatment Facility

Description	Units	Current Average	Future (2021)	Future Worst (2074)
Waste Rock Loadings		Current Average	Current Maximum	Future Worst
Pit Lake Loadings		Current Average	Current Average	Current Average
Rose Creek Tailings		Current Max.	Future Interm.	Future Worst
Operating	days/year	365	365	365
Design Flow	m^3/s	0.280	0.295	0.295
Surge Capacity Required	m^3	722,000	760,000	760,000
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
Costs				
Capital Cost		$ 6,359,000	$ 8,456,000	$ 10,129,000
Annual Operating Cost	Stage 1	$ 1,266,000	$ 1,266,000	$ 1,266,000
	Stage 2	$ 1,266,000	$ 3,935,000	$ 3,935,000
	Stage 3	$ 1,266,000	$ 3,935,000	$ 7,655,000

5.2.4 Sludge Production Rates

Unit sludge production rates are estimated as part of the water and mass balance calculations for the treatment model. The model calculations estimate sludge volumes at the ‘as produced’ solids content of about 20 percent, as well as at the estimated final density of about 50% solids. Estimates of cumulative sludge production at a final settled density for the first 50 and 100 years, for the site components and the site as a whole, are shown in Table 5.7.

Table 5.7 Summary of Estimated Faro Mine and Tailings Area

	Waste Rock		Pit Lake	Tailings		Total Combined	
Description	**Current Average**	**Future Worst**	**Current Avg.**	**Current Avg.**	**Future Worst**	**Min.**	**Max.**
Staged Sludge Production (m^3/year)							
Year 1 – 20	871	871	127	774	1481	1,772	2,478
Year 21 – 75	871	3221	127	774	12780	1,772	16,128
Year > 75	871	38121	127	774	13780	1,772	52,027
Cumulative Production(m^3)							
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

5.3 Vangorda – Grum Mine Area

5.3.1 Cases

Previously developed estimates of water quality and seepage rates were used to estimate water treatment requirements for the Grum - Vangorda mine area as follows:

1. Grum waste rock dumps
    a. Current average
    b. Current maximum
    c. Future maximum
2. Vangorda waste rock dumps
    a. Current average
    b. Current maximum
    c. Future maximum
3. Vangorda Pit
    a. Isolated current conditions
4. Vangorda – Grum site (Baseline)
    a. Current average conditions (waste rock – current average, isolated pit – current),
    b. Future intermediate conditions (waste rock – current maximum; isolated pit current conditions and tailings – future intermediate)
    c. Future maximum conditions (waste rock – future maximum; isolated pit current conditions and tailings – future maximum)

The Grum Pit was not included in the evaluation since it was assumed that a clean flow through pit lake will be established.

5.3.2 Flows and Loadings

The water quality and flow rate estimates for the Grum – Vangorda site are summarised in Table 5.8. These estimates were extracted from the water quality predictions (SRK 2004) and loading calculations completed for the pit lakes (SRK 2005). Assumptions that were adopted for estimating water treatment requirements are similar to those adopted in Section 5.2:

- Waste rock dump run-off was included in the volume of water to be treated;
- The catchment of the waste rock dumps were increased by about 50 percent to allow for runoff and other flows that cannot be diverted away;
- Wall rock loadings to the Vangorda pit lake were assumed to remain constant with time.

Table 5.8 Summary of Conditions Evaluated

Parameter	Units	Grum			Vangorda			Vangorda Pit Lake
		Current Avg	Current Max	Future Worst	Current Avg	Current Max	Future Worst	
Volume	m3/year	517,605	517,605	517,605	232,511	232,511	232,511	223,330
Water Quality								
pH	s.u	6.0	4.0	2.0	6.0	4.0	2.0	2.0
SO_4^{2-}	mg/L	391	602	3168	843	1292	7053	796
Al	mg/L	0.14	0.14	24	0.3	0.3	53.4	3.8
Ca	mg/L	139	189	242	309	419	539	71
Cd	mg/L	0.007	0.009	0.6	0.02	0.02	1.37	0.16
Co	mg/L	0.017	0.033	1.7	0.02	0.03	3.8	0.45
Cu	mg/L	0.007	0.007	13	0.02	0.02	28	1.5
Fe	mg/L	0.30	0.9	220	0.05	0.05	489	70
K	mg/L	3	4	7	6	9	15	2
Mg	mg/L	76	122	420	166	267	936	58
Mn	mg/L	0.6	1.9	190	0.2	2.1	422	39
Na	mg/L	4	6	9	8	13	20	3
Ni	mg/L	0.13	0.21	1.7	0.26	0.39	3.7	0.35
Pb	mg/L	0.034	0.034	0.209	0.08	0.08	0.46	0.18
Zn	mg/L	2.0	4.1	512	1.6	2.8	1,140	122

5.3.3 Estimated Treatment Costs

Site Components

The estimated water treatment requirements for the Grum and Vangorda waste rock dumps are presented respectively in Tables 5.9 and 5.10. The estimated water treatment requirements for discharge from the Vangorda Pit Lake, with the Vangorda Creek diversion in place, are shown in Table 5.11.

As shown in table 5.9, the initial water treatment requirements for the Grum dumps (for current and current maximum conditions) would be minimal with very low lime demands. Projections of neutralization potential depletion for the sulphide cell in the Grum dumps however suggest that acidic conditions may develop in a portion of the dump within about 40 to 50 years. It is possible therefore that little or no treatment of Grum dump seepage would be required for the next 30 to 40 years. However, when the change in water quality occurs, a significant increase in the annual treatment costs will result. The treatment costs would be expected to escalate from about $330,000 to about $900,000 per annum.

The estimated water treatment requirements for the Vangorda waste rock dumps are shown in Table 5.10. As for the Grum dump, the estimated treatment requirements for the current average and current maximum conditions are similar due to the similarity in the estimated water quality. Nonetheless, neutralization potential depletion calculations suggest that the Vangorda seepage is likely to become acid in about 20 to 30 years. At that time the annual treatment costs are expected to escalate from about $310,000 to about $900,000.

Table 5.9 Summary of Water Treatment Requirements for the Grum Dumps

Description	Units	Current Average	Current Maximum	Future Worst
Operating	days/year	365	365	365
Design Flow	m^3/s	0.032	0.032	0.032
Surge Capacity Required	m^3	83,000	83,000	83,000
Annual Treatment	m^3	518,000	518,000	518,000
Lime	tonne/year	2.2	6.7	1,195
Sludge Production Initial	m^3/year	1,019	1,327	13,827
Final Density	m^3/year	317	413	4307
Costs				
Capital Cost		$ 1,765,000	$ 1,785,000	$ 2,354,000
Annual Operating Cost	Stage 1	$ 330,000	$ 330,000	$ 330,000
	Stage 2	$ 330,000	$ 333,000	$ 333,000
	Stage 3	$ 330,000	$ 333,000	$ 897,000

Although the Vangorda Dump contains more severely acid generating waste rock, the estimated Grum Dump and Vangorda Dump treatment requirements (in terms of capital and operating costs) are very similar. This is because the catchment of the Vangorda Dump is significantly smaller than the Grum Dump, thus the Vangorda dump generates only about half the volume of water generated at the Grum Dump.

Table 5.11 provides the estimated treatment requirements for the Vangorda pit lake. As for the Faro Pit Lake, the loadings from the wall rocks are assumed to remain constant, resulting in no changes in water quality in the future. Since the pit lake provides ample surge capacity, an estimate for summer only operation is also shown in the table. As for the Faro Pit Lake, a significant savings in operating costs is possible for the summer only treatment scenario, albeit it a slightly higher capital cost. However, the higher capital costs would e offset by the lower operating costs within two to three years of operation.

Table 5.10 Summary of Water Treatment Requirements for the Vangorda Dumps

Description	Units	Current Average	Current Maximum	Future Worst
Operating	days/year	365	365	365
Design Flow	m^3/s	0.014	0.014	0.014
Surge Capacity Required	m^3	37,000	37,000	37,000
Annual Treatment	m^3	233,000	233,000	233,000
Lime	tonne/year	26	111	1,272
Sludge Production Initial	m^3/year	1,108	1,698	17,613
Final Density	m^3/year	345	529	5,486
Costs				
Capital Cost		$ 1,417,000	$ 1,474,000	$ 1,971,000
Annual Operating Cost	Stage 1	$ 306,000	$ 306,000	$ 306,000
	Stage 2	$ 306,000	$ 347,000	$ 347,000
	Stage 3	$ 306,000	$ 347,000	$ 889,000

Table 5.11 Summary of Water Treatment Requirements for the Vangorda Pit Lake

Description	Units	Current Average	
Operating	days/year	365	120
Design Flow	m^3/s	0.014	0.022
Annual Treatment	m^3	223,000	223,000
Lime	tonne/year	127	127
Sludge Production Initial	m^3/year	461	0.568
Final Density	m^3/year	144	461
Costs			
Capital Cost		$ 1,489,000	$ 1,701,000
Annual Operating Cost		$ 352,000	$ 194,000

Site Scenarios

Site water treatment requirements estimated for treating water from both the Vangorda and Grum waste rock dumps are provided in Table 5.12, and those for the site including the Vangorda Pit Lake are shown in Table 5.13.

Comparing the estimated requirements for treating the seepage from both dumps in a single water treatment plant (Table 5.12) with those estimated for independently treating the seepage (Table 5.9 and Table 5.10) indicates that a savings in capital cost of about $1.1 to 1.4 million is possible, and that the total annual operating costs could be reduced by about $280,000. The financial benefits of a single water treatment facility are clearly evident.

Table 5.12 Summary of Treatment Requirements for Combined Vangorda and Grum Waste Rock Seepage

Description	Units	Current Average	Current Maximum	Future Worst
Operating	days/year	365	365	365
Design Flow	m^3/s	0.047	0.047	0.047
Surge Capacity Required	m^3	120,000	120,000	120,000
Annual Treatment	m^3	750,000	750,000	750,000
Hydrated Lime	tonne/year	2	85	2,468
	g/L	0.003	0.113	3.290
Sludge Production	m^3/year	2,043	2,912	31,440
	m^3/year	636	907	9,793
Costs				
Capital Cost		$ 2,056,000	$ 2,156,000	$ 2,905,000
Operating Cost	Stage 1	$ 359,000	$ 359,000	$ 359,000
	Stage 2	$ 359,000	$ 404,000	$ 404,000
	Stage 3	$ 359,000	$ 404,000	$ 1,503,000

Comparing the site wide treatment requirements presented in Table 5.13 with those estimated for each of the site components (shown in Table 5.9, Table 5.10 and Table 5.11) indicates an even larger potential for costs savings. The capital cost savings are estimated to range from about $2.2 to $2.6 million and the annual operating cost would decrease by up to $590,000. Again, these estimates are based on year round operation of the treatment plant. Summer only treatment would lead to further operating cost savings. However, these would need to be offset against winter collection and pumping costs as well as a slightly higher capital cost for the treatment plant.

Table 5.13 Summary of Treatment Requirements for Vangorda and Grum Waste Rock Seepage and Excess Water from the Vangorda Pit Lake

Description	Units	Current Average	Current Maximum	Future Worst
Operating	days/year	365	365	365
Design Flow	m^3/s	0.060	0.060	0.060
Annual Treatment	m^3	973,000	973,000	973,000
Hydrated Lime	tonne/year	79	100	2,532
	g/L	0.081	0.103	2.602
Sludge Production	m^3/year	2,477	3,128	30,442
	m^3/year	771	974	9,482
Costs				
Capital Cost		$ 2,425,000	$ 2,438,000	$ 3,186,000
Operating Cost	Stage 1	$ 426,000	$ 426,000	$ 426,000
	Stage 2	$ 426,000	$ 437,000	$ 437,000
	Stage 3	$ 426,000	$ 437,000	$ 1,568,000

5.3.4 Sludge Production

Unit sludge production rates at the estimated final density of about 50% solids, together with calculated cumulative sludge productions at the final settled density for the first 50 and 100 years of treatment are shown in Table 5.14. The 'waste rock' column in the table represents the combined sludge loading from the Grum and the Vangorda waste rock dumps. As shown, the volume of sludge production will vary significantly into the future. As a result total sludge production and will be substantial and will require an appropriate management strategy.

Table 5.14 Summary of Estimated Vangorda-Grum Sludge Production

	Waste Rock		Pit Lake	Site Wide	
Description	Current Average	Future Worst	Current Avg.	Min.	Max.
Annual Production (m^3/year)					
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)					
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

6 Effects of Site Remediation on Treatment Requirements

6.1 Introduction

In this section, the effects of a number of potential remediation methods on water treatment requirements are evaluated. With the range of load estimates that have been generated for the site components, and the many remediation methods under consideration, there is a very large number of combinations and permutations that could be evaluated. Only a select number of methods and site combinations are evaluated in the following sections.

6.2 Faro Mine and Tailings Area

6.2.1 Waste Rock Dumps

Example Remediation Methods

The following conditions were considered for the Faro waste rock dumps:

- Rudimentary covers placed on all waste rock dumps. Rudimentary covers would be placed on all waste rock, oxide fines and low grade ore and were assumed to reduce infiltration to about 20 percent of MAP. The runoff from the covers was assumed to be ‘clean’ and not require treatment. Collection of seepage would occur in toe drains and shallow groundwater collection systems.
- Selection low infiltration covers. The oxide fines and low grade ore stockpiles would be consolidated and covered with low infiltration covers. All sulphide cells would be covered selectively with low infiltration covers, which were assumed to reduce net infiltration to about 5 % of mane annual precipitation. Rudimentary covers would be placed on the remainder of the waste rock dumps.

Because the relative load contributions from each of the waste rock dumps changes over time, the conditions were evaluated for both current average conditions as well as for future worst case conditions. The water quality estimates derived from the waste rock dump water and load balance calculations are shown in Table 6.1and Table 6.2 for current average and future worst case conditions respectively.

Estimated Treatment Requirements

The effects of these remediation measures on water treatment requirements are summarised in Table 6.3 and Table 2.14. These tables also contain the base case (i.e. no remediation) estimates for comparison. The results indicate that for the current average conditions, placing the covers will reduce the capital costs by about $700,000 due to the reduction in the seepage volume. Rudimentary covers would lower the annual operating costs by about $160,000 and, the use of the low infiltration covers over the sulphide cells and oxide fines would further reduce it by an additional $70,000 for a total savings of about $230,000 per annum.

The effect of covers on treatment requirements is significantly more pronounced for future worst case conditions. The capital costs would be lower by about $1.8 million by placing rudimentary covers, and by an additional $0.2 million with the placement of the low infiltration covers on the sulphide cells and oxide fines, for a total savings of about $2.0 million.

Placing rudimentary covers would substantially reduce the annual operating costs from about $5.3 million to $2.5 million for a savings of about $2.7 million per annum. The selective use of low infiltration covers would lead to a further savings of about $0.4 million per year, for a combined savings of about $3.2 million per year.

Table 6.1 Current Average Water Quality and Flow Rates for Faro Mine Area with Example Remediation Methods

		Current Average Conditions		
Parameter	**Units**	**Base Case (No Covers)**	**Rudimentary Covers**	**Selective Low Infiltration Covers**
Infiltration	% of MAP	45	20	20 / 5
Flow	m^3/year	1,711,260	1,254,924	1,232,107
Water Quality				
pH	s.u	6.0	6.0	6.0
SO_4^{2-}	mg/L	723	438	291
Al	mg/L	4.5	2.7	1.1
Ca	mg/L	76	46	42
Cd	mg/L	0.14	0.08	0.03
Co	mg/L	0.11	0.07	0.03
Cu	mg/L	1.9	1.1	0.3
Fe	mg/L	51	31	10
K	mg/L	2.9	1.8	1.4
Mg	mg/L	70	43	36
Mn	mg/L	7.6	4.6	1.7
Na	mg/L	6.8	4.1	3.7
Ni	mg/L	0.14	0.08	0.05
Pb	mg/L	0.06	0.04	0.03
Zn	mg/L	90	55	18

Table 6.2 Future Worst Case Water Quality and Flow Rates for Faro Mine Area with Example Remediation Methods

Parameter	Units	Future Worst Case Loadings Base Case (No Covers)	Rudimentary Covers	Selective Low Infiltration Covers
Infiltration	% of MAP	45	20	20 / 5
Flow	m^3/year	1,711,260	1,254,924	1,232,107
Water Quality				
pH	s.u	2.0	2.0	2.0
SO_4^{2-}	mg/L	7,073	4,287	3,611
Al	mg/L	97	59	48
Ca	mg/L	162	98	90
Cd	mg/L	1.8	1.1	0.9
Co	mg/L	2.1	1.2	1.0
Cu	mg/L	38	23	18
Fe	mg/L	1289	781	628
K	mg/L	15.3	9.3	8.0
Mg	mg/L	400	243	207
Mn	mg/L	185	112	89
Na	mg/L	28	17	16
Ni	mg/L	1.7	1.0	0.9
Pb	mg/L	0.5	0.3	0.3
Zn	mg/L	1284	778	652

Table 6.3 Summary Water Treatment Requirements for Covered Faro Dumps at Current Average Loadings

Description	Units	Current Average Conditions Base Case (No Covers)	Rudimentary Covers	Selective Covers
Operating	days/year	365	365	365
Design Flow	m^3/s	0.106	0.078	0.076
Surge Capacity Required	m^3	274,000	201,000	197,000
Annual Treatment	m^3	1,711,000	1,255,000	1,232,000
Lime	tonne/year	417	185	55
Sludge Production initial	m^3/year	2,796	1,243	574
Final Density	m^3/year	871	387	179
Costs				
Capital Cost		$ 3,406,000	$ 2,785,000	$ 2,675,000
Annual Operating Cost		$ 665,000	$ 502,000	$ 432,000

Table 6.4 Summary Water Treatment Requirements for Covered Faro Dumps at Future Worst Case Loadings

Description	Units	Future Worst Case Conditions		
		Base Case (No Covers)	Rudimentary Covers	Selective Covers
Operating	days/year	365	365	365
Design Flow	m^3/s	0.106	0.078	0.076
Surge Capacity Required	m^3	274,000	201,000	197,000
Annual Treatment	m^3	1,711,000	1,255,000	1,232,000
Lime	tonne/year	10,383	4,481	3,597
Sludge Production initial	m^3/year	122,388	47,828	36,577
Final Density	m^3/year	38,121	14,897	11,393
Costs				
Capital Cost		$ 5,864,000	$ 4,132,000	$ 3,894,000
Annual Operating Cost		$ 5,275,000	$ 2,522,000	$ 2,115,000

6.2.2 Tailings Area

Example Remediation Methods

The remediation methods considered for the tailings include partial relocation to the pit, and stabilization in place. Complete relocation will not require any long-term collection and treatment and therefore is not considered herein.

The assumptions adopted were as follows:

- In place stabilization of the tailings would entail placement of a dry cover that is assumed to decrease infiltration rates to about 5 mm per year. That assumption is consistent with the draft Rose Creek Tailings load and water balance calculations, but probably represents an unrealistically low infiltration rate. It is adopted herein only because the load and water balance study has already provided the estimates needed for water treatment calculations. More realistic estimates will need to be derived in future work;
- Partial relocation would entail removal of the tailings in the Intermediate impoundment. The tailings remaining in the Original and Secondary Facilities would be covered in place with a rudimentary cover.

The estimated flow rates and water quality that would be collected and treated in the aquifer are shown in Table 6.5. Flows would remain unchanged from the base case as the inflows occur predominantly upstream of the tailings deposit.

Table 6.5 Summary of Conditions Evaluated for the Rose Creek Tailings

Parameter	Units	Case Low Infiltration Cover	Partial Relocation
Volume	m^3/year	2,540,387	2,540,387
Water Quality			
Al	mg/L	0.74	2.27
Ca	mg/L	0.77	2.37
Cd	mg/L	0.003	0.008
Co	mg/L	0.02	0.06
Cu	mg/L	0.26	0.81
Fe	mg/L	51	157
Mg	mg/L	0.60	1.8
Mn	mg/L	0.22	0.69
Ni	mg/L	0.001	0.001
Pb	mg/L	0.001	0.001
pH	mg/L	3.8	3.3
SO4	mg/L	157	482
Zn	mg/L	7.8	39

Treatment Requirements

Estimated treatment requirements are provided in Table 6.6. Because the peak load estimates were adopted to derive the treatment requirements for the low infiltration and partial relocation cases, they are compared to the future worst case estimates as a reference case. Both remediation methods would result in lower treatment capital cost of around \$1.5 to \$1.8 million. However, the most significant savings would be achieved in the annual operating costs. The savings would be about \$2.2 million per annum for the assumed low infiltration cover, and about \$1.8 million per annum for the partial relocation scenario.

Table 6.6 Estimated Treatment Requirements for the Rose Creek Tailings

Description	Units	Base Case (Future Worst)	Low Infiltration Cover	Partial Relocation
Operating	days/year	365	365	365
Design Flow	m^3/s	0.158	0.158	0.158
Annual Treatment	m^3	2,540,000	2,540,000	2,540,000
Lime	tonne/year	5,339	900	1,642
Sludge Production initial	m^3/year	44,242	1,761	5,020
Final Density	m^3/year	13,780	549	1,563
Costs				
Capital Cost		\$ 6,199,000	\$ 4,355,000	\$ 4,659,000
Annual Operating Cost		\$ 3,167,000	\$ 955,000	\$ 1,318,000

6.3 Vangorda - Grum Mine Area

6.3.1 Example Remediation Methods

The following example remediation measures were considered for the Vangorda-Grum Mine Area:

- Rudimentary covers placed on all the waste rock dumps; the diversion around the Vangorda Pit is maintained so that it can be used as a water management facility;
- Low infiltration covers selectively placed on the Grum sulphide cell and the Vangorda oxide fines, and the pit is again used as water storage facility;
- In the event that the Vangorda Pit is backfilled, water treatment is limited to the Grum Dump, which is covered with rudimentary covers;
- Grum dump as above but with the sulphide cell covered with a low infiltration cover over the sulphide cell; and,
- Grum Dump as above but with the sulphide cell removed.

Flow and water quality estimates for the above scenarios are summarised in the next section.

6.3.2 Estimated Flows and Loadings

The estimated loadings and flows are presented in Table 6.7. Calculations were completed only for the ‘current average’ and ‘future worst case’ load estimates because the results for the ‘current maximum’ estimates were found to closely correlate with the results for the ‘current average’ estimates (see Table 5.13, for example). As in Section 6.1, it was assumed that rudimentary covers would reduce infiltration to about 20 % of mean annual precipitation, and that low infiltration covers would reduce infiltration to about 5 % of mean annual precipitation.

Table 6.7 Summary Estimated Remediated Conditions for the Vangorda – Grum Mine Area

Parameter	Units	Grum – Vangorda Rudimentary Covers		Grum – Vangorda Low infiltration on Sulphides		Grum Dumps Rudimentary Covers		Grum Dumps Low infiltration on Sulphides		Grum Dumps Sulphide Cell Removed	
		Cur Avg	Future Worst	Cur Avg	Future Worst	Cur Avg	Future Worst	Cur Avg	Future Worst	Cur Avg	Future Worst
Total Flow	m3/year	823,423	823,423	813,922	813,922	407,528	407,528	407,528	407,528	407,528	407,528
Acidity	mg/L	11.97	691.36	10.45	206.82	7	693	5	201	5	37
Alk	mg/L	150.50	206.29	137.72	203.92	151	207	136	203	132	201
Cl	mg/L	0.77	1.40	0.72	1.09	0.7	1.3	0.6	1.0	0.6	0.9
SO4	mg/L	434.43	1,986.21	401.53	1,012.23	221	1,789	183	793	170	461
Ca	mg/L	96.95	154.70	88.34	140.74	78	137	69	121	65	116
Mg	mg/L	58.05	250.56	52.10	149.29	43	237	36	133	34	99
K	mg/L	2.16	4.27	1.97	3.72	1.6	3.7	1.4	3.1	1.3	2.9
Na	mg/L	2.78	5.69	2.51	5.16	2.1	5.0	1.8	4.4	1.7	4.2
Al	mg/L	1.10	14.43	1.11	4.48	0.08	14	0.07	3	0.07	0.07
Cd	mg/L	0.05	0.39	0.05	0.14	0.004	0.35	0.004	0.09	0.003	0.01
Co	mg/L	0.13	1.08	0.13	0.43	0.009	0.97	0.005	0.30	0.004	0.08
Cu	mg/L	0.41	7.50	0.42	2.21	0.004	7.2	0.004	1.8	0.003	0.004
Fe	mg/L	19.04	141.55	19.14	52.44	0.17	124	0.05	33	0.01	3
Pb	mg/L	0.07	0.17	0.07	0.09	0.02	0.12	0.02	0.04	0.02	0.02
Mn	mg/L	10.82	116.43	10.74	40.16	0.3	107.0	0.1	29.5	0.0	3.7
Ni	mg/L	0.17	1.03	0.15	0.53	0.07	0.9	0.06	0.4	0.05	0.3
Zn	mg/L	34.19	319.10	33.96	114.13	1.13	289	0.50	81	0.29	11

6.3.3 Estimated Treatment requirements

Cover in Place

The estimated treatment requirements for rudimentary covers and selective covering with low infiltration covers are summarised in Table 6.8. It was assumed that water treatment would be limited to the summer months only. For comparison, Table 6.8 also presents base case estimates for summer only treatment.

Table 6.8 Estimated Site-wide Treatment Requirements for the Vangorda-Grum Mine Area with Rudimentary and Selective Low Infiltration Covers

Description	Units	Base Case		Rudimentary Covers		Selectively Placed Low Infiltration Covers	
		Current Average	Future Worst	Current Average	Future Worst	Current Average	Future Worst
Operating	days/year	120	120	120	120	120	120
Design Flow	m^3/s	0.094	0.094	0.079	0.079	0.079	0.079
Annual Treatment	m^3	973,000	973,000	823,000	823,000	814,000	814,000
Lime	tonne/y	79	2,532	83	909	82	186
Sludge Production							
initial Density	m^3/y	2,477	30,442	1,341	9,332	1,249	2,681
Final Density	m^3/y	771	9,482	418	2,907	389	835
Costs							
Capital		$3,033,000	$3,950,000	$2,790,000	$3,289,000	$2,778,000	$2,884,000
Annual Operating		$ 251,000	$1,370,000	$ 236,000	$ 623,000	$ 234,000	$ 287,000

For current average conditions, the covers provide little benefit. The reason for this is that the waste rock has not yet progressed far into acid generating conditions, and in particular, the sulphides currently contribute little to the overall loadings. However, for future worst case conditions, the benefits of covers are more apparent. The results suggest that for rudimentary covers, the capital cost of a treatment would be reduced by about $0.7 million, and the addition of low infiltration covers on the sulphides would reduce capital costs by about $1.1 million. More importantly, the operating costs would be reduced by about $750,000 per annum should rudimentary covers be placed. Low infiltration covers on the sulphide cells in conjunction with rudimentary covers would lead to an annual operating cost savings of about $1.1 million.

Grum Dump (Vangorda Backfilled)

The estimated treatment requirements for the three Grum Dump remediation methods are shown in Table 6.9. These can be compared directly to the base case estimates presented in Table 5.9. None of the remediation methods significantly change the estimated water treatment capital and operating costs for current average conditions. However, the estimated treatment requirements for the future worst case loads are significantly affected by the example remediation methods. Rudimentary covers would lower the capital cost marginally (about $0.4 million lower), but would reduce the operating costs by almost $400,000 per year. The low infiltration and cover on the sulphide cell would provide a capital cost savings of about $0.6 million, and lower the operating cost by about $540,000 per year. The complete removal of the sulphide cell would have a similar effect.

Table 6.9 Summary of Estimated Water Treatment Requirements for the Grum Waste Rock Dump for Rudimentary Covers, Low Infiltration Covers on the Sulphides, and, for the Sulphide Cell Removed

		Rudimentary Covers		**Selective Low Infiltration Cover on Sulphide Cell**		**Rudimentary Covers and Sulphide Cell Removed**	
Description	**Units**	Current Avg	Future Worst	Current Avg	Future Worst	Current Avg	Future Worst
Operating	days/y	365	365	365	365	365	365
Design Flow	m^3/s	0.025	0.025	0.025	0.025	0.025	0.025
Surge Capacity	m^3	65,000	65,000	65,000	65,000	65,000	65,000
Annual Treatment	m^3	408,000	408,000	408,000	408,000	408,000	408,000
Lime	tonne/y	3	395	2	84	2	9
Sludge Production							
Initial density	m^3/y	454	3,738	408	1,085	393	653
Final Density	m^3/y	141	1,164	127	338	122	203
Costs							
Capital		$1,621,000	$1,911,000	$1,609,000	$1,726,000	$ 1,606,000	$1,641,000
Operating		$ 313,000	$ 508,000	$ 312,000	$357,000	$312,000	$ 318,000

7 Conclusions

A water treatment options evaluation for the Anvil Range site indicated that metal precipitation by lime treatment is the most suitable process for the estimated water quality that may develop in the future. In particular, high density sludge (HDS) treatment is preferred treatment technology because it represents proven technology, is cost effective and is commonly used in the mining industry to treat acid rock drainage.

Laboratory scale tests were completed to assess lime demand for various water types, and to derive estimates of sludge production. Both these parameters were required for the development and calibration of water treatment cost estimates. The laboratory tests verified that lime precipitation will effectively treat a wide range of water quality likely to be encountered at the Anvil Range site.

A cost estimating model for a high density sludge treatment system was developed and calibrated against the available information. Estimates of major equipment costs were obtained by quotation in November of 2004, and used to adjust equipment costs previously compiled for similar water treatment systems. These estimates were then correlated with size and/or flow capacity to estimate approximate equipment costs. The model was configured to allow rapid estimation of operating and capital costs for known water quality and flow conditions.

Water quality and flow conditions were estimated for a wide range of estimates of previously reported dump water quality, pit lake water quality and Rose Creek aquifer water quality. Based on these results, the model was used to estimate treatment requirements for estimated current and future conditions and for a number of example remediation methods.

8 References

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Appendix A

Options Evaluation – Report Prepared by SENES Consultants

REVIEW
OF
LONG TERM TREATMENT OPTIONS
CLOSED ANVIL RANGE MINE
YUKON TERRITORY

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1 INTRODUCTION

1.1 Terms of Reference

As part of the overall planning for the long term management of the contaminated drainage from the closed Anvil Range Mining Site near Faro, Yukon Territory, SRK Consulting was retained to assess long term treatment costs. As part of this review, SRK (2004) completed an assessment of the upgrading of the water treatment plants located at the Vangorda/Grum, Faro Mill and Down Valley Dam to modern High Density Sludge (HDS) facilities.

This assessment indicated that there were definite advantages to reducing costs by upgrading of the Vangorda/Grum and Down Valley Dam Treatment systems. These cost reductions arise from reduced labour requirements for the operation of modern automated plants and improved efficiency of reagent use.

A second objective of this work was to assess whether there were other treatment options that could be considered for long term management of drainage from the site. This report reviews treatment alternatives available for the management of mine drainage and assesses whether any of these options is a practical alternative for long term management of mine drainage at the Anvil Range mine site.

2 DESIGN BASIS TREATMENT OPTIONS

2.1 Overview

There are three treatment plants at the mine site. Key operating information for the plants is provided in Table 2.1.

TABLE 2.1 Key Treatment Plant Operating Data for 2003

Treatment Plant	Flows		Lime use	Sludge Production[1]			Operating Cost
	Operating Flow USGPM	Volume Treated m^3/year	t/year as CaO	t/year	1000 m^3/y @2% solids	1000 m^3/y @20% solids	\$/m^3
Vangorda	2000	436,000	127	908	n/a	3.9	0.407
Faro Mill	5300	1,906,000	218	1023	51.2	4.4	0.144
Down Valley Dam	1500	440,000	200	450	22.5	2.0	0.288

Note 1: Based upon calculations from the HDS treatment evaluation (SRK 2004)

All of the plants operate seasonally in the summer months. Some key observations from Table 2.1 include:

1) Lime use is modest for such large plants ranging from 127 to 218 t/year

2) Operating costs are typical for lime treatment plants

3) Sludge production and disposal over the long term will be a major consideration for closure planning especially if low density sludges are continued to be produced from the Mill and Down Valley Dam treatment plants. At 2% solids, more than 70,000 m^3/year of sludge would be produced. If high density plants were constructed and sludge density increased to 20% solids, the annual sludge volume from these plants would be reduced to about 6,400 m^3/year.

A typical breakdown of the operating costs for the existing plants is shown in Table 2.2.

TABLE 2.2 Typical Water Treatment Operating Costs

Cost Item	Vangorda/Grum		Faro Mill		Down Valley Dam	
	Cost	%	Cost	%	Cost	%
Lime (CaO)	$44,800	25	$76,800	28	$70,400	55
Power	$87,360	50	$164,736	60	$29,484	23
Labour	45,425	25	$33,312	18	$27,255	22
Total Cost	$177,585	100	$274,814	100	$127,139	100

At the Faro Mill and Vangorda plants, power is the most significant cost item while for the Down Valley Dam, lime is the most significant cost item. The high proportional cost for lime at the Down Valley Dam is due in part to the poor efficiency of lime use which is projected to be at <20% as compared with a well operated HDS plant at about 80%.

2.2 Source Concentrations

The average concentrations in the drainage waters reporting to treatment are shown in Table 2.3

The following are key observations regarding the source water quality:

- Sulphate levels are below gypsum saturation limits
- The effluents are slightly alkaline with pH levels above 7.0. The measured acidity is primarily present as zinc.
- The primary metal contaminants are zinc, iron and manganese. Iron levels appear to drop as the summer proceeds (as ferrous iron is oxidized, the ferric iron precipitates).
- Sludges formed during lime treatment would be primarily comprised of zinc hydroxide, magnesium hydroxide, manganese oxide and iron oxide.

TABLE 2.3 Mine Drainage Water Quality Before Treatment

Parameter	Units	2003 Water Quality		
		Vangorda/Grum	Faro Mill	Down Valley Dam
Acidity	mg/L as $CaCO_3$	110-168	11-27	36-94
pH	units	6.9-7.4	7.4-7.8	7.3-75
Aluminum	mg/L	0.001-0.03	0.01-0.11	0.01-0.24
Iron	mg/L	0.12-1.55	0.06-0.27	0.1-20
Manganese	mg/L	16.5-29.2	0.47-2.8	9.1-14.4
Zinc	mg/L	51.3-73.3	6.3-13.8	9.4-16.7
Sulphate	mg/L	635-1041	132-657	649-799

3 Review of Treatment Methods

The potentially applicable treatment processes can be placed into one of six primary categories:

1) Chemical treatment,
2) Membrane processes,
3) Ion exchange systems,
4) Evaporation/distillation systems,
5) Biological and
6) Freeze separation.

3.1 Chemical Treatment Systems

3.1.1 Alkali Addition

A number of alkaline reagents have been proposed for pH control and metals precipitation. These include lime/limestone, soda ash and caustic soda. Because effluents are already alkaline, limestone would not be appropriate. Soda ash and caustic are often used where alkali demands are low and gypsum precipitation is to be avoided. At Anvil Range, the alkali demand would preclude the used of soda ash and caustic (typically 10 times the cost of CaO) given there is no offsetting benefit to their use. As such, lime (CaO) or hydrated lime ($Ca(OH)_2$) are the preferred alkali for chemical precipitation. Lime precipitation as practiced at Anvil Range is generally considered the standard method for treatment of base metal mine waste waters.

3.1.2 Sulphide Precipitation

Sulphides such as Na_2S can be used to precipitate most metals. One advantage of sulphide metal precipitation is that the solubility of the metal sulphide precipitate is often lower than respective hydroxide or carbonate precipitates formed during lime precipitation. Sulphide precipitation is typically used after lime treatment as a polishing process to reduce trace metals levels (e.g. cadmium). This combined lime and sulphide treatment process reduces the demand for sulphide reagent and is typically more cost effective as sulphide reagent costs are high. Sulphide precipitation also has the potential advantage of creating sludge with recoverable metals values (recyclable sludge). Given the low metals content of the Anvil Range waste waters in combination with the high cost for reagents, it is unlikely that sulphide precipitation would be considered as a stand alone process.

3.1.3 Co-Precipitation

Co-precipitation is a common method to remove several trace metals such as arsenic, molybdenum and antimony. The most common metal used to co-precipitate these metals is iron. Given that these metals are not at elevated levels in the Anvil Range effluents, co-precipitation is not an appropriate treatment alternative.

3.1.4 Chemical Reduction

Chemical reduction is applied to the removal of specific metals such as selenium and chromium (VI) to allow for improved precipitation. Given that these elements are not present at elevated levels, chemical reduction is not an appropriate treatment alternative.

3.1.5 Summary

There are no alternative chemical precipitation methods that would be appropriate to replace the current lime precipitation methods used at Anvil Range. Lime and or hydrated lime are the preferred reagents for metals precipitation at Anvil Range.

3.2 Membrane Processes

Membrane processes can be used:

- As a concentration step before application of other technologies such a lime precipitation, evaporation, bio-treatment or metals recovery
- As a stand alone process with brine disposal/management

Membrane processes can be distinguished based on the driving force for removal and the size of molecules rejected by the membrane. Reverse osmosis (RO) removes materials less than 0.001 µm (e.g. removal of monovalent salts); nano-filtration (NF) is used to separate larger molecules such as sugars and divalent salts; ultra-filtration (UF) can retain proteins and colloids in the 0.001 to 0.1 µm range; and micro-filtration (MF) is used for sterilization and removal of suspended material ranging in size from 0.1 to 10 µm. Only RO would be considered for use at Anvil Range.

RO could be used to produce an effluent with low metals content and a brine requiring management. Although RO is a well established technology, it has been rarely used in mining applications and is fraught with many drawbacks.

Membrane systems are susceptible to fouling by particulates, gas bubbles and other fouling contaminants and therefore the feed must be pretreated. Fine particulates and colloidal silica are usually removed by micro-filtration. Scaling agents such as iron salts, silica, calcium sulfate and calcium carbonate can also cause problems as saturation conditions may be met at the membrane surface resulting in precipitation of solids on the membrane. Calcium removal by ion exchange or soda softening and the addition of anti-scaling agents are used to alleviate some of these scaling problems. Pre-treatment systems can be expensive and may account for as much as half of the cost depending on the extent of pre-treatment required.

Another drawback to using membranes for wastewater treatment is the production of highly concentrated brine that must be treated prior to final disposal. The brine is often evaporated using a distillation and crystallization process or evaporation ponds (only practical in arid locations). Safe disposal of the dry salts can also be problematic and requires specially constructed disposal facilities. In some cases, brine may also be chemically treated. For Anvil Range, the brine would require chemical treatment and this would likely be achieved using lime precipitation.

Typical costs for reverse osmosis without brine treatment/management are in the range of \$0.5 to \$1.00/m^3 (SENES 1999). Brine management would add to these costs. Given that current water treatment costs are <\$0.5/m^3, there would be no advantage to adopting membrane processes at Anvil Range.

3.3 Ion Exchange

Ion exchange processes can be used:

- As a concentration step before application of other technologies such a lime precipitation, evaporation, bio-treatment or metals recovery
- As a stand alone process with brine disposal

Ion exchange is the reversible process of transferring undesirable ions (i.e. Cu^{2+}, Ni^{2+}, Ca^{2+}) from an aqueous solution to a solid support with the concomitant transfer of innocuous ions (i.e. H^+) from the solid to the solution. This process is widely used in a variety of industries for the purification of water (e.g. residential water softening) or the recovery of a valued component from solution (e.g. concentration of gold cyanide complexes).

Ion exchange resins consist of an insoluble support that has active functional groups attached to it. The functional groups are ionogenic (i.e. they are capable of dissociation) and are electrostatically balanced with mobile ions of the opposite charge. Undesirable ions in solution are substituted for these mobile ions during the ion exchange reaction. Cation exchangers are used to replace metals, and other cations in solution with H^+ or Na^+; anion exchangers substitute sulfate, phosphate, etc. with OH^- or Cl^-. Loaded resins are regenerated with acid or caustic, depending on the type of resin, to produce concentrated brine containing the ions removed from solution.

A number of natural materials exhibit ion exchange capabilities such as zeolites (a class of aluminosilicate minerals), coal, metallic oxides and some types of algae and bacteria. Hundreds of synthetic ion exchange resins have been developed and they tend to be more efficient than natural ion exchangers, have higher capacities and can be designed to be highly selective.

In theory, ion exchange can be applied for the removal of any dissolved contaminants related to mining. Exchange resins have been developed for the removal of heavy metals, calcium and magnesium, radionuclides, sulfate and ammonium. Although ion exchange process can remove contaminants effectively, their application is generally limited by high capital and operating costs, process complexity requiring highly skilled operators and the need for additional treatment of spent regenerant.

In general, ion exchange is not economically feasible for treating large volumes of concentrated wastewater due to the high cost of regeneration agents and the need to treat a concentrated regeneration brine. Ion exchange may have applications as a secondary treatment step to selectively remove specific contaminants such as heavy metals, ammonia, or calcium sulfate. There are several systems that have been developed for this purpose.

GYP-CIX is an ion exchange process that combines ion exchange processes with lime precipitation. Both cation and anion exchange resins are used. The resins are regenerated using sulfuric acid and lime to produce a gypsum slurry waste stream. Resin fouling is minimized by seeding the regeneration stage with gypsum crystals on which further precipitation takes place.

Like membrane processes, typical costs for ion exchange without brine treatment/management are in the range of \$0.5 to \$1.00/m^3 (SENES 1999). Brine management would add to these costs. Given that current water treatment costs are <\$0.5/m^3, there would be no advantage to adopting ion exchange processes at Anvil Range.

3.4 Evaporation/Distillation

Evaporation is the removal of a volatile solvent from a solution. In the case of mine water treatment, the solvent is water. Evaporation processes for the treatment of mine effluents can be divided into two categories, solar and mechanical evaporation. Solar evaporation involves simple disposal of the effluent to a shallow pond where it is allowed to evaporate. Obviously, solar evaporation of water can only be achieved in locations where evaporation exceeds precipitation. Mechanical or thermal evaporation refers to the use of various types of heat exchange equipment to achieve the heat transfer necessary for evaporation. Mechanical evaporation of an effluent stream to dryness is a very costly treatment option due to high energy consumption. For this reason, evaporators are usually only used for treating concentrated streams (e.g. following reverse osmosis) or if water recovery is imperative.

Evaporation processes produce a crystalline solid product and water vapor. In some cases, it may be possible to market some of the solid products such as gypsum, sodium sulfate and sodium chloride and offset the cost of treatment. Disposal of the soluble salt product may present significant problems and is often very expensive. Mechanical evaporation allows for the condensation of the vapor phase, which can then be recycled or discharged.

Costs for mechanical evaporation are >\$5/m^3 and as such mechanical evaporation is not a suitable technology for application at Anvil Range.

3.5 Biological Sulfate Reduction

3.5.1 Bioreactor Processes

Biological sulfate reduction has been applied for the removal of metals from contaminated waters. Systems that use biological reduction of sulfate to produce sulfide have many of the same positive and negative aspects as chemical sulfide precipitation, i.e. high removal of metals, possible recovery of saleable metal sulfide concentrates, H_2S gas emissions, sludge disposal issues. Bacterial sulfate reducing processes also have the added advantage of removing sulfate.

The Biosulfide process, patented by NTBC Research, separates the chemical precipitation step from the biological generation of H_2S. Pilot-scale testing at the Britannia mine in British Columbia was conducted using a reactor system capable of treating 50 L/min (13 gpm), (Rowley et al. 1997). Copper levels were reduced from 12 mg/L to less than 0.001 mg/L, zinc concentrations of 16 mg/L were reduced to 0.37 mg/L. This system was capable of producing saleable grade copper concentrate; however the zinc sulfide concentrate was not of sufficient quality due to copper contamination.

The first full-scale plant based on sulfate reducing bacteria (SRB) technology started operation in June 1992, in Budel-Dorplein, Netherlands, at the Budelco zinc refinery site (Scheeren et al. 1992 and Barnes et al. 1992). About 300 m^3/hour (1300 gpm) of groundwater is extracted from a combination of 12 shallow and deep wells and is currently being treated for the simultaneous removal of sulfate and metals by SRB, using ethanol as a source of carbon. The groundwater is contaminated with about 250 mg/L of zinc, 1,200 mg/L of sulfate and minor quantities of other metals. The final quality of the mine water treated at this facility has effluent concentrations of less than 0.1 mg/L for zinc, less than 0.2 mg/L for sulfate and less than 0.05 mg/L for cadmium, copper, iron and lead. In addition, the effluent pH varies between 6 and 7.

The Budelco process subjects the bioreactor to the entire acid mine drainage stream. This type of treatment system can reduce sulfate levels significantly but is more susceptible to fluctuations in the feed strength and flow. As well, the need for very large quantities of available carbon sources (e.g. ethanol) would make this treatment approach prohibitive at Anvil Range.

For biological treatment to be considered at Anvil Range, the plants would need to operate continuously as biological systems are not amenable to rapid start-up and seasonal operation. Cold weather operation would require heating of the water which in itself would make this process uneconomic.

3.5.2 Constructed Wetlands

There are two generic categories of constructed wetland systems, aerobic and anaerobic. Combinations of the two may also be considered. Wetlands are not likely to be appropriate technologies for effluent treatment at Anvil Range due to the very high flows, cold temperatures and the requirement for large land areas for wetland development.

3.6 Other Physical Processes

3.6.1 Freeze Thaw Technologies

There are a number of technologies that take advantage of freeze concentration of contaminants (i.e. when water freezes, the salts remain in the brine and the ice is low in salt content). Although novel concepts have been conceived for using snow making and or freezing technologies for management of acid and contaminated streams, the process has not proven to be practical, particularly for very large scale applications. In order to apply the technology, areas need to be developed where solutions can be frozen and the brine recovered for separate management. This requires large areas to be created to contain the contaminated solutions for freezing and a treatment plant to manage the resulting brine. Even after freezing, there will be a need to polish the effluent as residual contamination in the ice is a certainty.

4 SUMMARY

There are a number of treatment alternatives that could be considered for managing effluents at the former Anvil Range mine site. As a general rule, these systems are more complex and more costly to apply and are unlikely to produce superior water quality.

The proven performance of the conventional lime treatment and HDS processes make these lime treatment processes clearly the most attractive options for treatment of the drainage waters. These processes are simple, can be readily automated and have been commonly and successfully applied at remote sites. Improvement to the existing systems could be achieved through:

1) Improved water management systems to reduce the quantity of water requiring treatment, and;

2) Upgrading of the existing plants to: improve the efficiency of reagent use; reduce operations and maintenance labour demands and; minimize sludge volumes.

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SENES Consultants Limited, 1999. *Report On Technologies Applicable To The Management of Canadian Mining Effluents*. Report to Environment Canada, March

Appendix B

Treatability Testing Results

Appendix B - Treatability Test Results

Client	**: SRK Consulting**
Project	**: Faro - Metal Attenuation Testing**
CEMI Project	**: 0434**
Test	**: Bench Scale HDS Simulations**
Test Date	**: July 09, 2004**

[$Ca(OH)_2$]	**100**	g/L
Retention Time	25-35	minutes

Sample	**FPO1**	**X23**	**FRO01**	**VG01**
Starting pH	3.09	5.85	3.09	3.25
Target pH	9.50	9.50	9.50	9.50
Volume of Lime Added (mL)				
Cycle 1	6.25	20.55	10.80	61.50
Cycle 2	6.00	24.00	13.00	54.00
Cycle 3	6.25	28.30	14.80	63.05
Cycle 4	6.60	32.45	15.50	63.00
Cycle 5	6.30	32.80	15.25	68.55
Cycle 6	6.60	35.00	15.55	66.00
Cycle 7	6.65	35.00	16.50	65.00
Cycle 8	6.40	30.00	15.30	58.05
Cycle 9	5.30	21.50	14.30	59.95
Cycle 10	5.00	25.45	13.35	62.35
Lime Volume (mL)	61.35	285.05	144.35	621.45
Lime (g)	6.14	28.51	14.44	62.15
Lime (kg/m^3)	**0.61**	**2.85**	**1.44**	**6.21**

Sludge Production

Sample	Weights		Moisture	**Sludge Production**
	Wet	Dry	(%)	**(g/L)**
FP 01	70.7	6.0	91.5	**0.6**
X 23	314.8	58.2	81.5	**5.8**
FR 01	184.5	16.7	90.9	**1.7**
VG 01	555.8	134.2	75.9	**13.4**

Appendix B - Treatability Test Results

Client : **SRK Consulting**
Project : **Faro - HDS Simulation Tests**
CEMI Project : **0434**
Test : **ICP-OES**
Test Date : **July 21, 2004**

Parameter	**Units**	**FPO1**		**X23**		**FRO1**		**VG01**	
		Feed	Effluent	Feed	Effluent	Feed	Effluent	Feed	Effluent
pH		3.02	9.51	5.46	9.49	2.99	9.50	3.19	9.52
CONDUCTIVITY	(uS/cm)	1993	1180	2160	2150	3450	1775	3630	1424
ACIDITY	(pH 4.5)	107.5	-	0.0	-	157.5	-	177.5	-
	(pH 8.3)	340.0	-	872.5	-	775.0	-	4762.5	-
ALKALINITY	(mg CaCO3/L)	0.0	18.8	5.0	21.8	0.0	17.8	0.0	11.8
SULPHATE	(mg/L)	887	923	5985	3355	3532	2635	6705	1638
Total Metals									
Aluminum	(mg/L)	13.6	<0.20	0.6	<0.20	7.29	<0.20	42.4	<0.20
Antimony	(mg/L)	<0.20	<0.20	<0.60	<0.20	<0.40	<0.20	<2.0	<0.20
Arsenic	(mg/L)	<0.20	<0.20	<0.60	<0.20	<0.40	<0.20	<2.0	<0.20
Barium	(mg/L)	0.024	0.024	<0.030	0.016	<0.020	0.015	<0.10	0.011
Beryllium	(mg/L)	0.0065	<0.0050	<0.015	<0.0050	<0.010	<0.0050	<0.050	<0.0050
Bismuth	(mg/L)	<0.20	<0.20	<0.60	<0.20	<0.40	<0.20	<2.0	<0.20
Boron	(mg/L)	0.13	<0.10	<0.30	<0.10	<0.20	<0.10	<1.0	<0.10
Cadmium	(mg/L)	0.141	<0.010	0.194	<0.010	0.362	<0.010	3.04	<0.010
Calcium	(mg/L)	56.1	236	535	520	243	641	250	478
Chromium	(mg/L)	<0.010	<0.010	<0.030	<0.010	<0.020	<0.010	<0.10	<0.010
Cobalt	(mg/L)	0.298	<0.010	1.17	<0.010	0.810	<0.010	4.80	<0.010
Copper	(mg/L)	1.75	<0.010	0.213	<0.010	0.911	<0.010	18.5	<0.010
Iron	(mg/L)	11.5	<0.030	162	<0.030	27.6	<0.030	1460	<0.030
Lead	(mg/L)	0.303	<0.050	<0.15	<0.050	1.14	<0.050	3.11	<0.050
Lithium	(mg/L)	0.041	0.044	0.186	0.193	0.259	0.228	<0.10	0.087
Magnesium	(mg/L)	97.1	66.7	922	469	459	247	270	15.8
Manganese	(mg/L)	7.65	0.0845	85.5	0.0132	36.0	0.0059	178	0.0413
Molybdenum	(mg/L)	<0.030	<0.030	<0.090	<0.030	<0.060	<0.030	<0.30	<0.030
Nickel	(mg/L)	0.25	<0.050	1.52	<0.050	1.96	<0.050	2.31	<0.050
Phosphorus	(mg/L)	<0.30	<0.30	<0.90	<0.30	<0.60	<0.30	<3.0	<0.30
Potassium	(mg/L)	<2.0	2.6	17.3	16.1	10.5	11.5	<20	2.7
Selenium	(mg/L)	<0.20	<0.20	<0.60	<0.20	<0.40	<0.20	<2.0	<0.20
Silicon	(mg/L)	9.14	0.94	7.71	0.086	6.83	0.201	17.7	0.077
Silver	(mg/L)	<0.010	<0.010	<0.030	<0.010	<0.020	<0.010	<0.10	<0.010
Sodium	(mg/L)	3.6	3.8	55.2	51.8	16.5	15.1	<20	3.0
Strontium	(mg/L)	0.257	0.575	4.04	2.86	0.926	1.53	0.298	2.02
Thallium	(mg/L)	<0.20	<0.20	<0.60	<0.20	<0.40	<0.20	<2.0	<0.20
Tin	(mg/L)	<0.030	<0.030	<0.090	<0.030	<0.060	<0.030	<0.30	<0.030
Titanium	(mg/L)	<0.010	<0.010	<0.030	<0.010	<0.020	0.012	<0.10	0.013
Vanadium	(mg/L)	<0.030	<0.030	<0.090	<0.030	<0.060	<0.030	<0.30	<0.030
Zinc	(mg/L)	96.3	0.031	588	0.0735	380	0.0916	1560	0.0232

Appendix C

Equipment Costing Information

Table C-1. Clarifier Supplier Costs

		Supplier		
Description	**Units**	**Eimco**	**Westech**	**Westpro**
Clarifier Rake Mechanism				
Clarifier Diameter	m	33	33	33
Side water depth	m	3		
Side wall depth	m	3.15	3.35	3.15
Overall top of tank height from u/s of discharge cone	m	3.9		6.78
Tank bottom slope		1.75:12	1.75:12	1.75:12
Discharge Cone height and diameter	m	1.5 / 0.75	1 / 2.75	1.22 / 2.44
Mechanism				
Mechanism Model No.		EIMCO B60P-2 CLDT	Westech THS32	Westpro CL108
Mechanism type (mechanical or hydraulic)		Electro-mechanical	Mechanical	Hydraulic
Range of rake lift	mm	610	600	610
Drive motor	hp	10 (2x5)	2x3	15
Drive motor	RPM	1800	1750	1750
Rake Lift Motor	hp	1.5	3	Hydraulic
Rake Lift Motor	RPM		1750	
Duty-rated torque	N.m	650400	542400	340000
Drive head momentary peak torque rating	N.m	2227600	1084800	400000
Torque Measurement Device		Electronic Load Cell	Electromechanical	By pressure
V/ph/Hz		480/3/60	480/3/60	480/3/60
Materials of Construction				
Tank		Concrete on grade - tunnel not required		Concrete on grade with tunnel
Rakes		Mild Steel (A36 modified)	A36 Steel	MS A36/44W
Feedwell		Mild Steel (A36 modified)	A36 Steel	MS A36/44W
Bridge		Mild Steel (A36 modified)	A36 Steel	MS A36/44W
Monorail		Mild Steel (A36 modified)	A36 Steel	MS A36/44W
Dimensions				
Bridge width x length	m	1.2x16.5	2.75x33	1.99 x 33.61
Clarifier feedwell diameter and depth	m	3.5x2	4.3x2.1	4.88 x 3.05
Equipment location		outdoors		
Equipment rating		365 d/y, 24h/d		
Cost Estimate				
Clarifier		$330,400	$336,000	$319,750
FOB Point		Salt Lake City	Calgary	Vernon BC
Shipping dimension	m	five trucks 40'x8'		Bridge 2x34
Shipping weight	kg	22700	34000	30715

Table C-2. Lime Slaking Unit

		Supplier	
Description	**Units**	**ZMI/Portec**	**Mequipco / Stanco**
Equipment Model			
Silo Capacity	tonne	75 - 3000 cf	75
Silo Diameter x height	m x m	4.3 x 15.3	3.7x14.9
Silo material		A36 CS	
Volumetric Feeder Model & size		ZMI/portec - 2,500 pph	33ft3/hr
Lime conveyor type, model and size			6"x15' long
Lime transfer pump model & size			not required
Motor Hp / speed			
Lime Feeder		1 / 1750	1
Lime slaker		2 / 1750	3
Lime transfer pump		NA	NA
Cost Estimate			
Lime Package		$347,500	$462,000
FOB Point		Sibley, IOWA USA	Site
Shipping weight	kg	23000	n/a

Table C-3 Agitator Cost Estimates

			Supplier		
Description	**Tank Dimensions**	**Rating**	**Hayward Gordon**	**Bancroft Western Sales Ltd.**	**Black & baird (Lightnin)**
Sludge/Lime Tank Agitator	3 m Dia x 5.5 m H	3.7 kW	$12,700	$12,165	$16,987
Reactor Tank Agitators	4 m Dia x 5.0 m H	37.5 kW	$125,000	$104,000	$135,102
Mixing Tank Agitator	4 m Dia x 5.0 m H	3.8 kW	$13,100	$11,345	$16,064

Table C-4 PumpCost Estimates

			Supplier		
Description	**Size**	**Rating**	**Smith Cameron**	**National Process**	**Peacock**
Sludge Recycle Pump	100 x 75 R.L.	22.4kW	$20,430	$16,200	$23,110
Feed Pump	75 x 50 R.L.	22.4kW	$39,918	$13,200	$26,160
Sump Pump	37mm R.L.	18.7kW	$18,133	$7,740	$14,390
Recycle Water Pump	100 x 75 R.L.	18.7kW	$14,440	$8,250	$24,030
Clarifier Tunnel Sump Pump	37mm R.L.	18.7kW	$18,933	$7,740	$14,390
Water Pump	37mm x 25mm	5.6kW	$6,700	$8,440	$15,010
Lime Area Sump Pump	37mm R.L.	22.4kW	$14,890	$7,740	$13,100

Table C-5 Floculant Preparation System Costs

		Supplier		
Description	**Units**	**Ciba Specialty Chemicals**	**Mequipco**	**TWMackay**
Model number		MiniFAB 1250	Model DP500F	DO165H-OU
Dry polymer feed per batch	kg	6.25	3.3	2.1
Total batch time incl. feed, mix, transfer	min	82.5	45	50
Maximum number of batches per day		17.45 batches / 24 hours	32	29
Maximum polymer production	kg/day	109.1	106	90
Polymer solution concentration in storage tank	%	0.50%	0.50%	0.50%
Final polymer solution concentration	%	0.05%	0.05%	0.05%
Water supply requirement	L/min	100	69	170
Water supply pressure required max	kPag	620	480	345
Water supply pressure required min	kPag	410	275	
Dry polymer hopper capacity	L	113	161	227
Feeder capacity range	kg/h	84	60	116
Feeder motor	kW/ RPM	3.7 / 1720	0.19	0.373 1750
Polymer fluidising system description		Regenerative blower/Venturi assembly	Not Required	water operated eductor
Wetting system description		Auto Jetwet head	Vortex wetting system	high energy eductor
Mixing Tank Materials		316 ss	SS & acrylic	304 ss
Mixing tank dimensions	mm L W H	1524 x 1219 x 813	1000 x 1000 x600	762 x 1219 x 1016
Mixing tank capacity	m3	1.25	0.6	0.625
Mixing tank material of construction		304 ss	FRP	304 ss
Mixing tank residence time	min	60	45	83
Agitator material of construction		316 ss	SS	316 ss
Agitator motor	kW/ RPM	0.75 / 1750	1.1 / 1800	0.373 / 1750
Polymer solution storage tank dimensions	mm L W H	1828 x 1219 x 813	1000 x 1000 x700	1219 x 1219 x 1016
Polymer solution storage tank volume	m3	1.45	0.7	1.06
Storage tank material of construction		304 ss	FRP	304 ss
Polymer metering pumps		moyno pump 2L4 CDQ AAA	Seepex o5-12BN/110-1440-303-111	Netzsch Nm021
Design / max flowrate	L/min	15	6.9/11.4	7.6 / 12.6
Pump material of construction		rotor nitrile/ stator butyl	Cast Iron/SS internal/ Buna elastomers	316 ss Buna-N
Metering pump motor	kW/ RPM	0.75 / 1720	0.6 /1730	0.373 / 1750
Static mixer description		inline static mixer - 6 element design	USF/Stranco AF1200	Clear PVC
Static mixer material of construction		316 ss	PVC	PVC
Skid dimensions	mm L W H	NA	Powder Feeder 1371x1575x2388 Mix / hold tank skid 914x1016x1829 Feedpump skid 1200x1200x1200	Feed Skid 3041x1521x2648 Dilution Skid 1067x914x1676
Description of instrumentation and control		NEMA 4 enc, AB SLC1200 PLC,	Ab micro logic PLC &	PLC based control system
Cost Estimate				
Budget Quotation		$118,552	$111,269	$80,952
FOB point (ex works)		Job site	Toronto	Colmar PA
Shipping weight	kg	1800	2300	1300