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ENVIRONMENTAL IMPACT
REVIEW BOARD

13 February 2003

Mackenzie Valley Environmental Impact Review Board (MVEIRB)
Box 938, 5102 – 50th Avenue
Yellowknife, NT X1A 2N7

Attention: Glenda Fratton, Environmental Assessment Coordinator

Dear: Glenda

SUBJECT: Summary of Water Treatment Process Development, Selection and Comparison of Alternatives

Please accept the attached technical memorandum titled "Summary of Water Treatment Process Development, Selection and Comparison of Alternatives" for submission to the Public Registry. This memo was compiled in response to issues raised by Environment Canada during the MVEIRB Technical Sessions.

Additionally, information contained within this memo should address outstanding concerns identified by Indian and Northern Affairs Canada in their Request for Ruling to the Board dated 22 January 2003.

Should you have any questions, please feel free to contact the undersigned.

Sincerely,
SNAP LAKE DIAMOND PROJECT

Robin Johnstone
Senior Environmental Manager

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SNAP LAKE DIAMOND PROJECT

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SNAP LAKE DIAMOND PROJECT

MEMO

To:	Robin Johnstone, Senior Environmental Manager, De Beers Canada Mining Inc.	Date:	13 February 2003
From:	Tom Higgs, Senior Process Engineer, Water Treatment	File No.	4.9.3/1020
Tel:	604 664-4542 (fax: 604 664-3057)	Project No.	U638A
CC:			
Subject:	***Summary of Water Treatment Process Development, Selection and Comparison of Alternatives***		

This memo has been prepared to provide a summary of the process development and selection work that lead to the current proposed mine water treatment system (WTP).

Goldsim Modelling and Water Quality Sampling

Initial Goldsim modelling predicted that sedimentation in a settling pond would not be sufficient to remove fine suspended sediment to a level that would approach CCME guidelines for a number of metals, mainly Cr and Cu, which are present in untreated mine water in finely dispersed colloidal form. This conclusion was supported by water quality data collected during the water management pond (WMP) discharge in May 2001. The water quality data indicated that the mine water had a neutral to alkaline pH with dissolved metal concentrations close to the initial draft Ambient Water Quality Guidelines (summarized below) established by the EA team for the Snap Lake project at the start of the water treatment process selection and design program. The final guidelines and benchmark values used for discharge screening during the environmental impact assessment are provided in the EAR in Table 9.4-18.

Draft Ambient Water Quality Guidelines for Total Metals (ug/L)

Aluminum	100
Arsenic	5
Cadmium	0.08
Chromium	8.9
Copper	2
Iron	1000
Lead	1
Mercury	0.1
Molybdenum	73
Nickel	25
Selenium	5
Silver	0.1
Zinc	30

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Process Screening

The initial process selection and screening work was guided by three factors:
(1) an examination of maximum predicted mine water flows
(2) the expected waste characteristics
(3) the potential discharge permit limits.

Process option methods that were screened can be broken down into:
- physical methods to remove particulate matter
- conventional chemical precipitation methods for reduction of dissolved metals
- advanced treatment alternatives for removal of ammonia and chloride.

The physical methods and technology evaluated for removal of suspended solids included:
(1) sediment removal in sumps underground
(2) clarification in the WMP
(3) use of a mine water thickener
(4) filtration.

The conventional precipitation methods evaluated included;
(1) coagulant addition using alum, ferric sulphate or lime in combination with organic flocculants to treat either
  a. mine water directly in a thickener, or
  b. WMP overflow
(2) ferric co-precipitation in combination with lime, organic flocculant and sulphide addition in a high density sludge recycle system.

The advanced water treatment alternatives evaluated included;
(1) ion exchange for removal of residual metals, ammonia, nitrate or total dissolved solids (TDS)
(2) reverse osmosis (RO) for removal of residual metals, ammonia or TDS.

Process Screening Conclusions

Based on an initial review of expected mine water flows and chemistry the following conclusions were reached at the process screening stage
- Primary solids removal would be required with the alternatives being to use either (1) underground (U/G) sumps, (2) the WMP or a (3) above ground thickener.
- Final effluent filtration and discharge of an effluent with a low TSS would be required to approach the specific Snap Lake ambient water quality objectives, due to the elevated concentration of metals in the particulate form.
- The use of advanced alternatives using either membrane technology, such as RO or ion exchange (IX) was deemed impractical due to the large expected mine water flowrates and the resultant reject brine streams that would have required additional processing to produce a dry solids waste for disposal. The energy consumption, chemicals required

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and solids waste generated to implement advanced treatment alternatives were deemed unacceptably high. The potential environmental benefits did not appear to warrant further consideration. This is discussed further in the De Beers submission on TDS removal provided to the MVEIRB on February 10, 2003.

- Although the expected dissolved metal concentrations in the untreated mine water met most of the objectives, it was recognized that further reduction for specific dissolved metals such as copper and chromium could still be required to meet the Ambient Water Quality Guidelines. It was concluded that testwork would therefore be required to evaluate the removal efficiency of the proposed alternatives and to select and design the water treatment system. Finally it was recognized that continuous pilot testing of the selected key alternatives would be required to demonstrate the process and complete toxicity assessments.

Water Treatment Testing Program

The treatability testwork was performed in the following phases;

- **Phase 1**. Head characterization followed by settling and flocculant screening tests conducted using simulated mine water generated from samples of rock (granite, metavolcanic and kimberlite) collected underground by Golder Associates to refine source terms for Goldsim modeling (June/July 2001).
- **Phase 2**. Head characterization, flocculant screening, column settling tests and jar tests conducted on mine water and WMP samples collected during the Advanced Exploration Program (AEP)(July/August 2001). This work focused on basic screening and evaluation of different water treatment process configurations involving alternative coagulants (alum, ferric sulphate, and lime), different dosages and different pH set points.
- **Phase 3**. Head characterization followed by batch and continuous pilot plant studies using a bulk mine water sample consisting of 33 - 200 L barrels collected in August 2001 prior to shut-down of the AEP. This work carried out between September and December 2001 focused on evaluating alternative process configurations on a continuous basis. The flowsheets tested on a continuous basis are attached. These flowsheets can be described as follows:
  - **Flowsheet 1.** Flocculant addition to raw mine water, sedimentation in a thickener and direct filtration;
  - **Flowsheet 2.** Ferric sulphide addition to raw mine water, pH adjustment with lime, flocculant addition, sedimentation and direct filtration;
  - **Flowsheet 3.** Flocculant addition to raw mine water, sedimentation in a thickener with overflow reporting to a high density sludge (HDS) circuit. HDS circuit included ferric sulphide, lime and flocculant addition followed by direct filtration of clarifier overflow; and,
  - **Flowsheet 4.** Flowsheet 3 but with the addition of sodium hydrosulphide (NaHS) addition to the HDS circuit and hydrogen peroxide (H_2O_2) upstream of sand filter.

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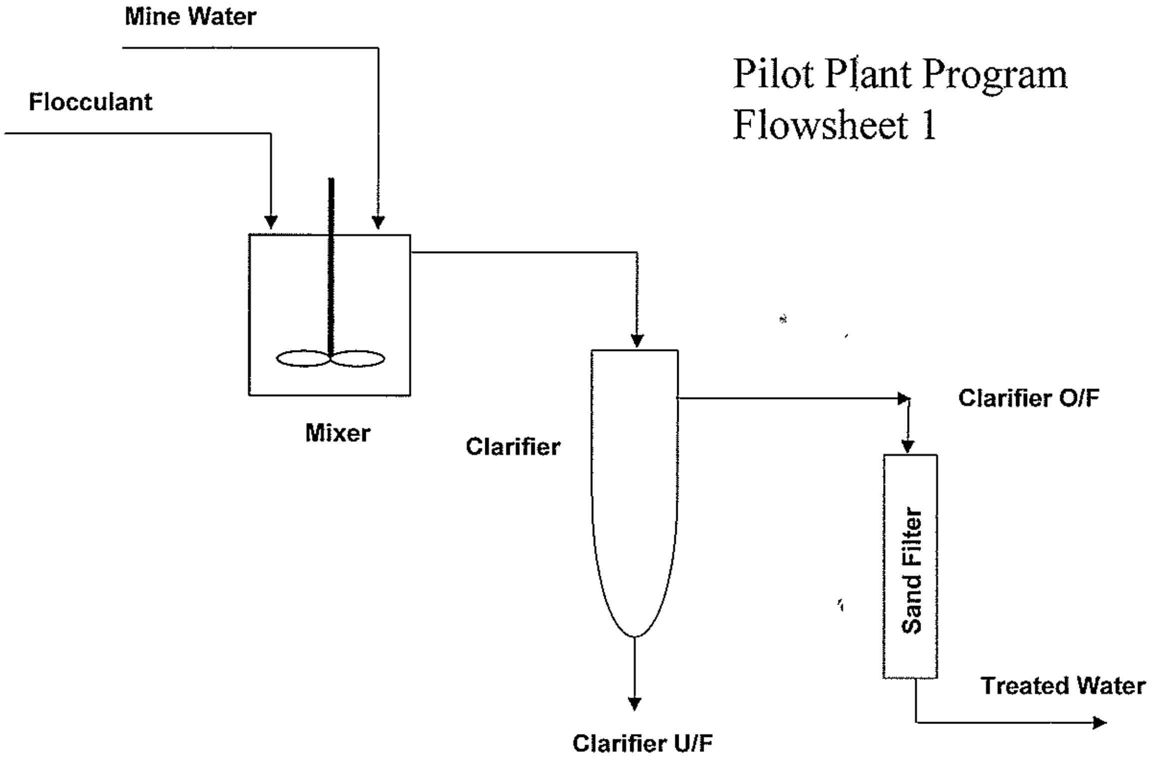
Pilot Plant Program
Flowsheet 1



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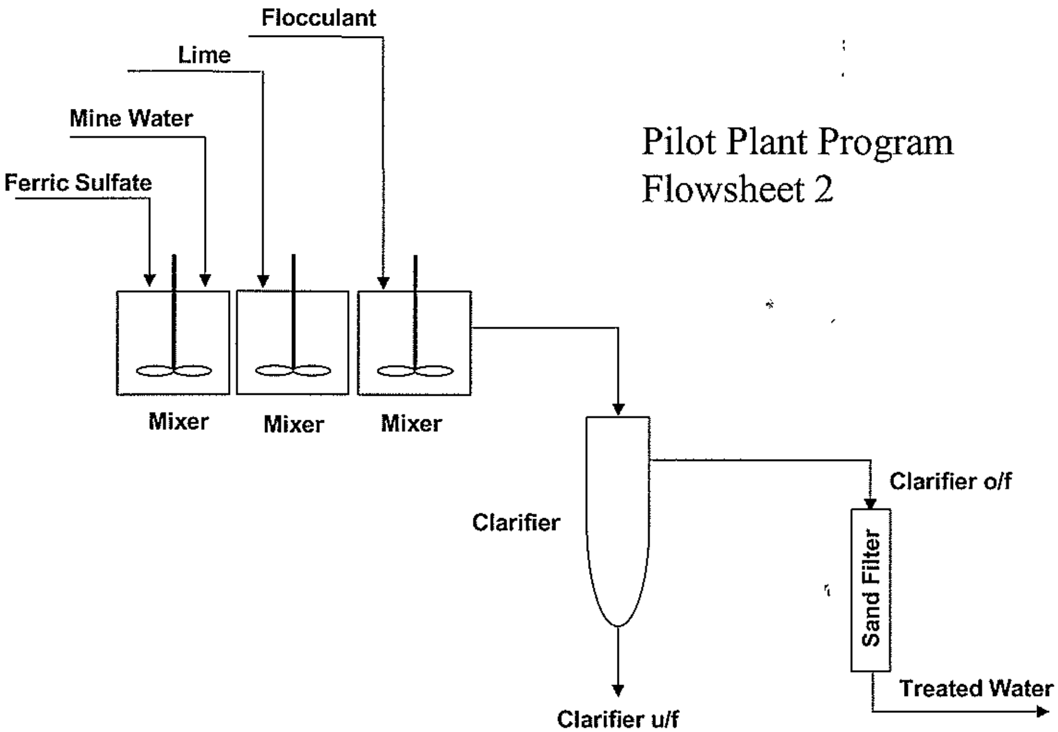

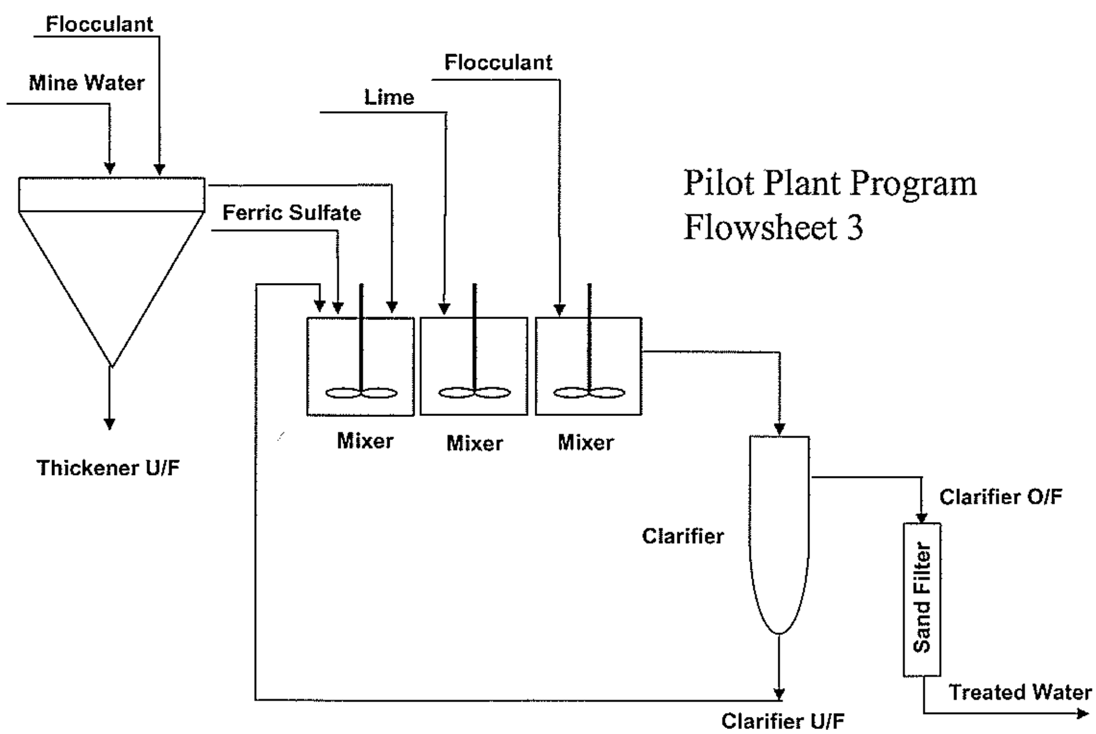

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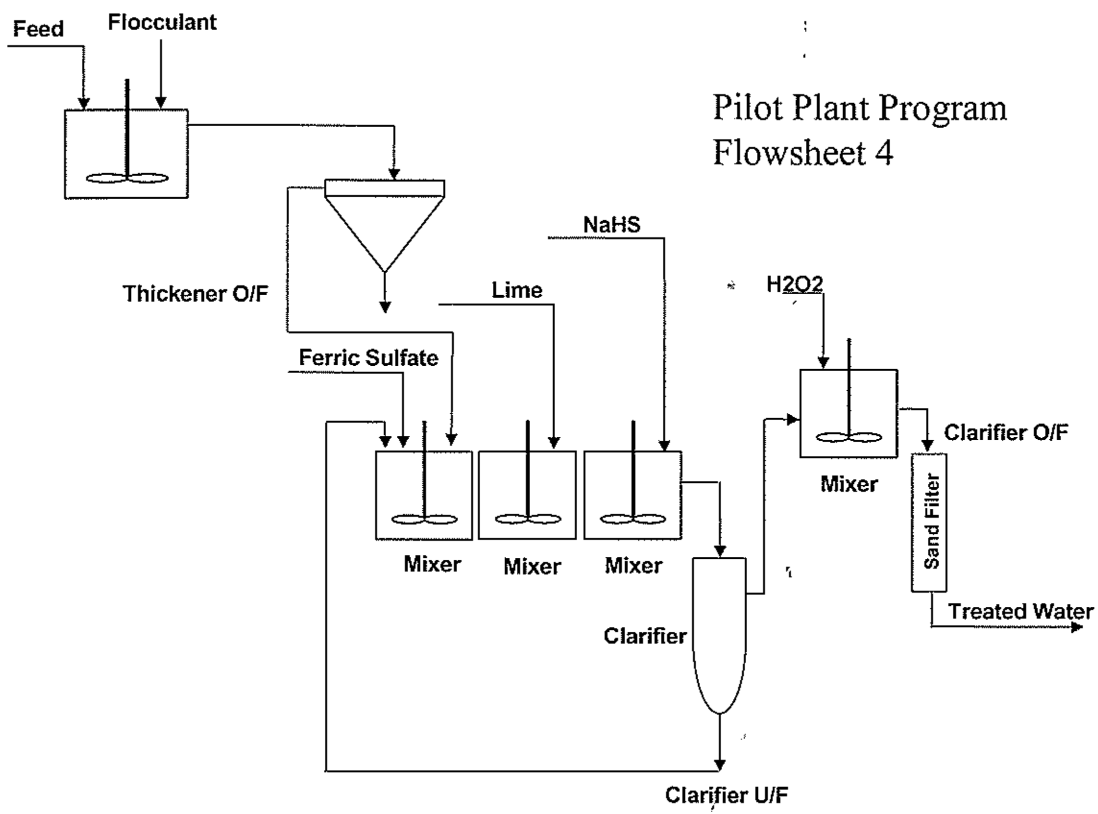

The Ambient Water Quality Objectives were used as targets to guide the testwork. Prior to the completion of Phase 2, preliminary modelling and prediction of final effluent quality based solely on TSS removal indicated that an effluent TSS target of 5 mg/L would generate an effluent that met the objectives. The Phase 2 tests confirmed this prediction and demonstrated that regardless of the combinations of reagents used, sedimentation plus filtration would be required to meet the 5 mg/L target. In addition, the Phase 2 tests demonstrated coagulation and filtration could reduce metals to comply with the objectives, with the exception of copper, which marginally exceed the objective of 2 ug/L.

Selection of Option for Primary Solids Handling

Based on the nature of sludge generated during the bench tests in Phase 2 and estimates of sludge quantities that could be generated underground, a decision was reached at this stage that primary solids and handling would be carried out a thickener. The use of sumps underground was negated by the complications associated cleaning of the sumps and transporting this material to surface for incorporation into the paste backfill. The use of the WMP

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pond for primary solids removal was evaluated and rejected due to projected short-term requirements for cleaning the WMP and the additional handling required to dispose of this accumulated sludge in either the North Pile or underground as paste backfill.
Therefore, the Phase 3 test work assumed that primary solids removal would be provided by a thickener c/w flocculant addition. Addition of ferric sulphate and lime as coagulants to further optimize suspended solids removal could be retained as a contingency.

The pilot testing conducted as part of Phase 3 focused primarily on evaluating the performance of alternative flowsheets in terms of both suspended solids reductions to meet the 5 mg/L target and potential further reductions in copper to meet the 2 ug/L guideline.

Conclusions from Pilot Testing (Phase 3) and Final Flowsheet Selection

Based on both the bench tests and the continuous pilot testing, the thickener/filter option with the use of flocculant only (Flowsheet 1) appeared to represent the most practical option for treatment. The addition of ferric sulphide and lime in the thickener/filter option with Flowsheet 2 did not appear to provide a clear demonstrated benefit over Flowsheet 1, considering the inherent variability in the assay results which occurs when testing is conducted near detection limits. The HDS options (Flowsheets 3 and 4) appeared to produce some reductions, however variability in the assays results was also high. The addition of an HDS circuit between the thickener and the filter did not appear to provide a clear benefit. Differences in total and dissolved copper, the primary target for the Phase 3 program, were marginal in all the flowsheets tested, supporting the selection of the simplest flowsheet – Flowsheet 1.
The selection of Flowsheet 1 was further supported by the toxicity testwork results, reported in Appendix IX.8, that demonstrated that all the flowsheets were able to produce non-toxic effluents as defined by standard fish bioassays. Based on the Phase 2 and 3 testwork, it was recognized that the availability of ferric sulphate and lime for coagulation might still be retained as a contingency for use in either the thickener or the filtration system. The use of a coagulant would apply in cases where the feed contained elevated levels of colloidal aluminum, phosphorous or chromium that may not respond to conventional flocculation using organic polyelectrolytes. However the base case would be to not use chemicals unless required.
An important point to recognize in the analyses of the alternative flowsheets is that Flowsheets 3 and 4 both require the addition of ferric sulphate and lime on continuous basis in order to operate the HDS portion of the system. Whereas, based on the testwork, the thickener/filter flowsheets will operate successfully without ferric sulphate and lime, relying solely on the use of flocculant at very low relative concentrations. The lower level of reagent consumption in Flowsheet 1 is environmentally preferable due the inherent reductions in chemical transportation and storage requirements, and subsequent reductions in environment risk.

Cost Evaluations

Further analyses to support the process flowsheet selection is provided from the capital and operating cost comparisons provided below. The capital cost estimates for the basic systems were factored from the Snap Lake feasibility study to reflect the maximum expected flow of

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35,000 m^3/d. Flowsheet 1 has a capital cost advantage of $3.6 million and operating cost advantage of $1.6 million/yr. Flowsheet 1 could also result in significant reductions in the use chemicals that would need to be transported to site as well requiring less power.

Capital Cost Estimate	Flowsheet 3 c/w High Density Sludge Plant and Thickener/Filtration System	Flowsheet1 Thickener/Filtration System only
Direct Cost	$15,132,500	$12,376,000
Indirect Costs		
Start-up	302,600	247,500
Freight	286,900	263,800
Spares	256,500	227,000
EPCM	2,269,900	1,856,400
Contingency	1,513,200	1,237,600
Total Indirect	$4,629,100	$3,832,300
Total Capital Cost	$19,761,600	$16,208,300

Operating Cost Estimate (per year)		
Chemicals	$1,500,000	$200,000r
Power	600,000	400,000
Labour	500,000	400,000
Total Operating Cost	$2,600,000	$1,000,000

Proposed Treatment System Process Description

The schematic flowsheet for proposed system is provided below and can be described as follows.

- There are two major sources of feed to the WTP; mine water is the major source to the WTP and North pile run-off, which is a relatively small flow.
- Mine water containing major amounts of solids will report directly to the thickener where flocculant will be added to assist with solids removal.
- The thickener overflow containing minor amounts of suspended solids will report to the filter feed tank.
- The thickener U/F will report to the process plant to combine with the paste backfill.

- As illustrated on the schematic, if the thickener is out of service mine water can be sent to the WMP for solids removal. - also, if the mine water is clean enough it may be possible to bypass the thickener and go directly to the filter feed tank.
- North Pile run-off (which will have low suspended solids) will be sent directly to the filter feed tank or alternatively to the WMP if short-term inflows are too high or the filtration portion of the plant is out-of-service.
- The filter feed tank is also a flocculation tank where ferric sulphate and lime can be added, if necessary, to assist with solids removal.
- An organic flocculant will be added upstream of the filter and finally the filter removes the remaining particles.
- Filter backwash will report back to the thickener.
- The system will also have the capability of adding ferric sulphate and lime to the thickener feed if required to deal with high levels of suspended solids.

Water Treatment By-Products

All solids by-product, which would include any reagents used in the treatment process, will leave the WTP with the sludge generated by the thickener. Solids in the filter feed, which originate from thickener overflow, will be discharged from the filters during backwash. These solids would then report to the thickener and ultimately be incorporated into the sludge, which is sent to the process plant and added to the paste.

WTP Optimization and Operating Strategy

Commissioning and start-up will involve a series of typical activities aimed at developing a detail operating strategy for the WTP plant. These activities will be:

- ensure full compliance with the discharge regulations
- set-up a control system that can rapidly respond to and correct mechanical problems and process upset conditions,
- minimize operating costs, and
- assemble a manual for plant personnel that can be used for both operation and training of new personnel.

Typical activities would include;

- A short-term monitoring program to demonstrate compliance, assist with short-term optimization and select key operating set-points.
- Programming to set-up interlocks and communication between the PLC/HMI (Programmable Logic Controller/Human Machine Interface), the on-line instrumentation and the mechanical equipment controllers.
- Development of a long-term monitoring program and optimization plan that will ensure continuing successful operation at minimum operating costs.

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The development of a sound operating strategy for the Snap Lake project will be important since the mine water flows and solids loading will increase steadily during the first few years of operation. The operating strategy will have to be flexible to accommodate the expected changes in operating conditions. Therefore, process optimization will be an on-going activity to ensure compliance and minimize costs.

Flocculant Screening and Optimization

The initial testwork was conducted with using a common water treatment flocculant, Percol 351, which is classified as a non-ionic polyacrylamide. Toxicity testing results for this flocculant were provided in Appendix IX.8 of the EA Report. Start-up of the WTP will take place using either this flocculant or a very similar formulation. Plant operation would likely continue with this flocculant unless bench testing demonstrates that improved performance could be achieved with an alternative flocculant. Based on past experience, some changes in the flocculant being used by a particular process can occur during the first few years of operation. However the alternative flocculants are typically only slightly different from the original. A decision to change flocculants would require confirmation, based on published chemical supplier data, that the toxicity of the alternate new flocculant was similar or less than the original.

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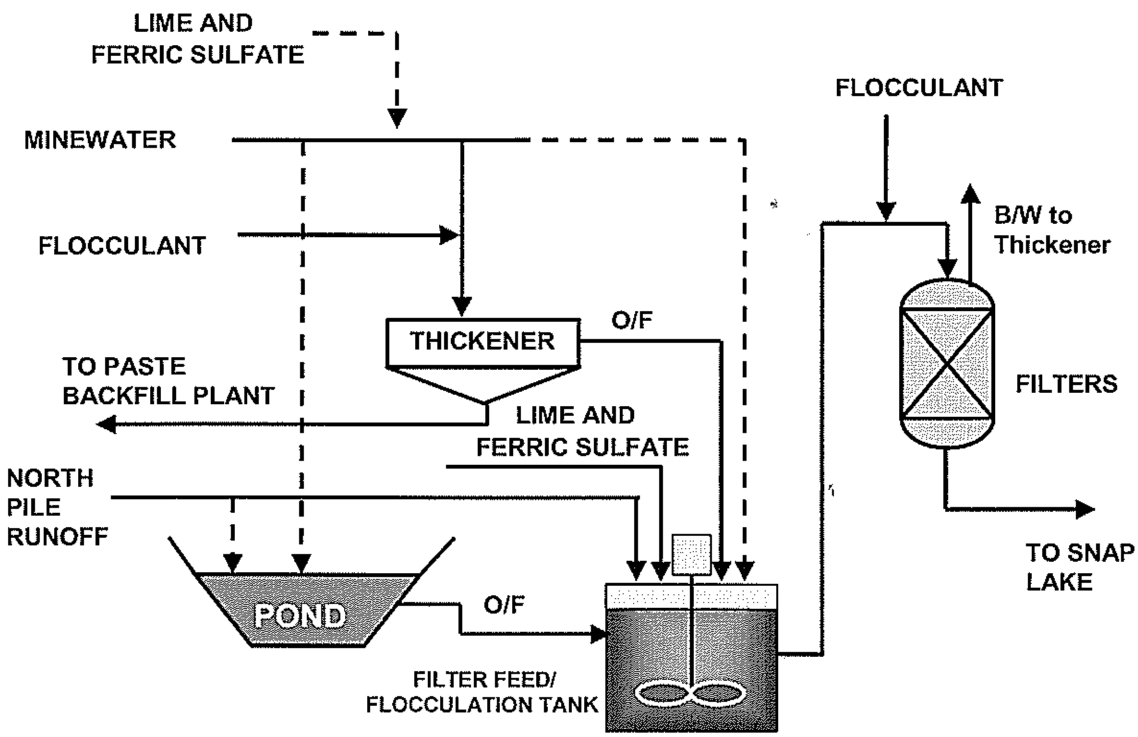
Water Treatment Process Schematic



Summary of Options Rejected During Process Selection

A number of options and alternatives were evaluated and rejected during the course of process selection. The options that were rejected and the bases used for rejecting them are summarized in the table below.

Summary of Process Alternatives Rejected

Option	Description	Advantages	Disadvantages	Reason for Rejection
Use of Mine Sumps for Primary Solids Removal	Primary removal of solids in sumps underground, that would be cleaned mechanically. The solids/ sludge would either be disposed of underground (if possible) or hauled (or pumped) to surface to be added to the paste backfill. Flocculant could be added to the sumps to increase solids removal.	Simple proven system, low capital and operating costs, provides for sludge removal. Provides equalization of flows and loadings.	Limitations in the removal of colloidal material. Sludge handling would require hauling or pumping to surface to allow for disposal in backfill. Solids not removed in the sumps would still require removal by either a thickener or pond.	Complicated method for solids handling. Not attractive for incorporating solids in backfill
Mine water Thickener plus WMP for polishing	Sumps underground would be sized to remove coarse material only from the mine water prior to forwarding to the thickener. Sumps would be cleaned out using mine equipment with the coarse materials deposited underground and fines pumped with the mine water to the thickener. Thickener O/F would report to the WMP for polishing	Conventional technology for treating mine water with high sediment loads. Allows for addition of reagents to improve solids removal and final clarification. Produces sludge for incorporation into backfill. Can produce higher quality effluent than the use of pond only. Potential lower operating costs than use of sumps.	Higher capital cost. Lack of equalization could negatively impact operation of thickener. Higher operating complexity than pond system. Some dissolved metals removed thru use of inorganic coagulants but typically not expected to reduce total metals concentrations to meet Objectives.	Use of WMP as Polishing Pond would eliminate its use for equalization. Water quality from polishing pond would not meet the Objectives without additional treatment (such as filtration)
WMP for Settling Pond plus Filter Plant	WMP used for primary solids removal with the addition of a filter plant to remove fine suspended solids prior to discharge. Coagulants such as alum or ferric sulphate and/or polyelectrolytes can be added to filter feed to optimize performance compared to straight filtration. Backwash to pond.	All the advantages of pond with the ability to reduce total metals and solids to lower concentrations than simple pond systems. Better able to deal with increases in feed contaminant concentrations. Able to remove some dissolved metals thru use of coagulants.	Does not produce a sludge that can be easily incorporated into backfill. More difficult to operate than thickener/filter option due variability in filter feed suspended solid's	Complicated requirements to clean pond and dispose of accumulated sludge during operation
Use of alum for coagulation versus ferric sulphate	Alum could replace ferric sulphate in either the thickener feed or the filter feed.	Conventional reagent for water treatment, less corrosive and reactive than ferric sulphate	Testwork demonstrated that feed already contained elevated levels of aluminium. Alum did not produce as low dissolved aluminium or copper levels as ferric sulphate. Alum requires lower operating pH range than ferric sulphate to avoid high	Inability to meet objectives for Al and reduced capability to depress copper.

Option	Description	Advantages	Disadvantages	Reason for Rejection
			dissolved aluminium residuals – reduces flexibility.	
Use of HDS system instead of thickener before filter	Mine water would report directly to HDS system where reagents would be added to generate a dense sludge for recycle. Solids in mine water would be incorporated in sludge. Flocculants would be added to enhance solids separation prior to filtration	HDS systems able to produce high effluent quality. Proven technology.	Performance would be negatively impact by presence of large amount of solids in feed. Consumption of chemicals to achieve acceptable overflow water quality could be high to overcome impact of mine solids. Complex operating and control requirements	Combining primary solids removal and ferric co-precipitate HDS in one system complicates operation. Could have significant operating costs disadvantage compared to separate systems to warrant capital cost savings. Could require significant consumption of chemicals.
Use of HDS system after thickener and before filtration	Mine water would report first to thickener and then to HDS system where reagents would be added to generate a dense sludge for recycling. Primary solids in mine water would be incorporated in sludge. Flocculant would be added to enhance solids separation prior to filtration	HDS systems able to produce high effluent quality. Proven technology.	Higher capital and operating costs than proposed system. Higher level of reagent consumption resulting in increased hazards associated with transportation and storage of chemicals. Higher operating complexity than proposed system increased risk of process upset.	Pilot testing did not demonstrate clear process advantage, especially with copper, to warrant additional cost, operating complexities and chemical handling increased requirements for ferric sulphate and lime.
Use of sulphide for metal precipitation either in HDS circuit or filter	Sulphide could be as an additional reagent to achieved enhanced metals removal	Sulphide addition can produce lower dissolved metal than hydroxide i.e. for Cd, Pb, Hg, and Ag.	Sulphide precipitates are added to sludge and present some disposal concern in terms of acid generation. Sulphide residual in water would require removal using oxidant such as hydrogen peroxide. Increase risk in handling of reactive chemicals. Higher operating cost.	Bench and pilot plant tests did not demonstrate process advantage especially in terms of copper. Other metals already met objectives. Would have required handling and storage of hydrogen peroxide as well as sulphide.

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