TAILINGS MANAGEMENT BEST PRACTICE: A CASE STUDY OF THE MCCLEAN LAKE JEB TAILINGS MANAGEMENT FACILITY

Michael A. J. Tremblay, P. Eng.
Dr. J. Rowson
COGEMA Resources Inc., Saskatoon, Saskatchewan, Canada

ABSTRACT

COGEMA Resources Inc. (which is part of the Areva Group) is a Canadian company with its head office in Saskatoon, Saskatchewan. It owns and operates mining and milling facilities in Northern Saskatchewan, which produce uranium concentrate. McClean Lake Operation commenced production in 1999 and its tailings management facility represents the state of the art for tailings management in the uranium industry in Canada.

Tailings disposal has the potential to cause effects in the surrounding receiving environment primarily through migration of soluble constituents from the facility to surface water receptors. In-pit disposal of mill tailings has become the standard in the uranium mining industry in Northern Saskatchewan. This method of tailings management demonstrates advances in terms of worker radiation protection and containment of soluble constituents both during operations and into the long term.

Sub-aqueous deposition of tailings protects personnel from exposure to radiation and airborne emissions and prevents freezing of tailings, which can hinder consolidation. The continuous inflow of groundwater to the facility is achieved during operations, through control of water levels within the facility. This ensures hydrodynamic containment, which prevents migration of soluble radionuclides and heavy metals into the surrounding aquifer during operations.

The environmental performance of the decommissioned facility depends upon the rate of release of contaminants to the receiving environment. The rate of constituent loading to the receiving environment will ultimately be governed by the concentrations of soluble constituents within the tailings mass, the mechanisms for release from the tailings to the surrounding groundwater system, and transport of constituents within the groundwater pathway to the receiving environment. The tailings preparation process was designed to convert arsenic into a stable form to reduce soluble concentrations within the tailings mass. The design of the TMF itself relies on the high permeability sandstone unit to provide a preferential flow path for groundwater around the low permeability tailings mass. This provides a passive means of minimizing the long-term release of constituents from the decommissioned facility to the environment.

A comprehensive tailings optimization and validation program was developed to reduce uncertainties related to the performance of the tailings management facility associated with the chemical and physical properties of tailings. This paper will describe the JEB tailings management facility and provide a summary of the findings of this research program.

I. INTRODUCTION

Canada's most recent and modern uranium milling facility is located at the McClean Lake Operation in northeastern Saskatchewan, Canada, see Figure 1. The McClean Lake Operation is jointly owned by COGEMA Resources Inc. (70%), Denison Mines Ltd. (22.5%) and OURD (7.5%) with COGEMA Resources Inc. as the operator. COGEMA Resources Inc. is a subsidiary of COGEMA S.A. of France, which in turn is part of AREVA. AREVA's aim on the nuclear and electricity distribution side is to provide a comprehensive scope of services in every aspect of the nuclear fuel cycle, nuclear power reactor supply and services, and electricity transmission and distribution. COGEMA Resources Inc. forms part of the Mining Business Unit.

Mill operation at McClean Lake commenced in late June of 1999 and has been operating at or above design production levels since January 2000. In the current configuration, the mill is processing the McClean Lake ore bodies at a current production rate of 6,000,000 lbs U3O8 per year. Planning calls for the future processing of ore from the Midwest and Cigar Lake mine sites. The operating life of the milling facility is expected to be approximately 40 years.

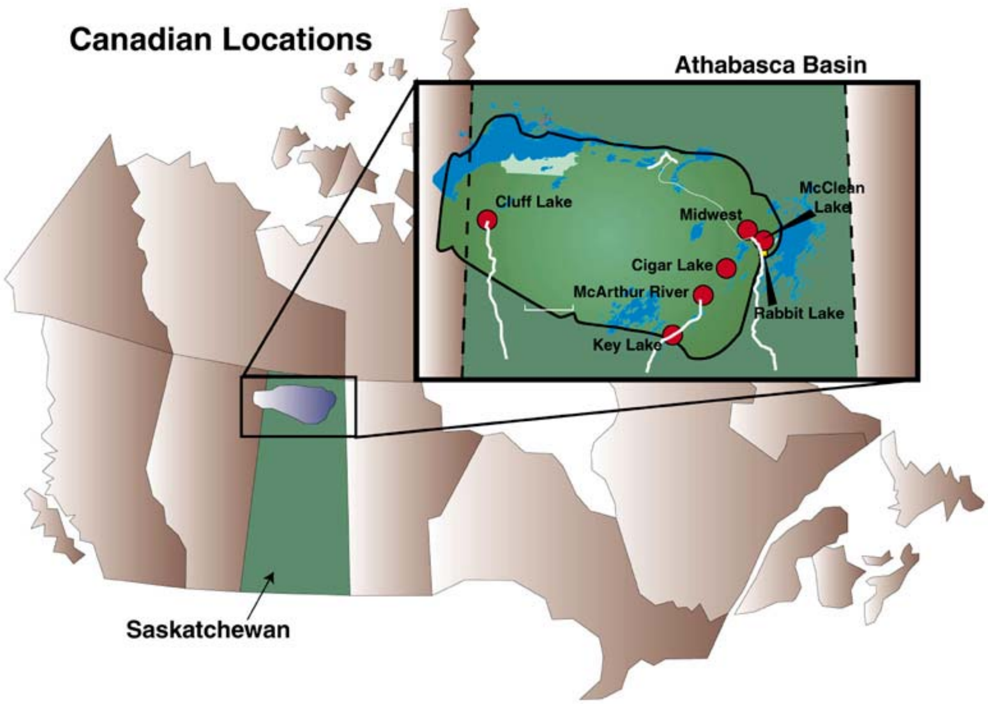


Figure 1. Uranium production locations in the Athabasca Basin of northern Saskatchewan

The nearby depleted JEB open pit mine has been converted into the JEB Tailings Management Facility (TMF). The TMF has the capacity to receive approximately 1.8 million m3 of tailings from the mill over its operating life. This is adequate for all the ores from the McClean Lake, Midwest and Cigar Lake projects. Adjacent to the TMF are two small lakes,

Figure 2, locally known as Fox Lake and Pat Lake. Hydrogeologic evaluations had indicated potential for long term (10,000 years) effects to the water quality of these receiving water bodies due to the presence of the placed tailings in the TMF. Chemical constituents of concern include arsenic and nickel, which originated in the pore water of the placed tailings. As a result, COGEMA Resources has developed the tailings preparation process in the mill and optimized the design and operation of the TMF to mitigate any potential environmental effects. It is now expected that none of the water quality parameters in Fox Lake or Pat Lake will exceed the Saskatchewan Surface Water Quality Objectives over the long term (10,000 years).

Figure 2. Aerial photograph of the McClean Lake milling site showing Fox Lake in the foreground followed by the TMF and the ore processing plant.

II. TMF DESIGN

The JEB TMF has been designed to minimize the migration of soluble constituents from the facility to the receiving environment both during the operating and post-decommissioning periods. During operations, the condition of hydrodynamic containment is maintained, whereby a constant inflow of groundwater to the facility prevents migration of soluble radionuclides and heavy metals into the surrounding aquifer. The design of the decommissioned facility relies on control of source concentrations within the tailings pore water and an hydraulic conductivity contrast between the tailings mass and the surrounding host rock such that groundwater preferentially flows around the tailings. This results in the relatively slow process of molecular diffusion being the dominant mechanism for contaminant release from the facility, which is minimized by relatively low source concentrations.

II.A. Post Operational Requirements

The key to the long-term performance of JEB TMF is the hydraulic isolation of the tailings materials within the decommissioned facility from the surrounding aquifer. Physical containment controls and geochemical controls provide the principal means of controlling the long-term release of potential contaminants to the groundwater flow system.

The control of flow through the tailings is dependent on site specific factors related to the physical characteristics of the tailings compared with those of the local Athabasca sandstone. The tailings as produced during mill operations contain a significant amount of fine-grained materials. Consolidation of these materials produces a tailings mass of low hydraulic conductivity, approximately two orders of magnitude less than the surrounding sandstone. Under these conditions for the long term, the consolidated tailings represent a low-permeability plug and groundwater preferentially flows around the tailings mass through the surrounding host rock. Solute release from the tailings pore water, Figure 3, is then dominated by a slow diffusion process driven by the solute concentration gradient between the pore water of the tailings mass and the ground water of the surrounding host rock.

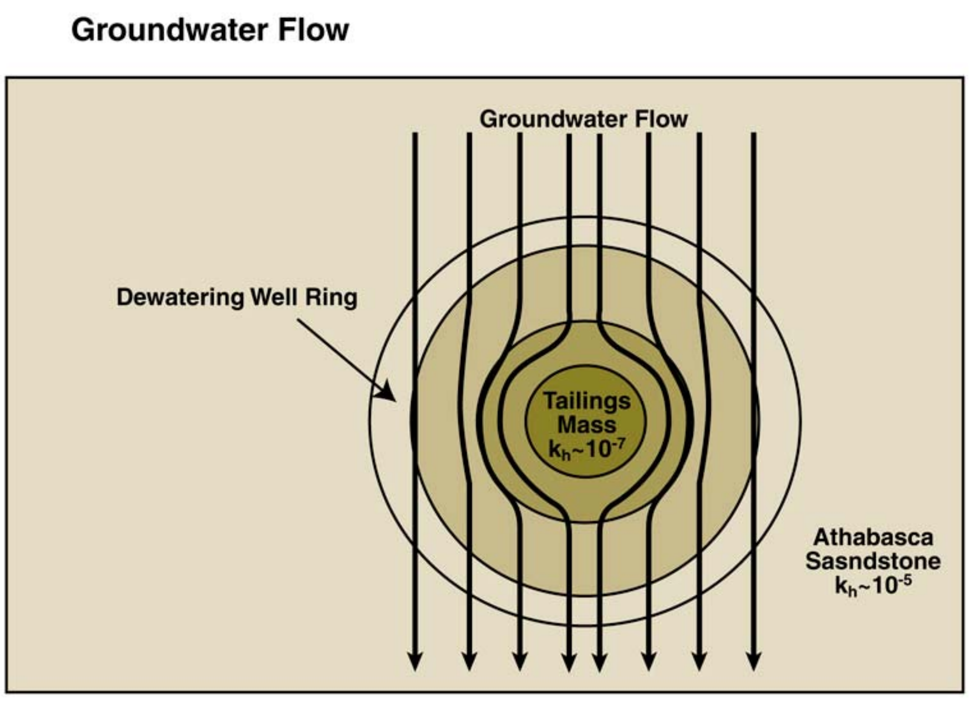


Figure 3: Plan view depicting the principle physical containment control. Ground water flows through the sandstone and around the relatively impermeable tailings mass.

The second control on contaminant release is the tailings solids chemistry, which is designed to keep the concentrations of constituents of concern in the tailings pore water at such low levels that releases by the diffusion process over the long term are environmentally acceptable. The elements of arsenic and nickel are of primary concern. Environmental objectives for these two elements require their concentration not to exceed 5 mg/L over the long term. To facilitate this environmental requirement, an internal operational objective of 1 mg/L has been implemented.

II.B. Operational Period

COGEMA Resources has introduced new technology to the tailings preparation circuit in the mill for the long term control of arsenic and nickel in the tailings pore water. The process is shown in Figure 4. A more detailed description of the process has been published elsewhere Ref. [1].

All the process wastes are mixed and transferred to the neutralization process. Prior to neutralization the soluble arsenic concentration in the total waste stream is first measured and the iron (III) to arsenic molar ratio is then adjusted to approximately 3 by the controlled addition of ferric sulphate. This critical step provides the means to specifically and consistently precipitate arsenic with iron in a form that is suitable for long term disposal. Barium chloride is also utilized to promote the removal of radium. Slaked lime is added to the first and second slurry tailings neutralization tanks. The pH is raised to approximately 4 in the first tank and then adjusted to approximately 8 before discharge from the second tank. Total retention time for the neutralization process is approximately 3 hours with 1.5 hours reaction time at pH 4 and 1.5 hours at pH 8.

The neutralized slurry is then pumped to a tailings thickener where flocculent is added to promote settling. Tailings are thickened to 30% to 35% solids by weight prior to discharge to the TMF.

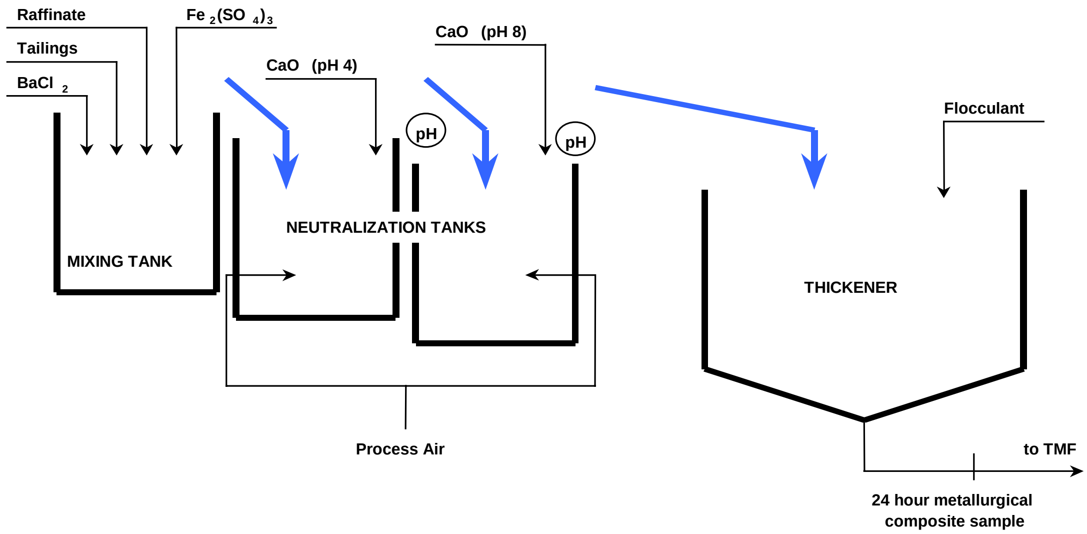


Figure 4. Flowsheet for the tailings preparation circuit.

The depleted JEB open pit mine was modified to suit the requirements for the TMF. The top perimeter of the TMF is approximately circular with a diameter of about 420 meters. The natural groundwater level is at or near the surface. The facility was excavated through approximately 10 m of glacial till overburden, 75 m of sandstone, and into the granitic basement rock to a total depth of approximately 118 m below grade. To ensure hydraulic containment of tailings pore water during the operating period (40 -50 years) a ring of de-watering wells have been installed around the edge of the pit, Figure 5. The submersible pumps in these wells are located at a fixed elevation slightly above the desired pond level. These wells act as the primary control on the TMF pond water level and to intercept clean ground water before it enters the TMF. To monitor ground water levels four observational wells (external) are installed within the ring. In addition, four internal monitoring wells are installed between the de-watering well ring and the pit. A base drain and graded filter package constructed of sand and crushed rock at the base of the TMF allows collection of tailings pore water to prevent the release of solutes to the surrounding aquifer and enhance tailings consolidation by dissipating excess pore water pressure within the tailings mass. Water is removed from the base drain and pumped to surface for treatment through a dewatering drift and raise system. Hydrodynamic containment of TMF waters is ensured by maintaining the following water level hierarchy: exterior well > interior well > pond level > base drain level.

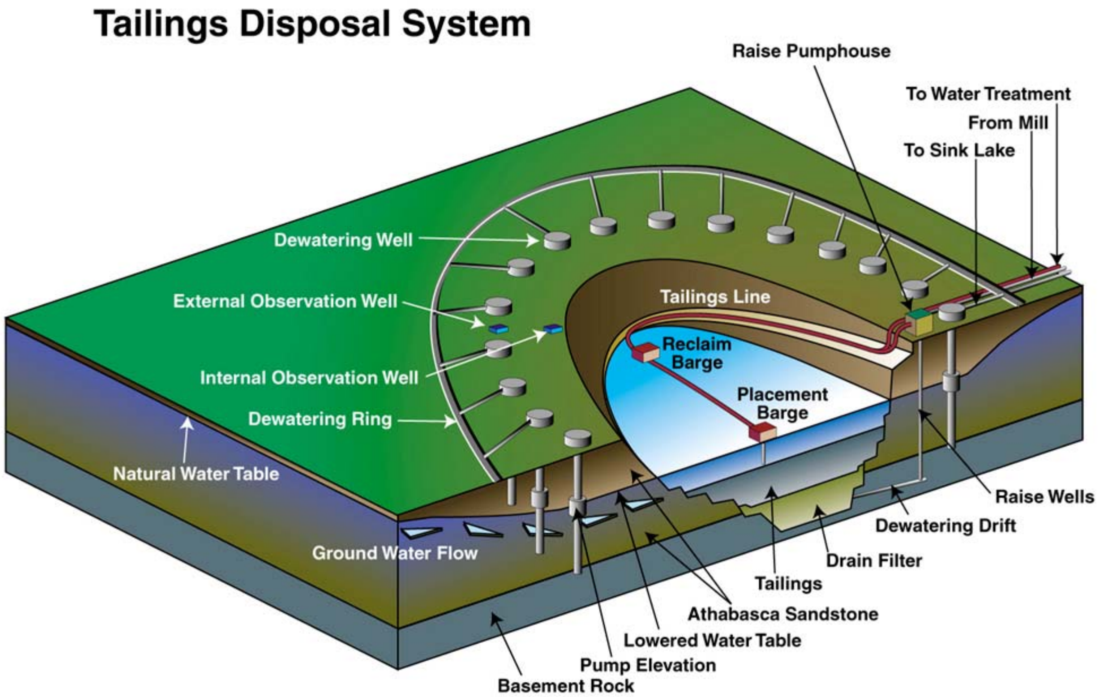


Figure 5. Design and Operational Features of the JEB Tailings Management Facility (TMF)

The tailings lines from the mill run down the TMF ramp and onto a floating walkway leading to the placement barge. The discharge pipe is suspended below the barge and the tailings are placed onto the surface of previously placed tailings using a shallow injection tremie method. This placement methodology minimizes particle size segregation and insures that relatively permeable pathways do not develop within the tailings mass. The reclaim water barge is used to precisely control the pond level by returning the mill tailings pumping water back to the mill.

III. TMF PERFORMANCE TO-DATE

III.A. Mill Tailings Preparation Circuit

During the first year of operation, the focus was to ensure that the tailings produced by the preparation process and discharged to the TMF met the arsenic and nickel pore water concentrations required for long term environmental protection. Figures 6 and 7 are summaries of daily results for nearly 7 months of operation of the tailings preparation process. The process has proven to be easily controllable, despite the fact that acidic waste solutions as high as 2,000 mg/L As have been processed. As can be seen from Figure 6 the addition of ferric sulphate solution to achieve an iron (III) to arsenic molar ratio of approximately 3 has successfully reduced As and Ni concentrations in the final tailings pore water to approximately 1 mg/L feeding the TMF. Similarly, the sensitivity of the process to terminal pH at a fixed Fe/As molar ratio is shown in Figure 7. This figure illustrates that soluble As and Ni pore water concentration objectives can be met within a reasonably broad pH window.

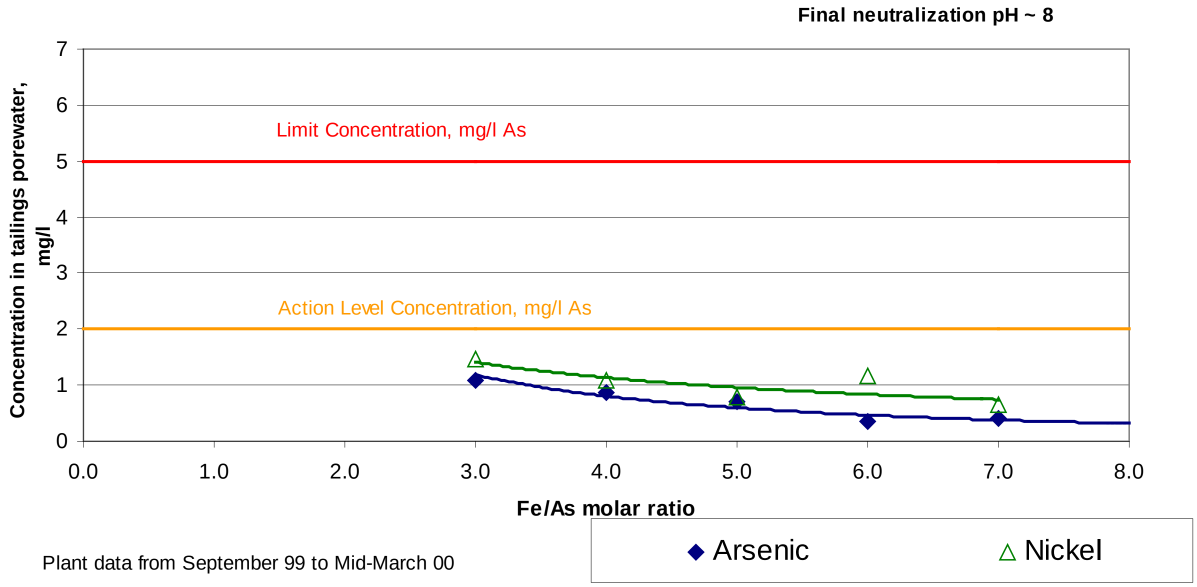


Figure 6. Arsenic and nickel concentrations in tailings pore water as a function of molar Fe/As ratio at a fixed pH of 8. Each point is the average of daily readings over a 7 months operating period.

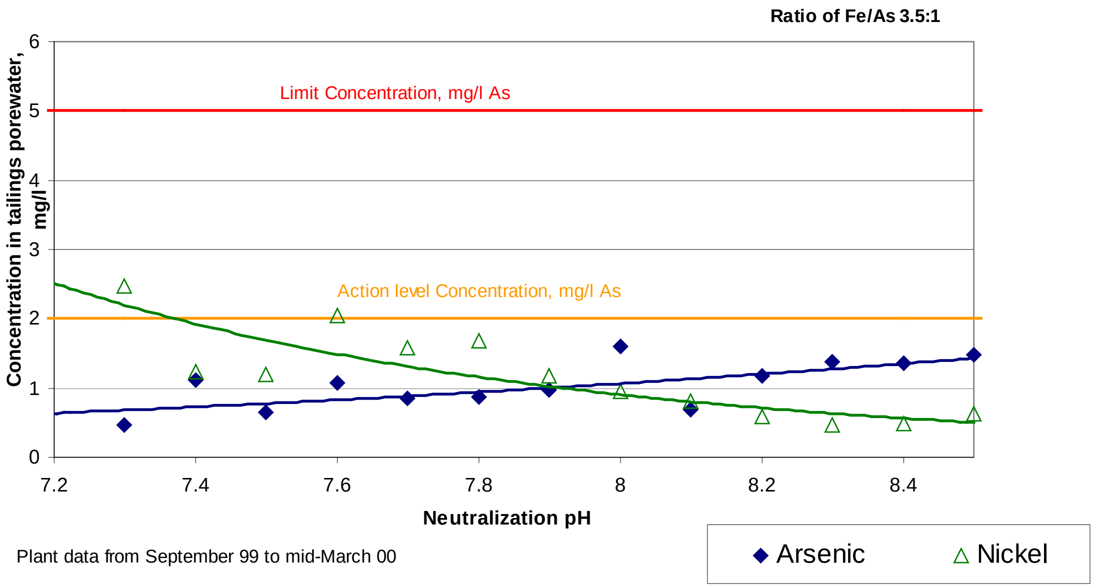


Figure 7: Arsenic and nickel concentrations in tailings pore water as a function of terminal neutralization pH at a fixed molar Fe/As ratio of 3.5.

III.B. Tailings Aging Test Work

A considerable amount of laboratory aging of mill tailings has been carried out to assess the long-term stability of the arsenic bearing minerals produced. During the design stage, a rapid aging technique was developed (SEPA aging tests) to determine soluble arsenic concentration equilibrium endpoints. Following mill startup aging tests were conducted over a ten-month period (TOVP aging tests) on production tailings to observe aging behavior with respect to soluble arsenic concentrations.

The results of aging tests have shown that arsenic pore water concentrations can be expected to remain at or below 1 mg/L over the long term. Mineral saturation index modeling further indicates that arsenic concentrations in tailings pore water are controlled by saturation with a poorly crystalline scorodite mineral complex. Aging test work shows a transient rise and fall of soluble arsenic concentrations during the early stages of aging.

Annual sampling of tailings from within the JEB TMF was conducted to track the aging characteristics of tailings for comparison with laboratory test work. Tailings core samples were collected from all ages of tailings within the TMF and pore water samples were extracted for analytical testing. The aging profile of soluble arsenic in tailings pore water within the TMF was consistent with laboratory aging tests, demonstrating a similar rise and fall, with equilibrium concentrations at or below 1 mg/L. Figure 8 provides a comparison of the results of all aging tests conducted to date.

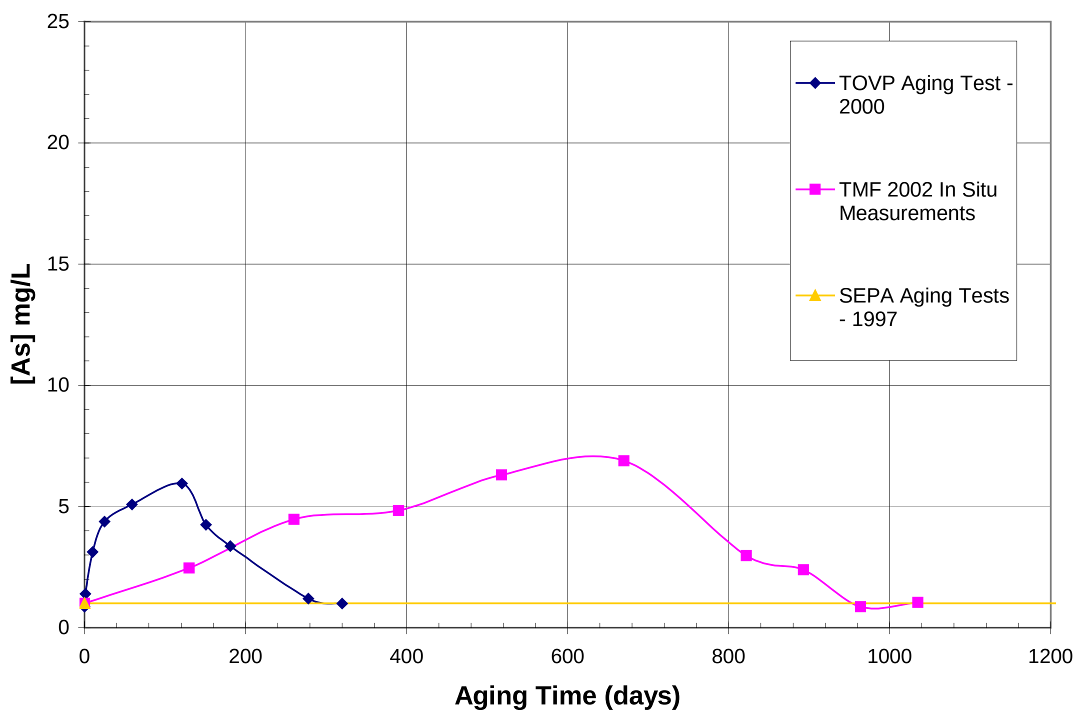


Figure 8: Summary Comparison of Laboratory and Observed Aging Behaviour

III.C. Tailings Geotechnical Properties

Five annual sampling campaigns to investigate the geotechnical properties of placed tailings within the JEB TMF have been undertaken. These investigations have focussed on tailings density and hydraulic conductivity. The densities achieved by tailings as they consolidate are important from the perspective of storage within the TMF. The hydraulic conductivity of placed tailings is important for limiting the flow of groundwater through the tailings of the decommissioned facility.

Results to date indicate that tailings are consolidating at a greater rate than initially predicted. After four years of operation, the height of tailings within the facility is several metres below predicted levels, in spite of greater than predicted volumes of tailings produced. This indicates that the available storage volume within the TMF will be adequate for all future planned tailings production. Tailings core samples from throughout the TMF were collected for grain size analyses and hydraulic conductivity testing. Grain size analyses results indicate that the tailings near the central deposition point are coarser in nature than whole tailings due to segregation during placement. Figure 9 presents average grain size distributions for whole tailings and the coarse and fines zones within the TMF. The coarse zone was found on average to contain approximately 20% fines (<75um), compared with 55% fines for whole tailings. The coarse zone was found to extend approximately 40 m radially outward from the deposition point, which corresponds to approximately 20% of the area of the tailings surface (Figure 10).

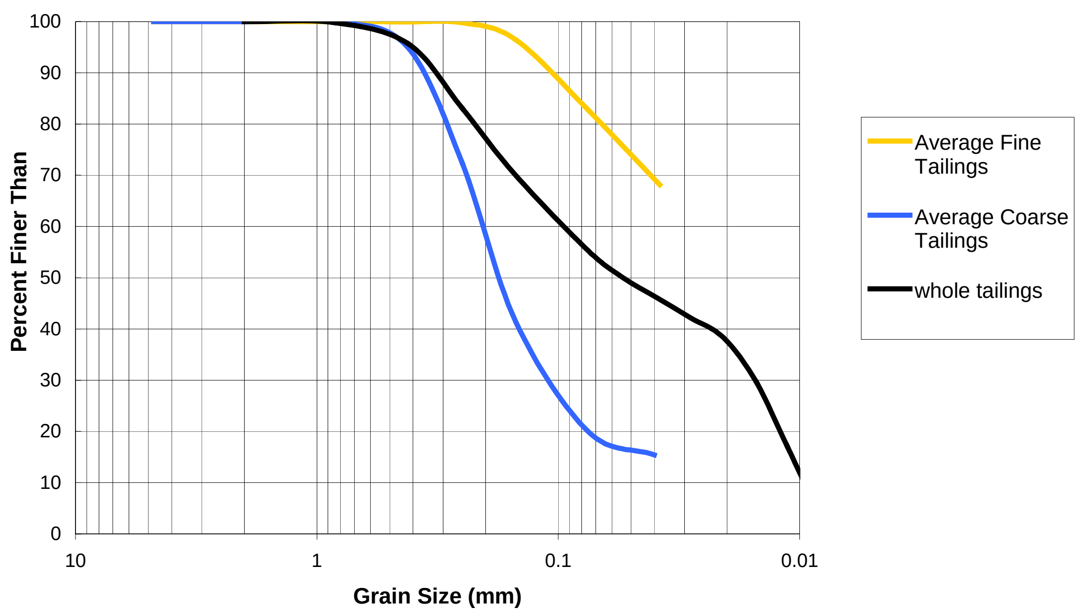


Figure 9: Grain Size Analysis – Average Coarse and Fine Zones

Figure 11 presents the results of hydraulic conductivity testing and shows the effect of fines content (<75 um) on the consolidated hydraulic conductivity of tailings samples. The results indicate that the coarse zone may be expected to achieve a hydraulic conductivity of approximately 1x10-7 m/s , while the surrounding fines are expected to reach hydraulic conductivities in the range of 1x10-9 to 1x10-8 m/s. Overall, the tailings mass is expected to exhibit a bulk hydraulic conductivity sufficiently low to ensure a contrast of at least two orders of magnitude less than that of the surrounding host rock. Typically, sandstone host rock exhibits hydraulic conductivities on the order of 1x10-5 m/s.

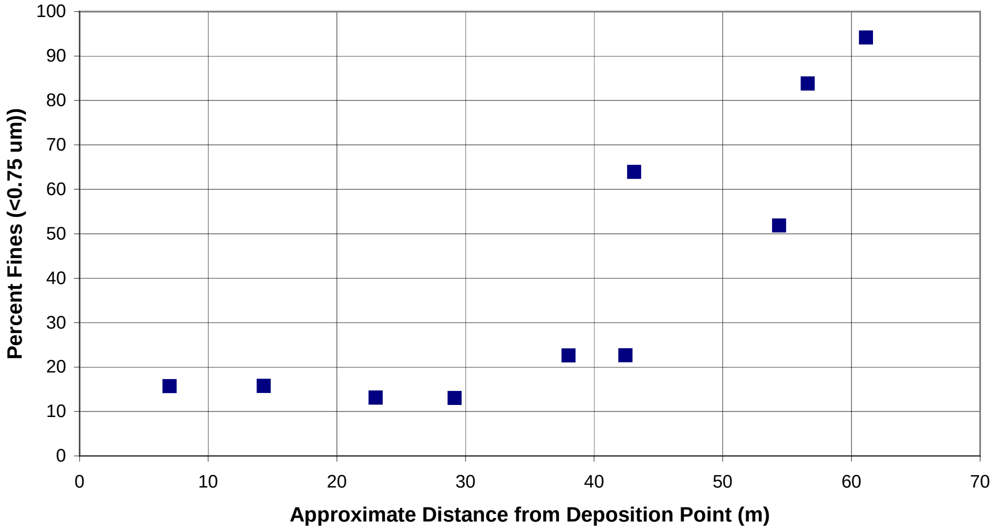


Figure 10: Percent Fines versus Distance from Deposition Point

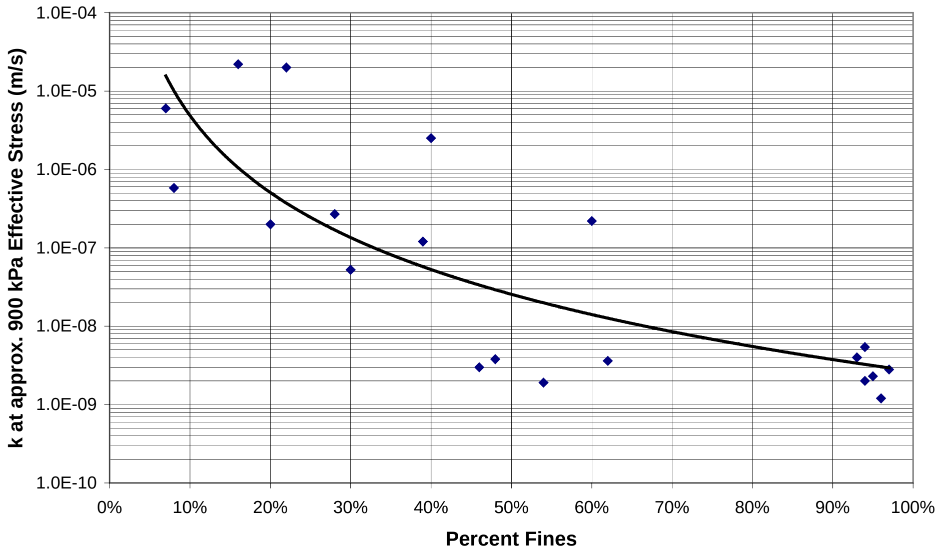


Figure 11: Hydraulic Conductivity versus Percent Fines

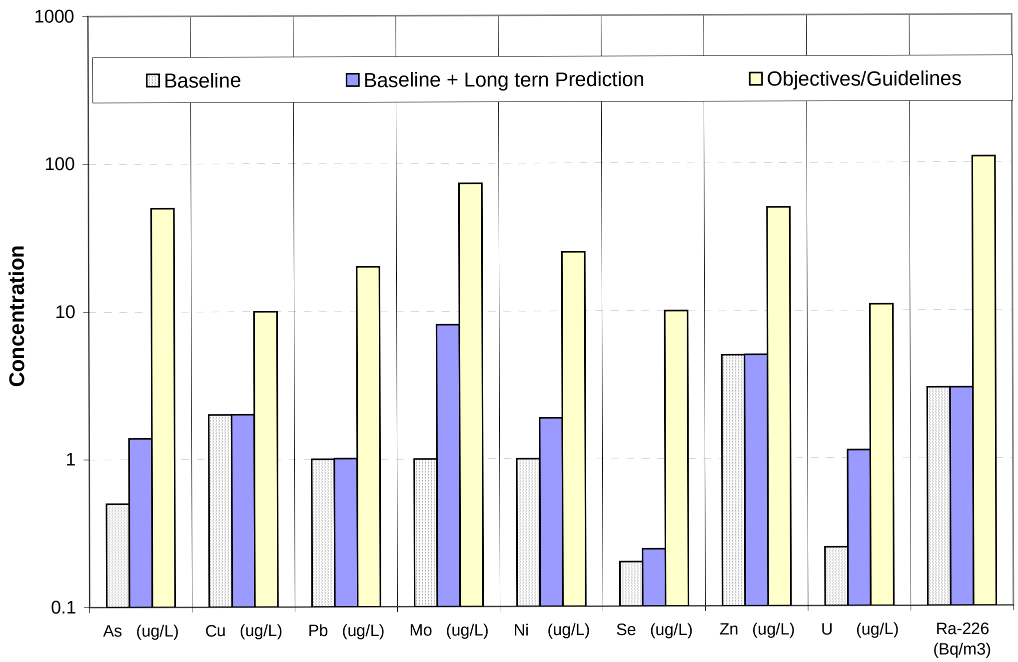
IV. PREDICTED LONG-TERM PERFORMANCE

Solute transport simulations, based on a groundwater flow model of the local JEB area, were performed to predict the long-term effects of tailings disposal within the JEB TMF to the surrounding surface water receptors. Based on the flow model output, and the predicted source concentrations of soluble contaminants within the tailings, the mass flux out of the decommissioned TMF and transfer to each receptor were calculated. Figure 12 presents the predicted long-term concentrations of solutes within Fox Lake and Pat Lake resulting from tailings disposal within the TMF along with water quality guidelines. Predicted concentrations of solutes are expected to be well within applicable guidelines into the long term and in most cases are only marginally elevated above background concentrations.

V. CONCLUSION

The JEB TMF at the McClean Lake Operation has been designed to minimize potential effects of tailings disposal both during operations and into the long term. Hydrodynamic containment prevents the migration of solutes out of the TMF during operations. Through engineered tailings geochemistry and proper tailings placement, migration of solutes from the decommissioned facility may be minimized. The long term effects associated with tailings disposal within the JEB TMF are predicted to be insignificant.

Fox Lake



Pat Lake

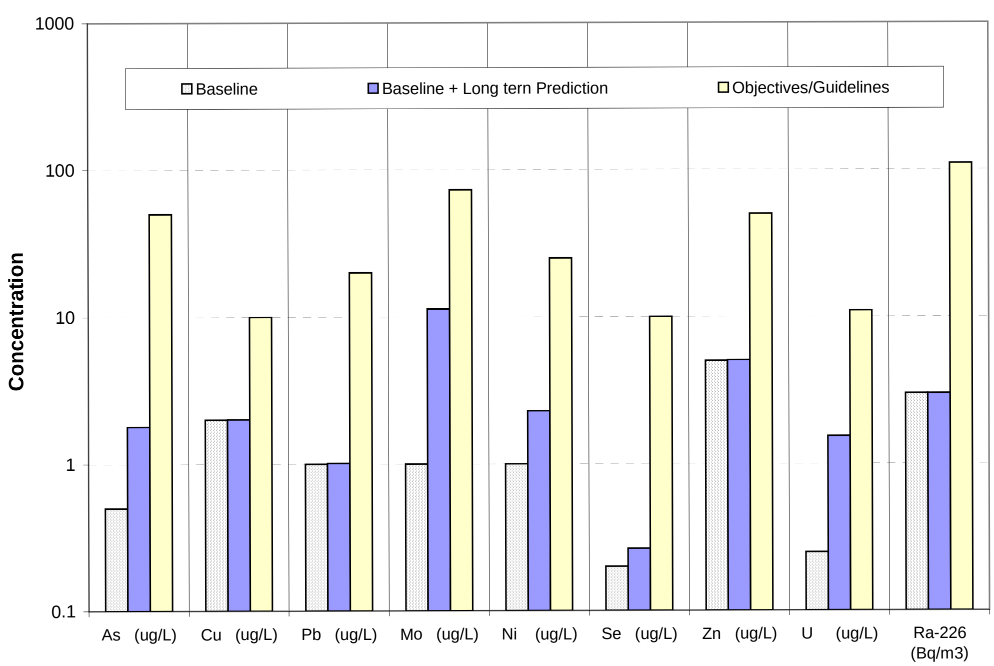


Figure 12: Predicted Effects for Fox Lake and Pat Lake Water Quality

REFERENCES

[1] LANGMUIR, D., MAHONEY, J., MACDONALD, A., ROWSON, J. “Predicting Arsenic Concentrations in the Pore Waters of Buried Uranium Mill Tailings”,Geochimica et Cosmochimica Acta, Vol.63,No.19/20,pp.3379-3394,1999