TECHNICAL MEMORANDUM

Date:	December 13, 2013	**Project No.:**	13-1349-0001
To:	Julie L'Heureux, Alexandra Hood	**Company:**	De Beers Canada Inc.
From:	Paul Pigeon		
cc:	Lasha Young, Peter Chapman	**Email:**	Paul_Pigeon@golder.com

RE: TREATMENT REVIEW FOR FOOTWALL WATER AS PART OF TDS MANAGEMENT PLAN

Golder Associates Ltd (Golder) was retained to provide technical water treatment support to the De Beers Canada Inc. (De Beers) Snap Lake Mine in their development of total dissolved solids (TDS) and nitrate management plans. Based on related information transmitted to Golder and teleconferences on November 22 and 26, Golder's scope of services involved two tasks:

- Task 1 – Technical evaluation and cost development for treatment of TDS in footwall water.
- Task 2 – Providing supplemental cost information for nitrate treatment developed by CH2M Hill (2012).

Background information and the required technical and cost information are presented in subsequent sections. Attachment A provides a review of treatment options for TDS along with detailed cost information, both of which are summarized in this technical memorandum.

1.0 BACKGROUND AND PROJECT SCOPE

De Beers has completed treatment evaluations for segregated and combined sources, as well as upgrades to existing treatment facilities. Additional technical and cost information for completion of the TDS and nitrate management plans are described in the following sections.

1.1 Task 1 – Treatment of TDS in Footwall Water

Task 1 involved developing treatment information for TDS removal from footwall water:

- Use technology and cost basis information from Golder (2008) developed for treatment of haulage drift water which is of similar quality as the footwall water;
- Review current water quality information for the footwall seeps. Note any significant differences from the previous evaluation basis which would lead to changes in the treatment approach;
- Generate an order-of-magnitude capital cost estimate for treatment of footwall water;
- Generate an order-of-magnitude estimate for annual operations and maintenance (O&M) cost. Identify key components of annual O&M cost at the lower and upper ends of the flow range;

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- Prepare a cost estimate summary table and short description of the selected TDS treatment system; and
- Edit the technology identification and selection information from the 2008 report for inclusion in the TDS Management Plan.

1.2 Task 2 – Supplement Cost Information for Nitrate Treatment

CH2M Hill (2012) addressed treatment for nitrate removal from the entire mine dewatering flow. Other constituents, which are, or may be exceeded without control or treatment, were also addressed. Golder was requested to provide supplemental cost information and a description, if needed, to put this treatment approach on an equal cost basis with the footwall water treatment system (Golder's Task 1). Specific elements of Task 2 were:

- Determine whether capital and O&M estimates are presented on a comparable cost basis with the capital and O&M estimate developed for footwall water TDS treatment;
- Review the flow rate basis;
- Generate supplemental cost estimation data as needed, such as representative costs for secondary waste management; and
- Prepare a modified description and cost estimate summary table.

2.0 TREATMENT OF FOOTWALL WATER FOR TDS REMOVAL

2.1 Footwall Water Quality Information

Footwall water quality data were provided for a limited list of parameters for four sampling events in June and August 2013. These data were for TDS, chloride, fluoride, nitrate, and sulphate for monitoring locations UG FW1 through UG FW11. No more than two samples were collected from each location; a total of sixteen TDS analytical results were reported. Three to five results were reported for other parameters. All data were combined to develop average and maximum values for each parameter. These data are identified as "Historic Data for TDS". In addition, a complete analytical report for samples collected on August 20, 2013 and identified as "2013-2726" and "2013-2727" was reviewed. Table 2.1 summarizes the available footwall data with comparison to water quality characterization used in the Golder (2008) TDS treatment evaluation.

Table 2.1: Footwall Water Quality versus 2008 Haulage Drift Water

Parameter	Units	2008 Haulage Drift Water [1]			Footwall Water Quality 8/20/2013[3]			Historic Footwall Water Quality[4]	
		Min	Max[2/]	Avg	2726[2/]	2727	Avg	Avg	Max
pH	SU[5]	6.9	10.8	8.1	7.1	7.93			
TDS	mg/L	596	5090	3178	8540	530	4535	10640	19200
Alkalinity	mg/L [6]	11	93	49	26.4	69.9	48.15		
Chloride	mg/L	191	2820	1561	4460	169	2314.5	6846	10700
Sulfate	mg/L	32	252	154	540	32.3	286.15	565	750
Calcium	mg/L	85	1210	631	1840	68.6	954.3		
Fluoride	mg/L	0.66	1.09	0.94	0.78	0.799	0.7895	0.73	0.83
Magnesium	mg/L	0.7	46.7	33	107	4.49	55.745		
Sodium	mg/L	69	543	306	863	63.6	463.3		
Silica	mg/L	9.6	15.4	13.13	24.6	12.8	18.7		
Metals (total for 2008 data and dissolved for August data)									
Aluminum	mg/L	11.2	31.4	21.3	<0.1	0.00068			
Boron	mg/L	0.19	0.37	0.55	0.65	0.087	0.3685		
Barium	mg/L	0.061	0.669	0.365	0.076	0.00869	0.042345		
Iron	mg/L	13	23.15	33.3	<1	0.0211			
Manganese	mg/L	0.097	0.318	0.208	0.14	0.00946	0.07473		
Strontium	mg/L	1.42	9.3	5.365	31.1	1.03	16.065		

Notes:
[1/] From Golder (2008).
[2/] Maximum constituent concentrations were used for cost estimate development (Golder 2008). Data from sample location 2726 was used to represent footwall water quality in this evaluation.
[3/] From ALS Analytical Report provided by De Beers.
[4/] From MS Excel file "For Golder", provided by De Beers. All data were from sampling in June and August 2013 at locations UG-FW1 through UG-FW11.
[5/] "SU" = pH Standard Units.
[6/] Alkalinity is reported in mg/L, as $CaCO_3$.

TDS concentration data from sample location 2726 were compared to historic (UG-FW1 through UG-FW11) sample locations. TDS concentrations from UG-FW5, UG-FW6, UG-FW-7, and one of the two samples collected at UG-FW11 were higher than sample location 2726 results. All other TDS data from historic sampling locations were lower than the TDS results from sample location 2726. The average TDS concentration calculated using one analytical result for each UG-FW location is 8,962 milligrams per liter (mg/L) which is close to the 8,540 mg/L value shown for sample location 2726. Therefore, the 2726 water quality data were assumed to be representative of the footwall quality.

Comparison of the location 2726 footwall data to haulage drift water data used for the 2008 cost estimate showed that they were of similar quality. The primary differences were:

- TDS concentration was higher in the footwall water than in the 2008 haulage drift water, with the majority of the increase due to chloride.
- Increased concentrations were noted in some scaling or fouling constituents (calcium, sulphate, silica, strontium), while other constituent concentrations showed decreased concentrations (fluoride, aluminum, barium, iron, manganese).

The footwall water is expected to require similar treatment processes and constituent removal efficiencies as the 2008 haulage drift water. Modifications may be made to account for increased treatment residues; however, it is expected that the equipment costs can be directly scaled based on flow rate.

The sample location 2727 footwall data are similar to the "minimum" data for the 2008 haulage drift water. Neither were used further in this evaluation but can be considered as the lower bound for treatment system influent water quality.

2.2 Footwall Treatment Flow Rate Basis

The footwall water is projected to be recovered at a rate ranging from 4,000 to 9,000 cubic meters per day (m^3/day). Treatment equipment would be sized to accommodate the full range of projected flows, while typically operating in the 4,000 to 6,000 m^3/day range. Projections through the year 2028 show only two 3-month periods when the flows reach 9,000 m^3/day.

Equipment cost estimation is based on two parallel trains, each with maximum capacity of 4,500 m^3/day. If treatment of the footwall water proceeds, a more detailed analysis of flow projections should be completed. Cost and operational efficiency may dictate design of one train with 6,000 m^3/day capacity and a second train of 3,000 m^3/day, to accommodate nominal and maximum flows.

The annual O&M cost estimate is provided at an average flow rate over life of mine (5,425 m^3/day).

3.0 DESCRIPTION OF PREFERRED TDS TREATMENT ALTERNATIVE

Brief descriptions of potentially applicable TDS removal technologies and the reasoning for developing the preferred treatment train are presented in this section. A description of the preferred treatment train is also provided. More detailed technology identification and selection information is presented in Attachment A.

3.1 TDS Technology Review

Potentially applicable treatment technologies for removal of TDS are evaporation, reverse osmosis, ion exchange, electrodialysis reversal, and chemical precipitation. Development of treatment alternatives may require implementation of a single primary technology from the candidate list (with minimal pre- or post-treatment steps), or may involve a combination of technologies (e.g., reverse osmosis and chemical precipitation). Minimization of secondary waste is an important aspect of the Snap Lake Water Management Project. While any of the above technologies can produce an effluent of acceptable quality, additional processing steps may be necessary to produce a secondary waste stream of manageable quality and volume. The other driving factor in the cost effectiveness of water treatment technologies is utility power demand.

Table 3.1 presents a summary and comparative screening evaluation for the treatment of footwall water. Reverse osmosis (RO) is retained as a primary TDS removal step with an evaporator to manage the brine

Table 3.1: Comparative Evaluation of Treatment Technologies for De Beers Snap Lake Footwall Water

Technology	Advantages	Disadvantages	Comments	Environmental Benefits/ Non-benefits	Potential of Economic Benefits Exceeding Costs	Retain/Reject
Evaporation	Zero liquid discharge treatment is an option with distillate released as water vapor to atmosphere, or a condenser could be utilized to recover high quality treated water. Residual stream requiring management or disposal is extremely low volume. Can be operated continuously or batch-wise.	Distilled water can be corrosive. Reuse and/or discharge may require post-treatment. Mechanical evaporation presents the highest capital and operating costs of all technologies screened. Lead time on equipment may exceed one year. High operating cost is driven by utility power demand. Batch-wise operation is not as efficient as continuous operation because reheating of the system is required for each start-up.	Evaporation is not cost-effective as the primary treatment unit. Treating a split stream and blending back with untreated water to maintain a TDS effluent goal may be viable although the reduction in treated throughput would be approximately 10%. Evaporation may be viable as a secondary treatment unit, to manage a small volume brine or concentrate stream resulting from any of the other screened technologies.	Evaporation produces extremely high quality effluent water with low volume of secondary waste. Secondary waste is a highly concentrated but leachable salt stream that must be disposed in an isolated cell.	Capital and annual operating costs are highest of the technologies screened. Unless there is a need for distilled water, there is no economic offset for the high cost of this process.	Retain as a secondary waste management option.
Reverse Osmosis (RO)	This membrane filtration process produces an extremely low TDS, high quality treated water stream. It is a proven technology for TDS treatment. RO systems can be operated continuously or batch-wise, but best operated in continuous mode.	Brine stream flow rate may be as high as 25 to 50% of the influent flow, and will require further treatment. Capital and operating costs are expected to be mid-range, relative to other technologies. Operations become problematic if system is shut down. Membranes must be properly cleaned and stored when not used for more than 1 to 2 days. Relatively highly skilled operations personnel are needed. Several parallel trains would be needed to provide treatment over the full range of projected influent flow rates.	Pretreatment may be required to remove foulants that could reduce treatment efficiency or require more frequent membrane cleaning. Treatment of RO brine for volume reduction could be accomplished by series RO treatment or by mechanical evaporation. Similar to evaporation, an untreated bypass stream could be recombined with treated flow while maintaining effluent quality at the required TDS effluent discharge limit. Similar to evaporation, the bypass would likely be limited to about 10% of total flow.	RO produces a high quality treated effluent; however, it also produces a relatively high volume liquid secondary waste stream that must be managed.	Capital and operating costs are expected to be lower in comparison to evaporation. If a recovery in excess of 75% can be achieved it may be reasonable to evaporate RO brine to provide a significant volume reduction. Residual brine disposal in an isolated cell will be required.	Retain as a primary water treatment option.
Electrodialysis Reversal (EDR)	The EDR process involves applying an electrical charge to filter membranes to retain dissolved ions of the opposite charge. It provides bulk TDS removal and is less susceptible to scaling problems than RO. It is a proven technology for TDS treatment, and can be operated continuously or batch-wise. It is expected to be less expensive than RO on the basis of contaminant mass removed.	EDR produces a smaller volume brine stream than RO. EDR brine will require further treatment. EDR is expected to produce treated water with higher TDS concentration than RO and may not meet the TDS treatment objectives. EDR requires more utility power than RO and is more sensitive to influent temperature. The footwall water TDS is at the upper range of typical EDR applications.	EDR is technically infeasible for this site, due to footwall water quality characteristics.	EDR is expected to produce a similar treated effluent as RO, but at a higher cost.	Capital and operating costs are expected to be higher than RO, and lower than evaporation. It may be reasonable to evaporate EDR brine to provide a significant volume reduction. Residual brine disposal in an isolated cell will be required.	Reject
Ion Exchange (IX)	IX is a simple “flow-through” technology, with contaminant ions being held on the IX resin. The resin releases innocuous ions into the treated stream. IX could be implemented on a relatively short lead time. IX can be operated continuously or batch-wise.	IX is ineffective for TDS reduction at concentrations projected for Snap Lake’s design basis influent. IX is typically used to remove specific contaminant ions when replacement of the removed contaminant with an innocuous ion is acceptable. IX produces a concentrated waste stream when resin is regenerated that would have to be treated or disposed.	IX is technically not feasible for this site. IX will not effectively reduce TDS concentration.	Not viable	Not viable	Reject
Chemical Precipitation	Chemical precipitation involves reaction between dissolved contaminants and chemical reagents, resulting in formation of solid precipitates that are removed from the treated flow. It can be implemented on a short lead time. Equipment is relatively inexpensive.	A sludge stream is produced as a secondary waste. TDS removal efficiency may not meet discharge requirement. Onsite chemical reagent storage is needed, and the required storage capacity could be prohibitively large.	Chemical precipitation is technically not feasible for this site as a primary treatment process. It could be considered as an RO pretreatment or brine treatment process. If used as a supplemental process it would greatly increase operations costs (primarily labour and chemical consumption).	Not viable	Not viable	Reject

from the RO. This is the same conclusion reached, for the same reasons, as the Golder (2008) evaluation for treatment of haulage drift water.

3.2 Alternative Description

The treatment cost for footwall water is based on an RO system as the primary TDS removal process and an evaporator as the main brine management process. RO, evaporation, and ancillary systems are discussed briefly below.

Ultrafiltration – the recovered footwall water would be prefiltered by an ultrafiltration system to remove fine particulate and colloidal material, allowing for efficient operation of the RO system. The solids rejected from the ultrafiltration system would be managed with the solids from the crystallizer and filter press.

Chemical Feed – RO modeling was completed to confirm that a 75% recovery could be achieved and that scaling could be controlled with antiscalent addition. Table 3.2 provides a summary of modeling results, indicating that a dose of 3 mg/L of antiscalent would be needed. The chemical feed would include the chemical storage (totes or drums) and a metering pump to add the chemical inline prior to the RO system.

RO System – the RO includes filtration membranes, high pressure feed pump, and a cleaning skid. The operating costs include replacement of the membranes every two years. Several parallel modules of RO membranes would provide maximum operational flexibility. The previous RO and secondary waste (brine) management evaluation was based on achieving 75% recovery. RO performance has been modeled to confirm that 75% recovery can be achieved for treatment of the footwall water. Table 3.2 shows a comparison of modeling results for the 2008 and footwall evaluation basis water quality. These two water qualities are highlighted in Table 2.1.

Table 3.2: Comparison of RO Data for Treatment of Haulage Drift Water Versus Footwall Water

Parameter	Drift Water – 2008	Footwall Water 2013
Recovery at 10°C (2 stage RO)	75%	75%
Feed Pressure (psig) at 10°C	358	326
Stage 2 Pressure (psig) at 10°C	340	421
Antiscalant Dose Pass 1 (mg/L)	2	2
Antiscalant Dose Pass 2 (mg/L)	3.68	2.01
Antiscalent Total (mg/L)[1]	3.84	3.0

[1] Pass 2 is at half the flow of pass one so the total antiscalent dose is equalized to the influent feed flow rate.

Brine Management – brine would be managed by an evaporation system to reduce its volume. Evaporator bottoms would be further treated through a crystallizer and filter press to minimize the volume of crystallized solids. For the purposes of projecting secondary waste volume it was assumed that the filter press cake would be 90% solids. At an average influent flow of 5,425 m^3/day the quantity of secondary waste that must be disposed at 90% solids is 9,200 m^3/year.

4.0 CAPITAL AND OPERATING COST ESTIMATE DEVELOPMENT

Capital and operating cost estimates have been developed for treatment of footwall water for TDS removal. De Beers also requested evaluation of the proposed water treatment plant (WTP) expansion and upgrade for nitrate removal (as reported by CH2M Hill 2012) as a comparison to treatment of footwall water for TDS removal. The CH2M Hill (2012) cost summary and their full report were provided to Golder for review, to ensure that the cost comparison could be performed on a “level playing field.” The following sections provide summary evaluation of capital and O&M estimates for footwall water treatment, and for CH2M Hill’s (2012) nitrate removal plant. Cost items which were not fully developed for the nitrate removal plant have been estimated. Finally, differences in evaluation basis parameters are described.

4.1 Footwall Water TDS Treatment

Based on similarities in water quality and flow rate, the cost estimates developed by Golder (2008) for treatment of haulage drift water were used as a basis with updates to reflect changes in equipment, materials, and energy costs. The capital cost estimate is inclusive of:

- Process equipment costs, based on supplier quotes (suppliers provided updated 2013 costs to their original quotes); and
- Factored costs for concrete foundations, electrical, insulation, process structural, process material labor, home office engineering, and field expenses.

The capital cost estimate is presented in greater detail in Attachment A.

Table 4.1 shows the projected capital and annual O&M cost estimates. The capital estimate is based on treatment of 9,000 m^3/day. The annual O&M cost estimate is based on the average flow of 5,425 m^3/day as projected for operations from 2014 through 2028.

Table 4.1: Summary of Costs for TDS Removal from Footwall Water

Item	Cost	Basis
Capital Cost Estimate	$84,000,000	9,000 m^3/day hydraulic capacity
Annual O&M Cost Estimate	$7,300,000	5,425 m^3/day average treatment rate

Components included in the annual O&M cost estimate are power at $0.27 per kilowatt-hour, lead operator and maintenance technician at $35 per hour, assistant operator at $25 per hour, RO chemicals (antiscalent and cleaning chemicals), RO membrane replacement on a 2-year cycle, and annual routine maintenance costs at 1.5% of initial capital equipment cost.

As shown in Table 3.2, a recovery of 75% can be achieved; however, the operating pressure will be higher for the footwall water due to higher TDS concentration. The projected dose of antiscalent for treatment of footwall water is lower, due to lower concentrations of scaling constituents. These differences are incorporated into the O&M cost estimate.

The annual O&M cost estimate does not include disposal of secondary waste (evaporator bottoms). Three disposal methods have been proposed: onsite disposal in an isolated waste management cell; blending with paste for mine backfill; or, development of a deep injection well. For the purpose of evaluation, the cost of secondary waste disposal is directly proportional to the volume of waste generated. Comparison of disposal costs can be made qualitatively, based on the total volume of secondary waste generated.

The breakdown of the annual O&M cost estimate is:

- Power: 80%;
- Maintenance: 15%;
- RO chemicals/membranes: 2%; and
- Labor: 3%.

The labor projections assume that the treatment system is covered by one lead operator and two assistant operators with 20% for overtime and callouts and supported by a half-time maintenance technician. The primary impact to annual operations and maintenance costs in operating at the low (4,000 m^3/day) or high (9,000 m^3/day) end of the flow range will be in power consumption and the secondary waste generation. The power cost and final volume of secondary waste can be directly scaled on the flow rate change from the basis of 5,425 m^3/day.

4.2 Water Treatment Plant for Nitrate Removal

CH2M Hill's (2012) treatment process and cost development addressed nitrate removal for treatment of the full mine dewatering flow. The treatment system included equalization, pretreatment for solids and metals removal by high rate clarification, followed by membrane filtration (microfiltration/ultrafiltration and RO) for further reduction in metals concentrations and to remove nitrate, chloride, and fluoride. In addition to equipment costs CH2M Hill (2012) included a lump sum estimate to cover mechanical, electrical, instrumentation and controls, structural and civil components as required, and provided a capital estimate for the fully installed treatment plant.

The CH2M Hill (2012) evaluation focused on treating influent flows projected for 2015 to comply with the new water license discharge limit for nitrate. The evaluation assumed that upgrades and new equipment would be installed at the existing WTP to allow treatment of flow rates up to 45,000 m^3/day. This flow rate was the maximum projected from a linear extrapolation of four years of influent flow data from January

2008 through December 2011. The average and minimum flows for 2015 were projected at 41,000 and 37,000 m^3/day respectively. CH2M Hill's (2012) capital cost estimate was presented as shown in Table 4.2. CH2M Hill (2012) did not develop an O&M cost estimate for the nitrate removal treatment plant.

Table 4.2: Capital Cost Estimate for Nitrate Removal from WTP

Cost Item[1/]	Cost
High rate clarification	$2,610,000
MF/UF + RO [2/]	$17,000,000
Equalization	$120,000
Mechanical, electrical, I&C [2/], structural, civil	$24,000,000
Subtotal	$43,730,000
Total capital cost range (-10% to +50%)	$39,357,000 to $65,595,000

Notes
[1/] A brine concentrator/crystallizer system was estimated at $33,000,000 but was not included by CH2M Hill (2012) in the equipment cost line items.

[2/] MF = microfiltration; UF = ultrafiltration; RO = reverse osmosis; I&C = instrumentation and controls.

4.3 Cost Estimate Comparison

There are significant differences in the cost bases between the CH2M Hill (2012) nitrate removal treatment plant and the Golder footwall water TDS removal plant. Differences are noted in the following section. A comparison of capital and O&M cost estimates is then presented. Cost bases have been equalized and revisions to CH2M Hill's (2012) cost estimates are described.

4.3.1 Differences in Operational Bases

There are two primary operational differences between the treatment systems. The CH2M Hill (2012) plant was conceptualized to treat the full mine dewatering flow along with high nitrate runoff from the waste management pond (WMP). The Golder plant was conceptualized to treat only footwall water due to its higher TDS concentration, with a goal of effluent TDS management. Despite these differences, there are similarities in the treatment technologies, specifically the utilization of membrane filtration and brine evaporation. Both systems can be expected to produce a very high quality treated effluent and a minimal volume of secondary waste in the form of crystallized salts.

The nitrate removal plant is likely to achieve equivalent removal of TDS as the footwall water treatment system. The footwall water treatment system is expected to be highly efficient for TDS removal, but does not address the WMP runoff nitrate source.

4.3.2 Capital Cost Estimate Equalization

In order to compare treatment system cost estimates on an equalized basis, Golder revised the CH2M Hill (2012) capital cost estimate to account for annual inflation, included brine management equipment, and increased the lump sum line item covering the non-process engineering disciplines in proportion to the increase in capital equipment cost. The revised cost estimate for the nitrate removal WTP is presented in Table 4.3.

Table 4.3: Equalized Capital Cost Estimate for Nitrate Removal from WTP

Cost Item	Cost
High rate clarification	$2,714,000
MF/UF + RO [1/]	$17,680,000
Equalization	$125,000
Brine concentrator/crystallizer	$34,320,000
Process Equipment Subtotal	**$54,839,000**
Installation - Mechanical, electrical, I&C [1/], structural, civil	$66,700,000
Subtotal	**$121,539.000**
Total capital cost range (-10% to +50%)	$109,385,000 to $182,308,000

Notes:
[1/] MF = microfiltration; UF = ultrafiltration; RO = reverse osmosis; I&C = instrumentation and controls.

The cost estimates for nitrate removal in Tables 4.2 and 4.3 are based on a maximum flow rate to be treated of 45,000 m^3/day, based on information from 2012. More recent estimates of future flows indicate that the maximum total mine water flow will reach 60,000 m^3/day during life of mine, with a 25% uncertainty factor. The nitrate treatment system needs to be designed for 75,000 m^3/day based on this information. The capital cost of nitrate treatment factored for this change in flow from 45,000 m^3/day up to 75,000 m^3/day (using the 7/10 rule) is $174 million.

For comparison, Golder’s capital cost estimate for footwall treatment is $84,000,000 including process equipment at $33,444,000, and factored installation costs at $50,566,000.

4.3.3 O&M Cost Estimation

As noted above, CH2M Hill’s (2012) report on nitrate removal did not include an estimate of annual O&M costs. Golder has estimated O&M costs for the nitrate removal plant on an equal basis with Golder’s O&M cost estimate for footwall water treatment. The comparison of annual O&M costs for the two treatment systems is presented in Table 4.4.

Table 4.4: Estimates of Annual O&M Costs for Nitrate Removal WTP and Footwall TDS Treatment

Cost Item	Cost	Basis
Annual O&M for TDS treatment of footwall water	$7,300,000	9,000 m^3/day hydraulic capacity, 5,425 m^3/day average treatment rate
Annual O&M for Nitrate Removal WTP [1/]	$19,000,000	45,000 m^3/day hydraulic capacity, 45,000 m^3/day average treatment rate

Note
[1/] O&M cost was estimated by Golder. CH2M Hill (2012) did not provide an O&M estimate.

The breakdown of the annual O&M cost for the nitrate removal WTP is as follows:

- Power: 67%;
- Maintenance: 10%;
- Chemical precipitation and RO chemicals, RO membranes: 19%; and,
- Labor: 4%

The labor projections assumed that the treatment system would be covered by one lead operator and one maintenance technician covering 10 hours per day 7 days per week, and 2 assistant operators covering continuous 24-hour per day operation with a 20% addition for overtime and callouts.

The secondary waste currently generated by TSS removal and the material generated by chemical precipitation have not been accounted for in the waste projections.

For the range of flows analyzed for the TDS and nitrate treatment systems, annual O&M costs would range as shown in Table 4.5.

Table 4.5: Range of Annual O&M Costs

	Range of Operating Flows (m^3/day)	**Range of O&M Costs ($million)**
TDS Removal Treatment	4,000	$5.4
	9,000	$12.1
Nitrate Removal Treatment	45,000	$19.0
	75,000	$31.8

5.0 CONCLUSIONS

A TDS Management treatment concept has been developed, through treatment of footwall water. Order-of-magnitude estimates for capital and annual O&M estimates have been developed. The work previously done by CH2M Hill (2012) for nitrate removal of the full mine dewatering flow and WMP runoff was reviewed for technical and cost evaluation.

The nitrate removal system has higher estimated capital and O&M costs, primarily due to its scale of treatment being five times larger than the footwall water treatment system.

The systems were conceptualized for two different purposes, one for TDS management and the other to meet specific constituent discharge limits in the 2015 Water License. While similar technologies have been conceptualized for both systems (RO-based treatment for removal of dissolved inorganic species, with secondary waste volume minimization by evaporation), the comparison is still skewed by the difference in treated effluent objectives. The footwall water treatment system is expected to effectively control the TDS concentration in treated effluent discharged to Snap Lake, but does not address the nitrate concentration in WMP runoff. Modifications to the existing WTP would be required, in concert with footwall water treatment, to achieve both TDS and nitrate effluent quality criteria.

6.0 REFERENCES

CH2M Hill. 2012. Snap Lake Mine Water Treatment Plant Alternatives Evaluation. Prepared for De Beers Canada Inc. Yellowknife, NWT, Canada.

Golder (Golder Associates Ltd.). 2008. Snap Lake Water Management Treatment Alternatives Report. Prepared for De Beers Canada Inc. Yellowknife, NWT, Canada.

ATTACHMENT A
DETAILED TECHNOLOGY SELECTION AND COST INFORMATION

1.0 POTENTIALLY APPLICABLE TREATMENT TECHNOLOGIES

Potentially applicable treatment technologies for removal of total dissolved solids (TDS) are mechanical evaporation, reverse osmosis (RO), ion exchange (IX), electrodialysis reversal (EDR), and chemical precipitation. Development of treatment alternatives may require implementation of a single primary technology from the candidate list (with minimal pre- or post-treatment steps), or may involve a combination of technologies (e.g., reverse osmosis and chemical precipitation). Minimization of secondary waste is an important aspect of Snap Lake water management. While a treatment process train utilizing any of the above technologies can produce an effluent of acceptable quality, additional processing steps may be necessary to produce a secondary waste stream of manageable quality and volume. Energy consumption is the other key operations and maintenance (O&M) component due to the high cost of energy at the Snap Lake Mine. Each of the candidate technologies is briefly described. A treatment train, developed from technology screening and site-specific considerations, has been developed and is described.

1.1 Evaporation – Mechanical Process Equipment

Evaporative techniques produce a treated effluent by vaporizing pure water from the influent flow into a distillate stream, and concentrating contaminants in a secondary waste stream known as evaporator bottoms. In cases where “zero liquid discharge” is preferred or required, distillate is released to the atmosphere. If there is a need for high quality water the distillate can be condensed and re-used. The evaporator bottoms byproduct typically consists of highly concentrated liquid slurry, which may be further treated to a dry residue. While the distillate typically exhibits a very high purity, there are some constituents that can vaporize and carry over. Examples of constituents that may carry over include ammonia, mercury, and volatile organics. While mercury and volatile organics are not expected to be present, there may be some ammonia in Snap Lake water treatment influent sources. Footwall water sample 2726 (August 20, 2013) had an ammonia concentration of 0.272 mg/L (as N) so there is potential for ammonia carry-over in evaporator distillate.

As noted above, mechanical evaporation involves boiling pure water out of the waste stream and leaving a concentrated brine slurry as a secondary waste product. Evaporation is broadly applicable to removal of non-volatile contaminants in wastewater including TDS. A mechanical vapor recompression (MVR) brine concentrator is a commonly used process for this type of application because of its lower energy requirement relative to other types of evaporative equipment. Approximately 95 to 98% of influent water becomes distillate, with 2 to 5% going into the concentrated brine slurry. Typical management methods for evaporative slurry are: crystallization to near dryness, deep well disposal, and off-site disposal. On-site disposal with waste rock is also a possibility for the Snap Lake site. The total volume of crystallized waste and potential for reintroduction of TDS to ground water or surface water (if leached from waste rock storage) would have to be evaluated to assess the viability of on-site disposal. An isolated disposal cell, effectively contained to prevent migration of evaporator salts into the environment, may also be viable as a final disposition option.

1.2 Reverse Osmosis

Reverse osmosis (RO) treatment is essentially an extremely fine filtration technique that utilizes a series of fine pore membranes. Pure water and extremely low concentrations of some contaminants will pass through the membranes (the permeate stream) while the majority of the contaminants are retained on the brine side of the membrane (the reject stream). RO systems can be relatively simple, consisting primarily of filtration modules, a high pressure pump, and a clean-in-place ancillary unit. Some pretreatment to protect the membranes is typically required, and may include filtration for suspended solids removal, antiscalent addition, and preheating. The osmotic pressure required for RO treatment is inversely related to the temperature of influent water. Thus, preheating can increase treatment efficiency while reducing the pumping power requirement.

Based on experience with similar water sources, the TDS concentration in RO permeate for Snap Lake water treatment could be in the 50 to 100 mg/l range. TDS in the RO reject stream could be in the range of 30,000 to 40,000 mg/l. The reject stream flow rate is typically in the range of 20 to 50% of the influent stream. Like the evaporation process, RO is broadly applicable to TDS contaminants and can provide a 95 to 99% reduction in the contaminant concentrations. Other than soluble organics, there are very few constituents that are not removed at efficiencies in the range of 95 to 99%. Some constituents that may be less efficiently removed by RO include boron, ammonia, and nitrate.

Ancillary equipment needed for a fully functional RO treatment system may include prefiltration, pretreatment to remove fouling or scaling parameters (aluminum, iron, manganese, alkalinity, hardness, sulfate, etc.), antiscalent addition, preheating, and a membrane cleaning system. The reject stream must be managed further by disposal or additional treatment. For treatment of the footwall water it is expected that scaling can be controlled with an antiscalent addition to achieve a 75% recovery and the only pretreatment needed will be filtration for removal of fine suspended solids.

1.3 Electrodialysis Reversal

Electrodialysis reversal (EDR) is an electrochemical separation process that removes charged species from water. EDR uses small quantities of electricity to transport these species through membranes composed of ion exchange material, creating separate purified and concentrated streams. The ion exchange membranes are configured in an alternating series of anionic and cationic membranes. Ions are transferred through the membranes by means of direct current (DC) voltage. When membranes become saturated, the electrical current is reversed, effectively cleaning the membranes for continued use.

EDR presents an advantage over RO in that it typically requires less pretreatment. In particular, silica (which can limit RO treatment efficiency) is not a concern as an influent contaminant for EDR. Control of influent pH and addition of antiscalent are generally not necessary with EDR. EDR has been demonstrated effective on groundwaters containing TDS concentrations as high as 5,000 mg/l, recovering clean water at 94% efficiency. Polarity reversal allows for concentrating brine beyond saturation. Through this electrically driven process, the quality of treated water can essentially be "turned up" or "turned down" by adjusting the DC (direct current) voltage applied to the membranes. EDR does not provide TDS removal to the same level achievable by RO. Final TDS treatment goals must be considered when evaluating EDR. If TDS removal efficiency of greater than 90% is required, EDR may not be viable.

The two primary disadvantages of EDR in comparison with RO are lower TDS removal efficiency and higher power usage. For treatment of the footwall water EDR is expected to be less feasible than RO, for operational efficiency and cost-effectiveness.

1.4 Ion Exchange

Ion exchange (IX) is the reversible exchange of ions between the stream to be treated and an insoluble solid ion exchange resin. It is a well-developed process for extraction of cations (such as calcium or magnesium) or anions (such as sulphate or nitrate) from wastewater. Ions present in the wastewater are exchanged with ions on the resin, without producing any permanent change to the resin structure. The most commonly used exchange ions (present on fresh resin) are sodium for cation exchange and chloride for anion exchange. Thus, the treated water stream will contain elevated concentrations of sodium and chloride. When the active sites on the resin are exhausted, the resin is regenerated by contacting it with a concentrated solution of the exchange ions originally associated with the resin. The contaminant ions are carried off the resin with the regeneration liquor in a concentrated form. The regeneration liquor is the IX secondary waste stream.

IX treatment efficiency can be in the range of 90 to 99% for common anions and metals. Suspended solids and organics must be removed from the wastewater prior to IX treatment to prevent fouling of the resin. IX media is contained in a column or series of two to three columns. Flow can be pumped or gravity-driven. Ancillaries include tanks for fresh and used regeneration chemicals, and pumps required for the regeneration cycle.

Due to the high ionic strength and TDS concentration in footwall water, IX is not viable as a primary TDS removal process. IX could be viable as a polishing process if there were trace constituents requiring removal for compliance with Snap Lake's water license. Since the water license does not provide discharge limits for specific constituents, IX polishing is not necessary.

1.5 Chemical Precipitation

Chemical precipitation is a pH adjustment process that involves minimizing the solubility of target compounds. Calcium hydroxide (lime) or sodium hydroxide (caustic) are commonly used to increase pH. Metal-hydroxide precipitates are formed and can be removed by gravity or flocculant-aided settling. Sulphate can also be removed through chemical precipitation, to the solubility limit of calcium sulphate (or sodium sulphate). Bulk solids removal is accomplished through removal of clarifier underflow, and the clarifier decant may be filtered to remove any remaining fine suspended solids. Clarifier underflow is typically dewatered by pressure filtration to minimize the volume of sludge prior to disposal. Sludge is generally stable and could be disposed as a conventional solid waste. Metals are typically immobilized in hydroxide form and require extended exposure to acidic conditions to re-dissolve. The pH of clarifier decant may have to be brought back into the neutral range as a final treatment step.

A large fraction of the TDS concentration present in footwall water is chloride, which will not be affected by pH adjustment. Thus, chemical precipitation is not viable as a primary treatment process. It is also not viable as a pretreatment process due to the relatively low concentrations of scaling constituents. Chemical precipitation would be technically effective as a secondary waste treatment process for RO reject; however, the volume of sludge generated would significantly increase the overall system's production of secondary waste.

2.0 TECHNOLOGY SCREENING

In most water management alternatives studies, there are two or three viable process trains that can be developed with equivalent capabilities to meet the treatment goals, which can then be evaluated against criteria such as capital and operating costs, labour requirements, ancillary equipment, and utilities consumption. However, Snap Lake presents unique conditions which severely restrict the range of viable treatment technologies. These conditions include the influent water quality characterization and treatment goals, site location, and limited secondary waste storage/disposal options. These conditions and their bearing on the technology identification and screening process are described below.

2.1 Influent Water Quality Characterization and Treatment Goals – Water Chemistry

The influent water quality characterization of the footwall water is based on a sample collected from location 2726. Key parameters are summarized on Table A.1. The evaluation basis influent water chemistry is not well-suited to treatment by EDR, IX, or chemical precipitation.

EDR is best suited to a relatively clean influent with TDS concentration of 5,000 mg/L or less. The TDS concentration of footwall water exceeds the operational capabilities of EDR.

IX is not viable for TDS reduction due to its contaminant removal mechanism of replacing the resin-absorbed contaminant ions from the treated flow with ions released from the resin. In the case of Snap Lake's discharge requirement to treat to a low TDS concentration, IX is not viable.

Chemical precipitation will not provide adequate removal of TDS since a predominant component of the footwall TDS is chloride, which is unaffected by chemical precipitation. As noted above, chemical precipitation may be a viable brine treatment, but the total volume of secondary waste would increase.

The water quality characterization also has process impacts on an RO or evaporation-based treatment system but can be handled with pretreatment steps, primarily filtration to remove suspended solids and antiscalent addition. Both the RO and evaporative systems will be negatively impacted by silica, which will limit the recovery on an RO system and may require removal prior to an evaporative system.

2.2 Flow Rates

The required treatment flow rate of 4,000 to 9000 m^3/day can be handled by either evaporation or RO as the main treatment operation; however, the turn-up and turn-down capability of these technologies is limited. Flow rate flexibility can be designed into the system through use of smaller capacity treatment trains in parallel configuration. For the purposes of this evaluation it is assumed that two parallel 4,500 m^3/day systems will be included.

2.3 Site Location

The primary issue with location is the inaccessibility of the site by surface transportation except during the limited time period of winter road operation. This presents problems for treatment processes that are dependent on routine use and replacement of chemical reagents or resins in bulk quantities. Requirements for chemical or resin storage or shipment are prohibitive for IX and chemical precipitation treatment systems.

Again, RO and evaporation will require some pretreatment steps but are more viable than IX or chemical precipitation treatment systems with regard to storage or delivery of bulk materials required for continuous operation.

2.4 Secondary Waste

Similar to the constraints of bulk deliveries to the site for process operations, location is also a constraint relative to storage or disposal of secondary wastes generated by treatment processes. The options for final disposition of secondary waste are limited to use in paste backfill, return to the mine workings, or offsite disposal.

The waste stream generated by a chemical precipitation system would be metal-hydroxide sludge. By adding a dewatering step, the volume could be somewhat reduced. Since there are limited constituents that would precipitate, the sludge volume may not be prohibitive and the characteristics of the sludge may or may not be suitable for use in paste backfill. The planned volume and rate of paste backfill in relation to mine development may also be a limiting factor in disposal of chemical precipitation sludge.

IX will produce a concentrated liquid waste stream when the resins are regenerated. The regenerant stream will require treatment for volume reduction and stabilization. Untreated IX regenerant will not be suitable for use as a paste backfill additive, nor can it be disposed in an uncontained waste pile. Disposal would require an isolation cell, and the volume of untreated backwash over the life of the project would make isolation infeasible.

Similar to IX regenerant, EDR and RO both produce a concentrated liquid waste stream. This reject stream will also require additional treatment for volume reduction and stabilization. Brine is not suitable for addition to paste backfill, and cannot be disposed in an uncontained waste pile. Disposal of RO or EDR waste without additional treatment is not feasible.

Evaporation will produce the lowest volume of secondary waste. If a crystallizer is utilized, evaporation will produce only dry solid salts as a waste stream. This dry solid waste will require the smallest volume of isolated disposal of any of the technology options. As such, evaporation is a viable option as the main treatment process and is also viable as an additional treatment step, for volume reduction of the secondary waste streams from RO.

The advantages and disadvantages of each technology are summarized in Table 3.1, in the Technical Memorandum. EDR, IX and chemical precipitation are not feasible due to failing the screening criteria described above. The development of viable treatment processes considered RO and evaporation as primary treatment processes. Cost evaluation led to RO development of the preferred treatment train utilizing RO as the main TDS removal process, with evaporation of the RO reject stream to minimize the volume of secondary waste.

3.0 TREATMENT TRAIN DESCRIPTION

The most viable treatment train for the water chemistry includes pretreatment for TSS removal, antiscalent addition, and primary TDS removal by RO. The RO reject would be evaporated and the dry salt residuals would be disposed in an isolated cell onsite (or trucked for offsite disposal). This is the same treatment scheme as described by Golder (2008). While utilizing evaporation as the primary treatment process is technically viable, the cost advantage favors RO. Because of the similarity in water quality between the 2008 haulage drift water and 2013 footwall water, there are no significant changes to the previously documented technical and cost evaluations. The design concepts and estimated capital and O&M costs for an RO system to treat footwall water are described in the following sections.

3.1 Pretreatment

The efficiency of RO operation is dependent on several factors in the influent stream: temperature, presence of suspended solids, and presence of dissolved species which are considered to be membrane foulants. Based on review of available water quality characterization data, pretreatment will be required for RO.

In some cases foulant species must be removed from the RO influent stream, while others can be controlled by addition of antiscalant. Modeling based on footwall water constituent concentrations indicated that scaling of RO membranes will not be a problem. Species which tend to scale in RO are calcium carbonate, calcium sulphate, barium sulphate, strontium sulphate, calcium fluoride, iron, manganese, aluminum, silicon dioxide (silica), and calcium phosphate. None of these species are present in concentrations which would require removal prior to RO treatment and can be controlled by addition of antiscalant.

The presence of total suspended solids (TSS) in the influent will require a pretreatment step. TSS removal could be accomplished with treatment equipment similar to the existing multi-media pressure filters. Alternatively, ultrafiltration units could be utilized. Ultrafiltration is recommended as the preferred pretreatment step for RO.

As noted above, the efficiency of RO treatment will be optimal if the influent water temperature can be raised to at least 20° and preferably to 30°C. Preheating, either by a dedicated heat exchanger or through re-use of waste heat, should also be considered for RO pretreatment steps.

3.2 Reverse Osmosis Treatment

The RO unit is capable of producing treated water at an efficiency of 75%. That is, 75% of the influent flow becomes RO permeate, while 25% becomes RO brine. High quality permeate production will allow for some bypass and blending of untreated water with treated RO permeate while maintaining the effluent discharge target concentration. Assuming an initial influent flow rate of 5,000 m^3/day, RO treatment would produce a treated effluent flow of 3,750 m^3/day. A bypass flow of 250 m^3/day could be blended into the RO permeate, effectively increasing the influent flow to 5,250 m^3/day. RO reject flow, requiring further treatment for volume reduction, would be 1,250 m^3/day.

GE's ultrafiltration/RO systems are available in a range of throughput capacities from 270 m^3/day to 2,450 m^3/day. Two of the largest units would provide the initial treatment requirement (5,000 m^3/day), if installed in parallel. A break tank and transfer pump would also be required to receive ultrafiltration outflow and provide equalization for RO inflow. The floor space requirement would be approximately 300 m^2 in a 12.2-m by 24.4-m arrangement. The system capacity could be expanded in any flow increment with skid-mounted stock units. Capacity expansion increments of 2,450 m^3/day would require additional floor space of 150 m^2. If initial installed treatment capacity is 5,000m^3/day, two expansions of 2450 m^3/day would be required to accommodate the maximum projected footwall water flow of 9000 m^3/day.

3.3 Post-treatment of Secondary Waste

Two secondary waste streams will result from ultrafiltration and RO unit processes. Ultrafiltration will produce a solids-laden filter backwash, and RO will produce a contaminant-concentrated reject stream. Both of these streams can be treated for volume reduction by evaporation. The RO reject stream will contribute the majority of flow to the evaporation process.

An evaporative process, capable of treating approximately 1600 l/min of RO brine, will be required to minimize the volume of secondary waste, at the maximum projected flow for footwall water treatment.

Evaporation of RO brine should achieve a volume reduction of approximately 95%, resulting in a secondary waste slurry volume of 50 m^3/day, at the initial footwall water flow of 4,000 m^3/day. Additional volume reduction could be achieved with a crystallizer, if isolation cell volume is inadequate for this volume of waste generation.

4.0 TECHNICAL EVALUATION OF RO-BASED TREATMENT

4.1 Capacity Expansion

The RO treatment process can be expanded for increased treatment capacity by adding new banks of RO units in parallel to the base treatment system. RO units can be stacked and would not necessarily require continuous expansion of the treatment facility footprint through the life of the mine. An initially oversized building could be provided as a long-term cost benefit. GE's maximum-sized RO unit is approximately 2,450 m^3/day. The initial requirement to treat 4,500 m^3/day in year 2014 could be met through installation of two units, followed by addition of two units to reach a capacity in excess of 9,000 m^3/day. The initial footprint of a two-unit system including feed tanks, pumps, and cleaning skid would be approximately 100 m^2. Assuming no economy of floor space design during expansion, the final treatment system would have a footprint of approximately 200 m^2.

RO units can be added to a treatment system with a relatively short lead time of approximately 3 to 4 months. RO units of standard design can be relatively quickly fabricated upon order. Use of a vendor's standard unit presents some capacity expansion advantage to RO. In fact, assuming that long-term storage space is available, the units required for capacity expansion could be ordered and delivered to storage as early as economically advantageous in the life of the mine. Units could be brought out of storage and installed into the treatment system as needed.

As noted in the process alternative description, the secondary waste treatment step (evaporation) would be sized for an RO reject stream of 50 m^3/day. No more than two expansions over the life of the mine would likely be required to increase the evaporator capacity to the projected maximum footwall flow rate of 9,000 m^3/day.

4.2 Flexibility

RO operates optimally when there is little change in influent flow rate and water quality characterization. An RO-based treatment system could require a relatively large equalization basin so that influent flow and quality are consistent and the treated effluent can continually meet the discharge requirements. RO treatment efficiency can also vary based on influent quality with permeate recovery varying from 50 to 80%. While the permeate would still be of high quality, the reject stream volume could increase by a factor of 2.5, which would carry through the secondary waste treatment process. Flow equalization or oversizing the secondary treatment unit could be required.

4.3 Secondary Waste

RO will produce a brine stream that is assumed to be 25% of the influent flow. RO brine must be further volume-reduced for process viability. The RO brine evaporator should provide an additional volume reduction on the RO brine stream of 95 to 99%. A final product of brine slurry or crystallized waste in a solid form will require isolated disposal if kept on site. At an RO efficiency of 75% and a secondary evaporator efficiency of 95%, the initial 4,000 m^3/day treatment system will produce 50 m^3/day or approximately 18,250 m^3/year. Annual production of RO brine and evaporator concentrate is shown in Table A.1. Onsite disposal is assumed, if adequate volume of isolated storage can be developed.

Table A.1: Projection of RO-based Treatment System Treated Effluent and Waste Generation for Years 2014 through 2028 (m^3)

Year	Daily Flow	Annual Flow	Treated Effluent Discharged	Secondary Waste (RO Reject)	Final Waste (Evaporator Bottoms)
2014	4,546	1,659,188	1,244,391	414,797	20,740
2015	5,581	2,036,963	1,527,722	509,241	25,462
2016	6,723	2,454,026	1,840,520	613,507	30,675
2017	6,400	2,336,161	1,752,120	584,040	29,202
2018	7,427	2,710,913	2,033,185	677,728	33,886
2019	5,788	2,112,518	1,584,388	528,129	26,406
2020	5,324	1,943,275	1,457,456	485,819	24,291
2021	5,043	1,840,520	1,380,390	460,130	23,006
2022	4,968	1,813,320	1,359,990	453,330	22,667
2023	4,786	1,746,832	1,310,124	436,708	21,835
2024	4,670	1,704,521	1,278,391	426,130	21,307
2025	4,670	1,704,521	1,278,391	426,130	21,307
2026	7,038	2,568,870	1,926,653	642,218	32,111
2027	4,330	1,580,611	1,185,458	395,153	19,758
2028	4,206	1,535,278	1,151,458	383,819	19,191
Total		**29,747,515**	**22,310,636**	**7,436,879**	**371,844**

Notes: An RO recovery efficiency of 75% is assumed. The secondary waste is treated by evaporation and assumes a 95% volume reduction from the RO brine secondary waste stream to the evaporator bottoms as the final waste product.

Secondary waste may also be used in paste backfill production. The characteristics of the secondary waste cannot be predicted at this time and suitability for incorporation into paste is unknown. If later work is performed to demonstrate the compatibility of the secondary waste with paste, this would be the preferred method for final disposition.

The potential for development of a deep disposal well is also a possibility. A high capacity deep well could reduce the need for secondary treatment of RO reject. Under the scope of this study, deep well disposal is not evaluated, but would also likely be a preferred option over development of isolation cells for surface disposal over the life of the mine.

5.0 ORDER-OF-MAGNITUDE CAPITAL AND OPERATING ESTIMATES

5.1 Capital Cost

Updated pricing estimates for process equipment were obtained for an RO-based system for treatment of footwall water. Other components of capital cost were estimated as percentages of the equipment cost as shown in Table A.2.

Table A.2: Capital Cost Estimate for RO-Based System for Treatment of Footwall Water

Item	% of Total Constructed Cost	Cost Estimate
Process Equipment	40%	$33,444,000
Concrete Substructures	4%	$3,344,000
Electrical	3%	$2,508,000
Insulation	3%	$2,508,000
Process Structural	7%	$5,853,000
Process Material Labor	10%	$8,361,000
Home Office Engineering	8%	$6,689,000
Field Expenses	25%	$20,903,000
Total	**100%**	**$83,610,000**

Process equipment was vendor-quoted as a lump sum including the components listed in Table A.3.

Table A.3. Process Components Included in Quoted Equipment Cost

UF/RO system	Brine Concentrator	Forced Circulation Crystallizer
1. Influent storage tank with agitation 2. Influent transfer pumps w/ feed strainers (2) 3. Feed tank and pump skid 4. Chemical dosing skids (3) 5. Sodium hypochlorite storage tanks 6. Ultrafiltration (UF) system 7. UF backwash pump 8. Filtrate storage tank 9. Filtrate forwarding pumps 10. Sodium bisulfite storage tank 11. Acid storage tank 12. RO cartridge prefilters (2) 13. RO booster pumps (2) 14. RO membrane system 15. RO membrane clean-in-place skid	1. Influent storage tank with agitation 2. Influent transfer pumps w/ feed strainer (2) 3. Feed tank and pump skid 4. Chemical dosing skids (3) 5. Preheater and de-aerator 6. Brine concentrator vessel 7. Vapor compressor skid 8. Recirculation pump skid 9. Distillate tank and pump skid 10. Prefab recirculation piping 11. Prefab vapor ducting 12. On-skid piping 13. Instrumentation and PLC controls 14. Structural steel platforms, access ladders 15. Interconnecting piping between skids	1. Influent storage tank with agitation 2. Concentrate pumps (2) 3. MVC forced circulation evaporation unit 4. Heat exchanger 5. Flash tank 6. Mist eliminator 7. Vapour compressor w/ motor and auxiliaries 8. Distillate receiver 9. Pumps and motors for liquid flow within the crystallizer unit 10. Chemical dosing systems for crystallizer 11. Process piping and ducting 12. Instrumentation 13. Slurry pump 14. Belt filter press 15. PLC-based control panel with HMI

6.0 OPERATIONS AND MAINTENANCE COST ESTIMATION

O&M cost components include labour, power, chemicals and routine equipment maintenance. The average flow rate over years 2014 through 2028 was used for O&M cost estimation. While flow rate variations will result in “peaks and valleys” in O&M annual costs, use of the average flow rate provides a reasonable estimate of total O&M costs over the full time period. The annual O&M cost estimate breaks down as shown in Table A.4.

Table A.4: Estimated Annual O&M Cost Components

Item	Estimated Annual Cost
Labour	$256,000
Utility power	$6,402,000
Chemicals	$158,000
Maintenance	$502,000
TOTAL Annual Average O&M Cost Estimate	**$7,318,000**

The estimated annual cost for labour includes:

- One full-time lead operator at $35 per hour
- Two full-time assistant operators at $25 per hour
- One half-time maintenance technician at $35 per hour

All labour positions include an additional 20 percent factor for overtime and call-outs.

Utility power was calculated by summing the total connected load in kilowatts, and assuming 24-hour per day operation. The unit cost for utility power is $0.27 per kilowatt-hour. Additional detail on utility power is provided in the following section.

The estimated annual cost for chemicals includes:

- Antiscalant: dosed at 0.36 mg/L, 1,581 pounds annual consumption $33.40 per pound for total annual estimated cost of $52,800
- RO cleaning chemicals at $5,200 per year.
- Membrane replacement at $100,000 per year.

The annual cost estimated annual cost for routine maintenance (replacement of wear parts, calibrations, etc.) is estimated at 1.5 percent of the capital equipment cost.

7.0 UTILITIES COST ESTIMATION

7.1 Projected Utilities Cost Estimates

For the purpose of utility power estimation, an estimate of total connected load was developed and adjusted in direct proportion with treatment system throughput. The resulting annual power consumption and power cost estimates for the RO-based treatment system are presented in Table A.5.

Table A.5: Projected Utilities Annual and Total Cost Estimates for RO-based Treatment

Year	Daily Flow (m^3)	Annual Flow (m^3)	Annual Power (kw-hr)	Power Cost ($)
2014	4,546	1,659,188	19,870,000	5,365,000
2015	5,581	2,036,963	24,394,000	6,586,000
2016	6,723	2,454,026	29,385,000	7,934,000
2017	6,400	2,336,161	27,973,000	7,553,000
2018	7,427	2,710,913	32,462,000	8,765,000
2019	5,788	2,112,518	25,298,000	6,830,000
2020	5,324	1,943,275	23,270,000	6,283,000
2021	5,043	1,840,520	22,042,000	5,951,000
2022	4,968	1,813,320	21,714,000	5,863,000
2023	4,786	1,746,832	20,919,000	5,648,000
2024	4,670	1,704,521	20,412,000	5,511,000
2025	4,670	1,704,521	20,412,000	5,511,000
2026	7,038	2,568,870	30,762,000	8,306,000
2027	4,330	1,580,611	18,926,000	5,110,000
2028	4,206	1,535,278	18,384,000	4,964,000
Total		**29,747,515**	**356,223,000**	**$ 96,180,000**

8.0 WASTE DISPOSAL COST ESTIMATION

As described above in the alternatives evaluation of technical factors, there are a variety of waste disposal options including isolation cells, incorporation of waste into paste backfill, or deep well injection. Both alternative waste forms (RO brine or evaporator bottoms) would require isolation if disposed in the North Pile. Both wastes forms are expected to have similar compatibility if incorporated into paste backfill. And both waste forms could be deep well injected if the site geology and hydrogeology allow for this alternative. The primary difference in waste that will affect the operations cost estimate for disposal is the volume of waste produced. As noted in Table A.1, the volume of RO brine is projected at approximately 7,500,000 m^3 through year 2028. If this stream is volume-reduced via evaporation, the total volume is projected at approximately 372,000 m^3.

Since all three disposal options are possible for the two waste forms, the cost differential that can be estimated is based on waste volume only. Minimizing the final waste volume through evaporation of RO reject will result in the lowest cost for disposal in isolation cells or incorporation into paste backfill. If a deep injection disposal well could be developed, there would be a cost advantage to injecting RO reject directly, without evaporation.

Key to this evaluation of waste disposal options are the assumptions that adequate disposal space is available onsite for evaporator bottoms as a final waste product, or that a deep injection well can be developed with sufficient capacity to handle the RO reject flow.

9.0 LIFE OF MINE – YEARLY CAPITAL AND OPERATING COST ESTIMATES

Initial capital for the RO-based system, combined with annually adjusted power costs, and average operating labour, chemical and maintenance costs, are estimated in constant dollars as follows:

Table A.6: Estimated Capital and Operating Costs (constant dollars) for RO-based Treatment of Footwall Water

Year	Daily Flow (m3)	Estimated Capital Cost	Operations Cost Estimate (Utilities)	Operations Labour, Chemicals and Maintenance	Total Annual Estimated Cost
2014	4,546	$83,610,000	$ 5,365,000	$916,000	$89,891,000
2015	5,581		6,586,000	$916,000	$7,502,000
2016	6,723		7,934,000	$916,000	$8,850,000
2017	6,400		7,553,000	$916,000	$8,469,000
2018	7,427		8,765,000	$916,000	$9,681,000
2019	5,788		6,830,000	$916,000	$7,746,000
2020	5,324		6,283,000	$916,000	$7,199,000
2021	5,043		5,951,000	$916,000	$6,867,000
2022	4,968		5,863,000	$916,000	$6,779,000
2023	4,786		5,648,000	$916,000	$6,564,000
2024	4,670		5,511,000	$916,000	$6,427,000
2025	4,670		5,511,000	$916,000	$6,427,000
2026	7,038		8,306,000	$916,000	$9,222,000
2027	4,330		5,110,000	$916,000	$6,026,000
2028	4,206		4,964,000	$916,000	$5,880,000
Total		**$83,610,000**	**$ 96,180,000**	**$13,740,000**	**$193,530,000**

10.0 CONCLUSIONS AND RECOMMENDATIONS

The technical factors evaluated favor the RO-based system, as do the cost-based evaluation factors. The recommended treatment alternative is the RO-based system with a brine concentrating evaporator for volume reduction of RO reject.

Based on vendor review of design basis influent data, pretreatment may be limited to a relatively simple injection of antiscalant. Pretreatment equipment and costs have not been extensively researched, as they would be insignificant by comparison to the main treatment units.

The primary operating cost factor is power consumption. All other operating costs (labor, supervision, maintenance, and chemical reagents) total approximately 20% of the annual O&M estimate.

Waste disposal is considered to be of critical importance due to the extremely remote location of the mine. The final disposition options for waste streams are isolation cell storage in the North Pile, incorporation into paste backfill, or deep well injection. In the event that a deep well of adequate capacity can be developed, the cost advantage of the RO-based system will be enhanced. If waste must be stored in isolation cells, a “trade-off” analysis between power consumption costs for the smallest possible waste stream versus isolation cell construction and installation costs for a larger waste stream should be performed. Further evaluation of the suitability of the waste as a paste backfill additive would also play into the cost evaluation for waste disposal.