SUBAQUEOUS DISPOSAL OF SULPHIDE TAILINGS – RECLAMATION OF THE SHERRIDON ORPHAN MINE SITE, MANITOBA, CANADA

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ABSTRACT

The Sherridon Orphan Mine Site is a large abandoned Cu-Zn mine site in northwestern Manitoba, Canada. The site is the responsibility of the Province of Manitoba and has been identified as a priority for the remediation of environmental and human health and safety risks associated with the acid generating tailings and waste rock on the site. The reclamation concept, which provides a walk-away solution, involves placement of the ARD materials under a water cover. This presentation will present the detailed design and review the progress of implementation.

1. INTRODUCTION

The Sherridon Orphan Mine site, located in northwestern Manitoba, Canada (Figure 1) has been identified as one of five high-risk orphaned or abandoned mines sites in Manitoba. The site is the responsibility of the Province of Manitoba and has been identified as a priority for the remediation of environmental and human health and safety risks. This paper provides an overview of the studies completed to develop a remedial design for the site and details the final design and predictions of the environmental improvements expected to result from the project. Construction of the project began in October 2008 and will continue through to October 2012. This project was commissioned by the Mines Branch of the Manitoba Department of Science, Technology, Energy, and Mines. The remediation plan has been developed by Wardrop Engineering, Inc., as the prime contractor with technical assistance from SENES Consultants Limited.

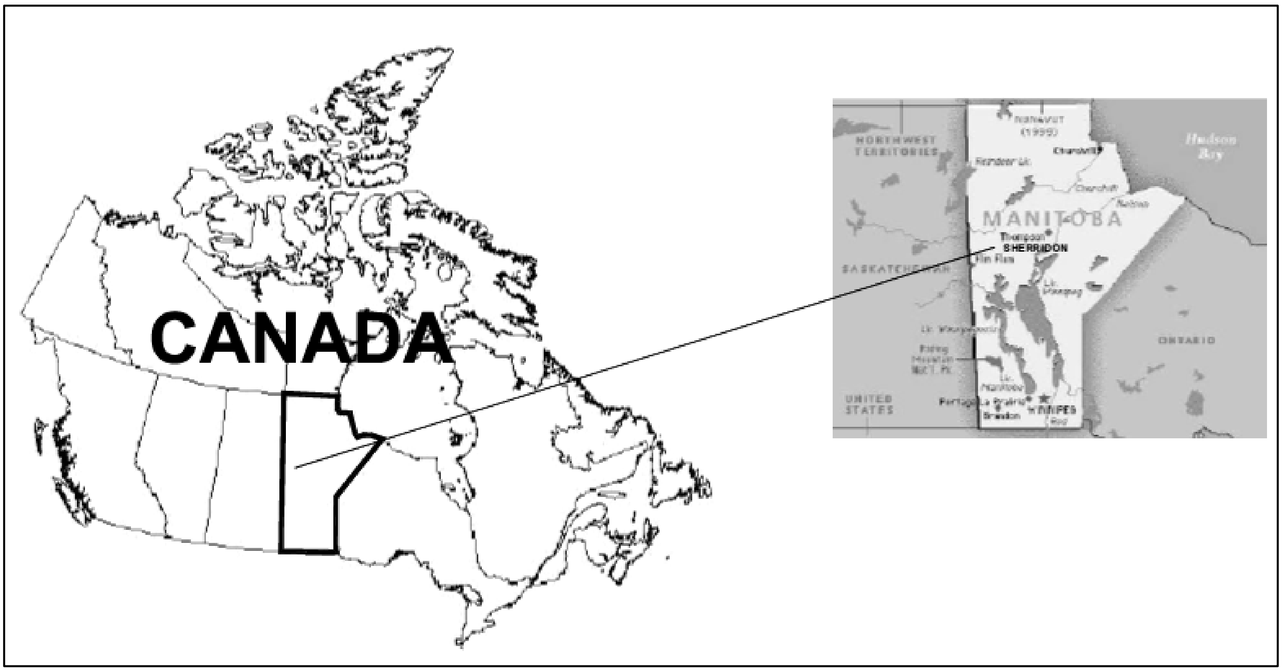

Figure 1. General site location of the Sherridon Orphan Mine site, Manitoba, Canada.

2. SITE HISTORY

The Sherridon VMS copper-zinc deposit was discovered at Cold Lake (55º08’22”N 101º06’25”W), approximately 65 km northeast of Flin Flon, in 1922. Sherritt Gordon started mining the deposit in 1928. Mining was suspended in 1932, re-started in 1937, and ceased in 1951 when the ore deposit was depleted. The Sherridon Mine initially recovered copper and minor amounts of silver and gold. Zinc recovery was added in 1942. The adjacent communities of Sherridon and Cold Lake developed to support the mine operation and the communities remain to the present. Overall, 7.7 million tonnes of pyretic ore were mined, and 7.4 million tonnes of tailings generated. Tailings disposal was primarily subaerial, with the tailings pile covering approximately 47 ha adjacent to Camp Lake (Figure 2). Tailings are 60 % sulphides mainly consisting of pyrite and pyrrhotite.

Exposure of the sulphides in the tailings to oxidizing conditions has resulted in the production of acidic drainage which has leached heavy metals from the tailings and has acidified Camp Lake. The current pH of Camp Lake is approximately 3.2, with total zinc concentrations in the range of 0.5 to 1.0 mg/L and total copper concentrations in the range of 0.1 to 0.2 mg/L. The lake no longer supports a fish community. Camp Lake discharges to the Cold Lake arm of Kississing Lake (Figure 2), a large lake in the Churchill River watershed with important sport, commercial sport, commercial and domestic fisheries. Water and sediment contamination and altered benthic invertebrate and fish communities have been documented throughout the Cold Lake arm of Kississing Lake (Wardrop 2009) and approximately 9.5 km^2 of lake sediment have elevated concentrations of metals attributable to the Camp Lake discharge (UMA/SENES 2004).

The tailings also are subject to wind suspension, creating dust clouds over the tailings pile during wind events and resulting in localized contamination of the terrestrial environment up to 500 m from the tailings pile (UMA/SENES 2004).

A human health and ecological risk assessment (UMA/SENES 2004) determined that the tailings dusting was not a significant risk to human health or the natural environment. The discharge of acid and metal contaminated water to Kississing Lake was identified as a significant ecological risk.

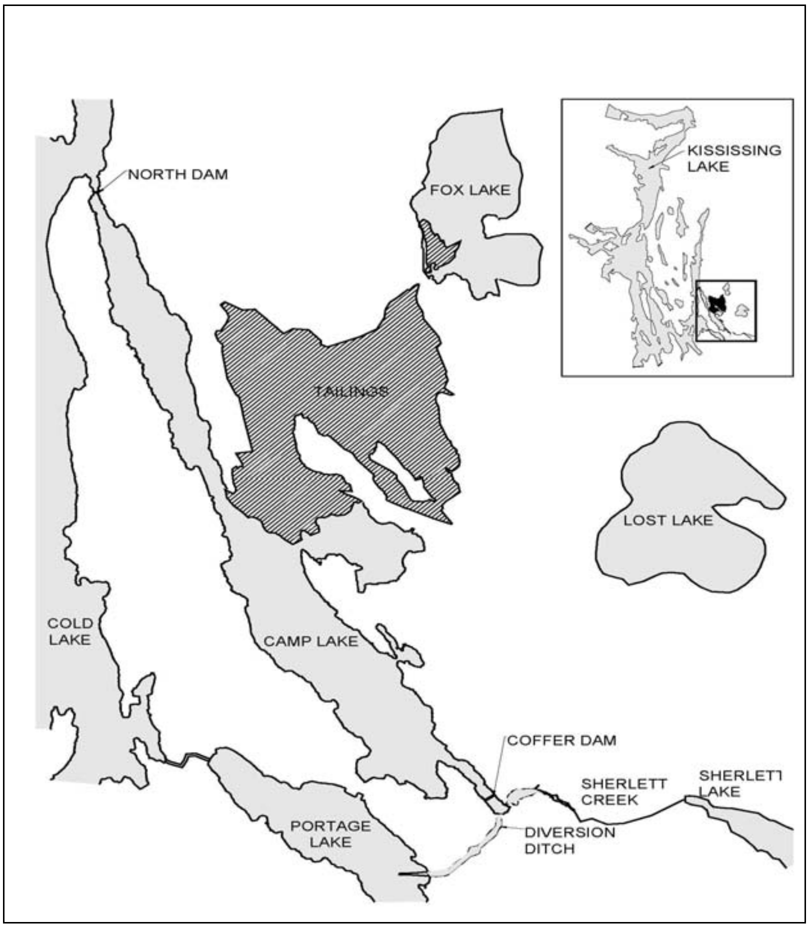

Figure 2. Location of Sherridon tailings in relation to Camp Lake, Manitoba, Canada.

3. REMEDIATION OBJECTIVES

The Manitoba Mines Branch applies a risk-based management approach to the orphan mine sites for which they are responsible. Remediation is therefore considered effective if all significant risks to human health, safety, and the natural environment associated with the site are controlled. Remediation or “clean-up” for purely aesthetic considerations is not an objective of the orphan mine site management program.

Based on the human health and environmental risk assessment completed for the site (UMA/SENES 2004), the primary risk to be managed is acid and metal loading to Kississing Lake via the Camp Lake discharge. Tailings dusting is a quality of life issue of concern for the local residents but was not found to be a risk to human health, either directly in the dust or indirectly via the consumption of local plants or wildlife. Similarly, adjacent terrestrial contamination resulting from tailings dusting was not found to be a significant risk to the natural environment. Consequently, control of acid and metal loading to Kississing Lake and elimination of tailings dusting were selected as the primary remediation objectives for the site. These objectives were to be achieved at the lowest possible cost, based on a net present value determination, and preferably would minimize or eliminate any requirement for continuing active treatment. Finally, Manitoba requested that the remedial works be completed by 2012 in accordance with a directive of the provincial auditor.

4. REMEDIATION DESIGN PROCESS

The remediation project was designed using a multi-step process. The first step involved the identification of potential remedial approaches and a screening-level analysis to identify fatal flaws and general applicability to the remedial objectives. The remedial options considered in the screening analysis were reduced to a short-list of three options, all of which had the potential to meet the primary remedial objectives, for which preliminary cost estimates were developed, leading to the recommendation of a preferred remedial option (Wardrop 2007).

The preferred option and the process followed in reaching that recommendation were reviewed by a Technical Advisory Committee (TAC) comprised of representatives of all provincial and federal departments and agencies with a potential interest in the project. Based on this TAC review, Manitoba approved the development of the detailed project design for the preferred remedial option. The detailed design process began with consultation with the adjacent communities of Sherridon and Cold Lake to explain the process, describe the preferred remedial option, and solicit questions or concerns. The community consultation and information sessions have since been held at approximately six month intervals, initially to provide reports on design progress and forthcoming construction plans and this information/consultation schedule will be maintained throughout the construction phase of the project.

5. REMEDIAL CONCEPTS SCREENING

The remediation design study initially identified and screened six remedial concepts for their suitability on the basis of the site remediation requirements and effective application elsewhere. The options considered at the screening level are summarized in Table 1.

Based on the screening comparison, three options (the base case, engineered cover, and subaqueous disposal in Camp Lake) were identified for further detailed evaluation. The terraced flooding option was eliminated on the basis of high permeability of tailings and expected difficulty in maintaining water cover. Disposal in the underground workings was eliminated on the basis of inadequate capacity, foreclosure of future mining options, and complexity and cost of a multiple remedial approach concept. Raising the Camp Lake water level to flood tailings was eliminated on the basis of the extensive dam development required, the related long term dam safety concerns, potential difficulty in maintaining water cover during drought conditions, and increased advective flux of contaminants at the elevated water level.

Table 1. Screening level comparison of remediation options.

REMEDIATION OPTIONS	CONCEPT	DETAILS	ADVANTAGES	DISADVANTAGES	COMMENTS
1 Base Case – Re-vegetate Tailings Pile and Treat Camp Lake Outflow on a Seasonal Basis	- minimum cover to enable re-vegetation - treat and discharge excess water from Camp Lake on a seasonal basis	- grade tailings for drainage, place capillary break, soil cover, vegetation - divert Sherlett Creek flow around Camp Lake - construct perimeter dams as needed to direct runoff and control run-on - construct treatment plant to treat discharge on a seasonal basis - construct polishing pond and sludge storage	- relatively low capital cost - decreases contaminant flux to Kississing Lake - prevents dusting - improves aesthetics of tailings basin - southern portion of Camp Lake could be reclaimed	- active treatment required in perpetuity, operating cost offsetting lower capital cost - sludge management required - tailings pore water quality remains poor - Camp Lake remains in a substantially degraded state serving primarily as a treatment pond	- essentially "manages" the tailings problem but does little to actually remediate the area - requires care and maintenance in perpetuity
2 Raise Water Level in Camp Lake to Flood Tailings	- construct perimeter dams around Camp Lake and tailings pile - raise water level of Camp Lake to flood the tailings in perpetuity - batch treat initial pulse of contaminants	- dams required to bridge all topographic lows, including a dam across the south basin of Camp Lake - divert Sherlett Creek flow around Camp Lake - require seepage cutoff (e.g., grout curtain) to control advective flux from the basin - minimal relocation of existing subaerial tailings beaches - temporary batch treatment plant at outlet - may require alkalinity barrier cover on tailings	- minimize future tailings oxidation - minimal requirement for relocation of existing tailings - oxidized tailings would act as a diffusion barrier in the long-term - short-term post-flooding treatment of discharge - may be able to reclaim the southern portion of Camp Lake	- increased water level will increase the advective flux of contaminants from the tailings pile - relatively large dams required - increased risk associated with dam failure - tailings pore water remains highly contaminated in the long-term	- small catchment area for Camp Lake may be problematic for maintaining water cover, requiring provision of supplementary water from Kississing Lake during periods of extended drought - high tailings permeability may be problematic at Sherridon
3 Terraced Tailings with Seepage Control to Encourage Full Saturation	- re-contour tailings surface to create multiple flooded terraces (similar to the Quirke Tailings Basin in Elliot Lake)	- re-contour tailings into multiple terraces - construct low dams and cut-off trenches to ensure complete saturation of the tailings - could incorporate oxygen diffusion cover to minimize requirement for water cover - divert Sherlett Creek flow around Camp Lake - construct water control structure at north end of Camp Lake - construct treatment plant to treat Camp Lake outflow for uncertain period	- maintains tailings saturation and inhibits oxidation - prevents dusting and erosion of the tailings surface - shallow berms and cut-off trenches are relatively easy to construct - may be able to reclaim the southern portion of Camp Lake	- increased flushing of tailings pore water into Camp Lake - susceptible to drought conditions - effectiveness of a cut-off trench within the tailings is uncertain - active treatment required for long period of time	- would continuously flush the highly concentrated tailings pore water (high treatment demand) - long term stability of structures built in tailings uncertain - water quality in Camp Lake would take a long time to improve - small catchment area for Camp Lake may be problematic for maintaining water cover, requiring provision of supplementary water from Kississing Lake during periods of extended drought
4 Subaqueous Disposal in Camp Lake	- excavate all tailings below elevation 314.5 m ASL and relocate to Camp Lake - neutralize tailings during relocation - establish 1.5 m water cover over the tailings, maintained by the Sherlett Creek watershed	- temporary diversion of Sherlett Creek around Camp Lake - relocate all tailings above 314.5 m ASL - add excess neutralizing potential during relocation to precipitate soluble metals - temporary treatment plant to treat Camp Lake water before and during tailings relocation - may require alkalinity barrier cover over tailings - reclaim and re-vegetate exposed areas	- water quality of Camp Lake would be expected to improve, potentially to the degree that fish habitat may re-establish in lake and lake may be suitable for some recreational uses - tailings dusting eliminated - as close to a "walk away" solution as can be reasonably achieved - most likely to eliminate requirement for continuing water treatment	- Camp Lake becomes a uniformly shallow lake	- technically superior provided sufficient subaqueous storage capacity available
5 Tailings Relocation to the Underground Workings	- excavate and relocate tailings to the underground mine workings	- divert Sherlett Creek around Camp Lake – uncertain duration - relocate all tailings above 314.5 m ASL to underground - engineer controls to minimize contaminant migration - reclaim and re-vegetate exposed areas - construct treatment plant and treat Camp Lake until water quality stabilizes	- improved water quality in Camp Lake - remove significant load of contaminants to Lake Kississing - may be able to reclaim the southern half of Camp Lake	- inadequate underground capacity to accommodate all tailings - prevents any further mining of the deposit - balance of tailings would require reclamation using one of the other approaches	- involves the complexity of multiple reclamation approaches
6 Engineered Cover	- cover the entire tailings pile with an impervious cover to minimize infiltration	- re-contour tailings surface and cover with a high quality liner - permanent diversion of Sherlett Creek to isolate Camp Lake and install controlled discharge to the north - construct treatment plant and treat water from Camp Lake	- may be possible to reclaim the southern portion of Camp Lake - improved water qualify in Camp Lake	- active treatment required for long term - sludge management required - tailings pore water quality remains poor - Camp Lake remains in a substantially degraded state serving primarily as a treatment pond	- tailings porewater remains long term source of contamination (albeit much lower advective flux) - essentially "manages" the tailings problem but does little to actually remediate the area - requires care and maintenance in perpetuity

6. DETAILED OPTION EVALUATION

A description of the short-listed closure options and their expected environmental performance is provided below, followed by a cost comparison, and an evaluation of the options. Quantities and unit costs employed in the analysis are detailed in Wardrop 2007.

Vegetated Cover and Treatment of Camp Lake

This is the “base case” option, considered to represent the minimum level of remediation necessary to achieve the reclamation objectives.

Acid rock drainage release rates in the Sherridon tailings are anticipated to continue to rise as neutralisation potential in the tailings is depleted and the higher strength cores of the existing acidic contaminant plumes within the tailings reach adjacent surface water bodies. Under this option, Sherlett Creek flows would be isolated from Camp Lake because the creek represents approximately 95% of the hydraulic load to Camp Lake and it is more efficient to treat as small a volume of water as practical. The existing tailings and waste rock surface would be regraded where required to establish a vegetative cover. A cover would be required to minimize windblown tailings and to improve the aesthetics of the site.

Establishment of a vegetation cover would require the placement of a phreatic break to control the upward movement of contaminants. The break would consist of 30 cm of coarse material (gravel and possibly some of the existing waste rock), covered with 30 cm of a finer material such as till. The cover would be seeded and maintained as necessary until the vegetation becomes self sustaining.

A high-density sludge (HDS) lime treatment plant would be constructed adjacent to Camp Lake to treat accumulated precipitation and local watershed runoff before discharge of the treated water to Kississing Lake. A sludge disposal facility would be needed for long term management of the produced metal hydroxide sludge.

The treatment plant would be required to remain in operation for centuries. As noted in Moncur (2004) without “an effective remedial program, sulphide oxidation in the vadose zone will continue to release acid, elevated concentrations of metals and sulphate to the tailings pore water for many decades to centuries. Once in the tailings pore water, the metals will be transported to surface waters for even longer”. In the Camp Tailings, the highest concentrations of metals and sulphates occur in the tailings farthest inland from Camp Lake (Moncur 2004).

Over time it is expected that groundwater quality will deteriorate along the flow paths within the tailings, such that pore water quality discharging to Camp Lake will worsen over time. Consequently, loadings to Camp Lake will increase in the future under this long-term treatment scenario, resulting in increasing lime costs and rates of sludge production over time. For the purpose of the cost comparison, it was assumed that loadings from the tailings area double over the next 100 years and that operation of the treatment plant would be required for at least 100 years – a conservative estimate in consideration of the above. A detailed study would be required to improve on this prediction.

Implementation of this option would have a dramatic effect on water quality in Kississing Lake, as the treated water discharged for the HDS plant would be of good quality. Water quality would continue to be poor in Camp Lake and in ponds adjacent to the tailings pile. The simple cover over the tailings areas and mine/mill area would control tailings dusting improve the aesthetics of the site.

Engineered Cover

A variety of engineered covers could be applied to the tailings, each with different infiltration rates and oxygen barrier properties. For the Sherridon tailings, the performance of the cover as a barrier to infiltration is considered to be more important than its performance as an oxygen barrier. This is due to the large existing inventory of sulphide oxidation products in the porewater and, to a lesser extent, in the hardpan. Discharge of the existing inventory will only be decreased by reducing infiltration. A reasonably good engineered cover could reduce infiltration by 80% over current levels. For the Sherridon tailings, the current infiltration is estimated at 108 mm/year, or a discharge of 50,760 m^3/year for the entire area. A reduction by 80% would result in infiltration of 22 mm/year, or a discharge of 10,150 m^3/year.

For the purposes of this comparison, a conceptual cover design has been employed that consists of the following layers, from top to bottom:

- 0.5 m layer of vegetated, un-compacted granular material;
- 1.0 m layer of compacted low permeability clay till; and,
- 0.5 m capillary break layer consisting of coarse gravel and/or processed waste rock.

Alternatively, a cover could be constructed containing a synthetic barrier layer such as high density polyethylene (HDPE) or a geosynthetic clay liner (GCL). The final cover design would be determined through a detailed study, which would consider performance, cost, and the availability of construction materials such as granular and low permeability clay tills.

Covers that are good barriers to infiltration typically are also good oxygen barriers, so improvements in one area usually result in improvements in another area. With the engineered cover in place, there could still be some ongoing sulphide oxidation however it will likely be reduced significantly. Even with no ongoing sulphide oxidation, the current porewater inventory will result in long-term loadings.

After installation of the cover, the discharge of contaminated porewater from the tailings pile would continue at pre-cover levels for some time. Discharge would then gradually decline, as the hydraulic gradient and the stored porewater in the tailings (above the level of Camp Lake) both decrease in response to the cover. This process would take years to decades. Once discharge volumes stabilise at a lower level, loadings would increase in a similar fashion as described above for the base case, due to the migration of the core of the contaminant plume toward Camp Lake.

The environmental benefit of an engineered cover mainly depends on how effective the cover is in reducing infiltration. As discussed above, a reduction of infiltration by 80% would be reasonable to expect. However, the expected future degradation of porewater would partially negate any improvement (reduction) in loading due to reduced infiltration. If the contaminant concentrations in the porewater discharging to the water bodies eventually double, then the reduction in loading would only be 60% of current levels. If left untreated, this level of loading would result in continued degradation of Camp Lake and Kississing Lake. The engineered cover would effectively eliminate dusting and deal with visual impairment. For the engineered cover to provide environmental benefits comparable to the base case, above, a treatment system would be required over the long-term. Sherlett Creek also would be permanently diverted as described for the base case.

Consequently, both the capital and operating costs of this option would be relatively high as both a cover and some form of continuing treatment would be necessary.

Subaqueous Disposal in Camp Lake

Subaqueous disposal in Camp Lake has been considered in a manner that does not require raising the lake level above 316 m ASL, the nominal natural lake level, on completion of the tailings relocation into the lake basin. This requires the excavation of all tailings to elevation 314.5 m ASL in order to ensure at least 1.5 m of water cover over the relocated tailings.

The benefits of relocation and flooding of the tailings include:

- minimize or eliminate the hydraulic gradient that is currently driving the discharge of contaminated porewater from the tailings;
- minimize further oxidation of the tailings;
- eliminate the need for long-term treatment; and,
- stabilise the tailings surface from wind and water erosion.

The hydraulic gradient in the flooded tailings is expected to be flat, therefore eliminating gradient-driven porewater discharge to Camp Lake. Groundwater mounding in the surrounding bedrock ridges is unlikely to provide a significant head to drive ongoing groundwater discharge, as the bedrock is for the most part a relatively impermeable gneiss and the watershed area is small. Instead, it is expected that precipitation in the bedrock ridges would tend to flow mainly as surface runoff to Camp Lake.

In preparation for tailings relocation, Camp Lake would need to be isolated from Sherlett Creek flows by a dyke and diversion channel to route flows around the south end of the lake and reduce the hydraulic load, both to facilitate treatment and level management for tailings placement. Once this structure is in place, Camp Lake and other acidic water bodies in the watershed would be batch-treated with lime to reduce existing acidity and precipitate metals. When water quality becomes acceptable for discharge to Kississing Lake, the level of Camp Lake can be managed as needed by pumping out the treated water. Potential pumping requirements range from moving the water displaced by tailings to pumping the basin empty to allow tailings placement in the dry. Requirements for the addition of neutralization potential to relocated tailings vary with the tailings properties and the method of placement. Similarly, some tailings benefit from the placement of an alkalinity barrier over the tailings.

Cost Evaluation

Comparative costs of three approaches were developed on the basis of physical and chemical characteristic of the tailings and on typical unit costs for materials and earth moving. These are detailed in Wardrop (2007). For purposes of cost comparison among dissimilar approaches, the long term operating costs were estimated for a period of 100 years using a 3% discount rate. Although the long term operating costs of the continuing treatment options would likely extend for longer than 100 years, costs beyond that horizon do not materially affect such a cost comparison. On this basis, the estimated net present value costs (in millions of 2007 CAD) for the three options are:

Minimal Cover and Long-term Treatment of Camp Lake	\$35.4
Engineered Cover with Long-Term Treatment of Camp Lake	\$35.1
Subaqueous Disposal in Camp Lake	\$34.4

All three options carry effectively the same net present cost, although subaqueous disposal brings additional advantages including no requirement for a long term presence on the site and reclamation of Camp Lake, in addition to providing protection for Kississing Lake and controlling tailings dusting, which all three options address. On this basis, and considering that long-term treatment would likely be for much longer than 100 years, subaqueous disposal was recommended as the remedial approach for the site.

7. DETAILED DESIGN

The overall objective of the remedial design process is to achieve water quality in Camp Lake that is in compliance with the Manitoba Water Quality Standards Objectives and Guidelines (MWQSOG; Williamson 2002) for the protection of aquatic life and to do so with a minimum of post-relocation water treatment, all at the lowest possible cost. The base case for the remedial design included:

- Diversion of Sherlett Creek around Camp Lake for period of remedial works
- Neutralization of Camp Lake to pH 9 prior to the initiation of tailings relocation
- Maintenance of neutralized lake water through the period of tailings relocation.
- Relocation of all tailings above elevation 314.5 m ASL to the Camp Lake basin; and,
- Cover all the tailings with a 1.5 m deep water cover on completion of relocation to bring the Camp Lake level to elevation 316.0 m ASL, which is within the historic natural range of lake levels.

The neutralization specification for Camp Lake of pH 9 was determined from a PHREEQC simulation run on Camp Lake water at one unit pH increments between pH 7 and pH 10 and indicated that concentrations of both copper and zinc dropped significantly between pH 8 and 9 (Table 2).

Beyond the base case, the following four specific design variations were evaluated:

- Tailings relocated without neutralization, no barrier cover;
- Tailings relocated without neutralization, covered with an alkalinity barrier;
- Tailings relocated with neutralization, no barrier cover; and,
- Tailings relocated with neutralization, covered with an alkalinity barrier.

The expected effects of each design variant on water quality in the post-remediation Camp Lake were evaluated using the Reactive Tailings Program for Base Metal Tailings (RATAP.BMT) (MEND/NRCan 1990). Model input included tailings dimensions (size, depth, depth to water table), tailings particle size distribution, gaseous transport characteristics (diffusion coefficient, gas filled porosity), precipitation (hydraulic flows), mineralogy (bulk density, reactive sulphide minerals, other primary minerals, secondary minerals, buffering minerals), water quality (background water quality, porewater quality), pond option (pond size, depth, pond water quality, inflow water quality), and dry cover option (number of cover layers, cover diffusivity, cover thickness). Input data are subjected to statistical analysis to identify outliers and significant data clusters. All water quality data were checked for ion balance and solid/solution equilibrium by employing US Geological Survey's PHREEQC water quality program. The model was run at a one month time step for a period of 600 months (50 years) following completion of the remedial works. Specific model inputs are detailed in Table 3.

The key water quality parameters for assessment of the effectiveness of the design variations were identified as pH, sulphate, total zinc, and total copper. The RATAP-estimated post-remediation water quality indicates that both neutralization of the tailings is adequate to achieve all the remediation objectives but that the additional placement of an alkalinity barrier improves performance with respect to zinc and sulphate (Figures 3, 4, 5, and 6). The applicable chronic exposure MWQSOG for total zinc is 129 µg/L at a total hardness of 108 mg/L and the objective for total copper is 9.9 µg/L. In comparison, the estimated total Zn concentration in Camp Lake the first year following completion of tailings relocation is 70 µg/L. The estimated total Cu concentration in Camp Lake the first year after tailings relocation is 6.2 µg/L. Both neutralization and an alkalinity barrier reduce sulphate release over neutralization alone during the first approximately 150 months after tailings relocation (Figure 4), indicating sulphide reduction may also be better controlled as well.

Table 2: Camp Lake Neutralization – PHREEQC simulation of parameter concentration response to pH adjustment (SENES 2008).

pH		**3.2**	**7**	**8**	**9**	**10**
Temp	**°C**	**4**	**4**	**4**	**4**	**4**
Ca	mg/L	13.7	81.5	92.1	96.4	110.7
Mg	mg/L	7.4	7.4	7.4	7.4	7.4
Na	mg/L	2.6	2.6	2.6	2.6	2.6
K	mg/L	1.8	1.8	1.8	1.8	1.8
Al	mg/L	1.9	0.06	0.5	1.4	1.9
Ba	mg/L	0.01	0.01	0.01	0.01	0.01
B	mg/L	0.01	0.01	0.01	0.01	0.01
Cd	mg/L	0.002	0.002	0.0006	0.0005	0.0005
Cu	mg/L	0.14	0.14	0.018	0.001	< 0.001
Fe	mg/L	34	0.03	0.01	0.001	0.001
Pb	mg/L	0.0005	0.0005	0.0005	0.0005	0.0005
Mn	mg/L	0.3	0.3	0.1	0.07	0.001
U	mg/L	0.0003	0.0003	0.0003	0.0003	0.0003
Zn	mg/L	0.77	0.77	0.77	0.27	0.18
Cl	mg/L	6	6	6	6	6
Si	mg/L	1.2	1.2	0.8	0.5	0.1
SO_4	mg/L	165	165	165	165	165
NO_3	mg/L	2.2	2.2	2.2	2.2	2.2
NH_3	mg/L	0.3	0.3	0.3	0.3	0.3

Table 3. RATAP model input data – surface and tailings porewater quality, Camp Lake hydrology and morphometry, tailings solids mineralogy (SENES 2008).

		Tailings Porewater	Camp Lake	Surface Water	Ground Water	Woods Lake	Neutralized Tailings Porewater
pH		3.24	3.2	7.6	8.2	2.4	6.12
Temp	°C	4	4	4	4	4	4
Ca	mg/L	170	13.7	9.8	49.3	320	575
Mg	mg/L	7.4	7.4	3.1	20.3	290	17.6
Na	mg/L	2.6	2.6	2.1	41.3	40	5
K	mg/L	1.8	1.8	1.5	11.7	5	10.3
Al	mg/L	1,000	1.9	0.193	0.007	140	0.62
Ba	mg/L	0.01	0.01	0.01	0.05	0.2	0.03
B	mg/L	0.01	0.01	0.03	0.04	0.3	0.06
Cd	mg/L	0.002	0.002	0.0001	0.0002	0.027	0.004
Cu	mg/L	0.35	0.14	0.006	0.001	1.1	0.004
Fe	mg/L	31,000	34	2.45	0.2	2,430	0.5
Pb	mg/L	0.0005	0.0005	0.0001	0.0001	0.01	0.00004
Mn	mg/L	36	0.3	0.014	0.37	19	0.17
U	mg/L	0.0003	0.0003	0.0001	0.0001	0.017	0.0003
Zn	mg/L	754	0.77	0.076	0.007	38	0.05
Cl	mg/L	6	6	2.3	6	6	6
Si	mg/L	1.2	1.2	1.2	7.4	38	0.3
C(4) as C	mg/L	8	8	8	60	8	8
SO_4	mg/L	60,000	165	12	56.1	7,520	1,445
NO_3	mg/L	0.5	0.5	0.05	0.15	0.15	0.01
NH_3	mg/L	0.25	0.25	0.03	0.8	1.97	0.01
Ion Balance	(%)	0.88	0.42	0.5	-0.09	-0.07	0.06

Camp Lake Post Relocation

Total Outflow :	17,490,000	m^3/yr	**Lake area :**	1,300,000	m^2

Tailings Solids Mineralogy(mol/m^3)

Pyrite	**Pyrrhotite**	**Chalcopyrite**	**Sphalerite**	**Arsenopyrite**	**Pentlandite**
2,610	4,860	51	441	1.5	0.6
Calcite	**Dolomite**	**Siderite**	**Gypsum**	**$Al(OH)_3$**	**$Fe(OH)_3$**
3.2	2.5	0	975	0	412
Mica	**Pyroxine**	**Quartz**	**Ymg**	**YK**	**YNa**
679	939	4,050	2	1	0.5

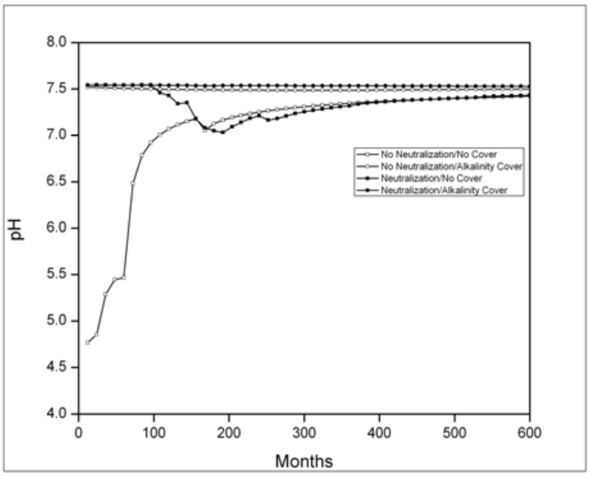

Figure 3. RATAP model results - pH

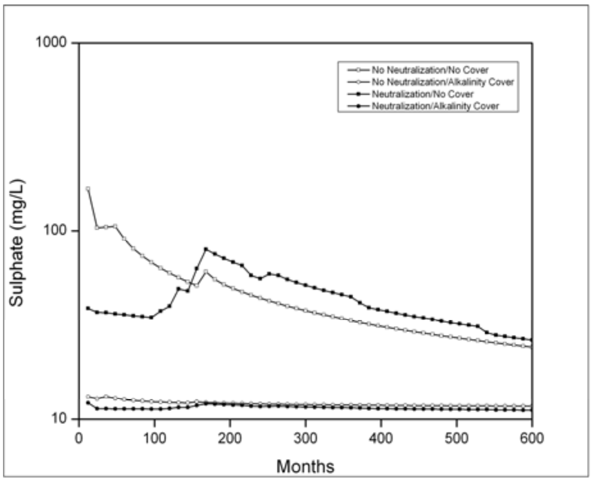

Figure 4. RATAP model results – Sulphate

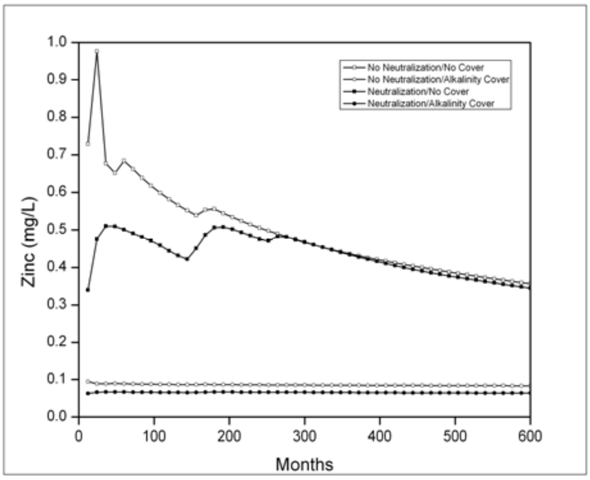

Figure 5. RATAP model results – Zinc

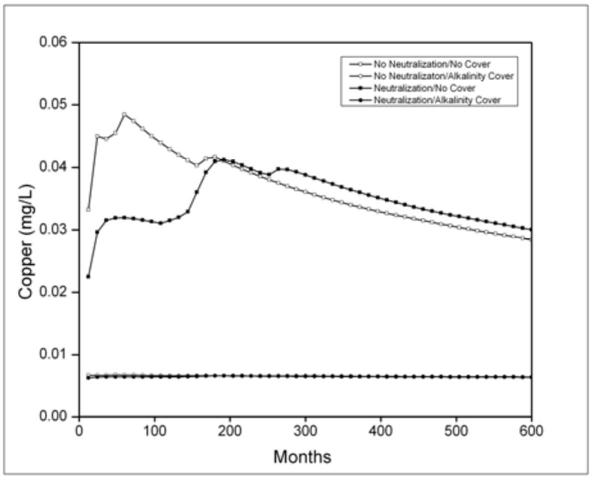

Figure 6. RATAP model results – Copper

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