The Successful Reclamation of Acid Generating Tailings in the Elliot Lake Uranium District of Canada: A Good-News Case

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Abstract

Uranium mining from underground operation began in the 1950s in the Elliot Lake District of Ontario Canada. Several mines and tailings facilities were decommissioned in the early 1990s. The effects of acid generation from the pyritic tailings were identified in the 1970s. During late operations, decommissioning plans were developed to mitigate the acid at most tailings facilities. Flooding of existing tailings in-place was the fundamental decommissioning strategy. Because these were uranium mines, there are extensive monitoring programs associated with individual tailings basins, as well as the regional watershed. The results from monitoring have demonstrated the resounding success of the tailings decommissioning strategies, as well as the recovery of the tailings basins and the watershed downstream of the mines. The Denison tailings were typical of flooded tailings at Elliot Lake. The near-field and far-field data at the former Denison Minesite are presented to illustrate environmental performance of the tailings facilities more than fifteen years after final decommissioning.

Key Words: acid generation, mine tailings, decommissioning, flooding.

Introduction

The Elliot Lake Uranium Mining District in Ontario was one of several early sources of uranium in Canada. Other uranium areas included Port Radium on Great Bear Lake, NT; the north shore of Lake Athabasca, SK and Bancoft, ON. Uranium was discovered near Elliot Lake in 1953 and the first of 12 underground mines started operation in 1955. Many of the Elliot Lake mines ceased operation in the early 1960s. Some mines, however, operated until the early 1990s producing almost 200 million tonnes of tailings before closure. Denison Mine operated from 1957 to 1992, producing about 60 million tonnes of tailings that were stored in two Tailings Management Areas (TMA).

Hawley (1971) acknowledged the first observation of acid drainage in Ontario, Canada at mines in the Elliot Lake District. In the late 1970s, groundwater investigations at the Nordic TMA discovered acidic conditions down-gradient from an inactive on-land tailings impoundment (Moffat and Tellier, 1978; Blair, 1981). The studies were the first of many that focused on the pyritic nature of the tailings, the geochemistry of pore water within the tailings and the effects on local groundwater and surface water that received the acidic drainage. Prior to the 1970s, acid drainage was recognised at coal mines in the eastern United States but acid generation at metal and uranium mines was not a topic of publication in the professional literature. The recognition of acidic conditions at the Nordic tailings led to an understanding that the Elliot Lake uranium ore body contained pyrite and that all tailings from that ore would be acid generating in typical on-land impoundments.

A Canadian federal initiative was established in 1981 to study and develop an understanding of the long-term effects of uranium tailings, including acid generation. The National Uranium Tailings Program (NUTP) was planned for a five year period, ending in 1986, and focused on developing the capability to predict effects of uranium tailings on humankind. At the request of the metal mining industry in Canada in 1983, a joint federal, provincial and industry research program was developed to address acid generating tailings specifically. The Reactive Acid Tailings Sulphides (RATS) program was initiated in 1986 with the objective of developing practical techniques to manage acid generating tailings and reduce environmental impacts, with an overall goal of achieving ultimate abandonment without the need for continuing intervention (John and Joe, 1987). The RATS program evolved into the Mine Environment Neutral Drainage (MEND) Program.

From 1989 to 1997, over $20M (CAD) was invested to address such topics as Prediction, Prevention and Control, Treatment and Monitoring, as well as to facilitate technology transfer through report publishing, workshops and conferences. The MEND initiative continues through 2012 at a much reduced funding level, with the objective of facilitating technology transfer and information sharing for mine waste management topics. The results from the NUTP, RATS and MEND initiatives led to the development of the decommissioning plans for several TMAs at Elliot Lake that led to successful mitigation of acid generation at facilities that had not been initially constructed with knowledge of the challenges that accompany potentially acid generating tailings. The following discussion presents the highlights of the decommissioning program at the Denison TMAs, as well as the evidence of successful remediation of the TMA and of the Serpent River Watershed that includes 11 of the 12 former minesites.

Description of Denison Mine TMA

Elliot Lake is 30 km north of Lake Huron and 130 km west of Sudbury and is on the Canadian Shield, a region of exposed Precambrian rock that mantles a large area across Canada. The Denison property is located about 11 km north of Elliot Lake and is within the Serpent River watershed that drains to Lake Huron (Figure 1). The underground mine began operation in 1957 and continued production until 1992. The mill was located on site and the original production rate of 5,000 tonnes per day was increased to 6,350 tonnes per day in 1977 and 13,600 tonnes per day in 1982. More than 60 Mt of ore were processed over the life of mine and the tailings were stored in two TMAs, TMA1 and TMA2 (Figure 2). The combined area of the TMAs is 280 ha.

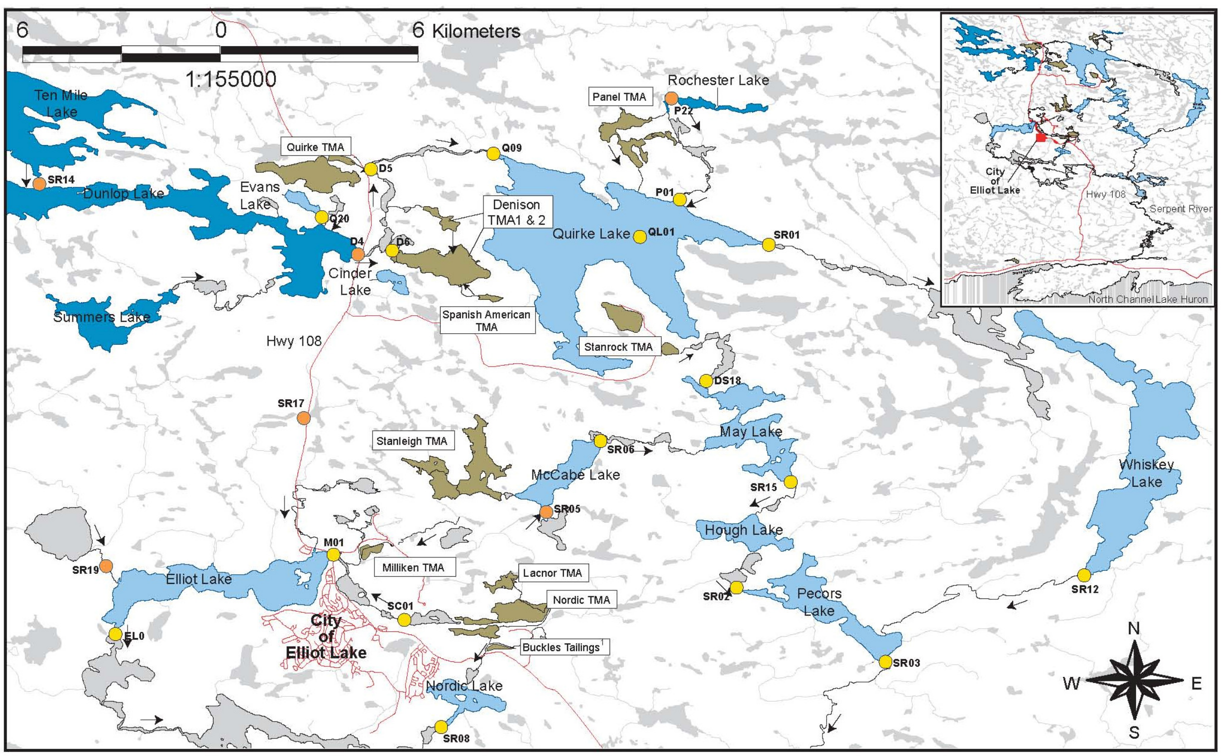

Figure 1: Location of the Denison Mine

The TMAs were originally lakes that had dams constructed at lower sections of the perimeters in order to increase capacity. Tailings deposition was typical with low density slurry delivery to the impoundments.

Spigotting resulted in the development of long beach areas near the spigot and ponds where fines settled near the dams.

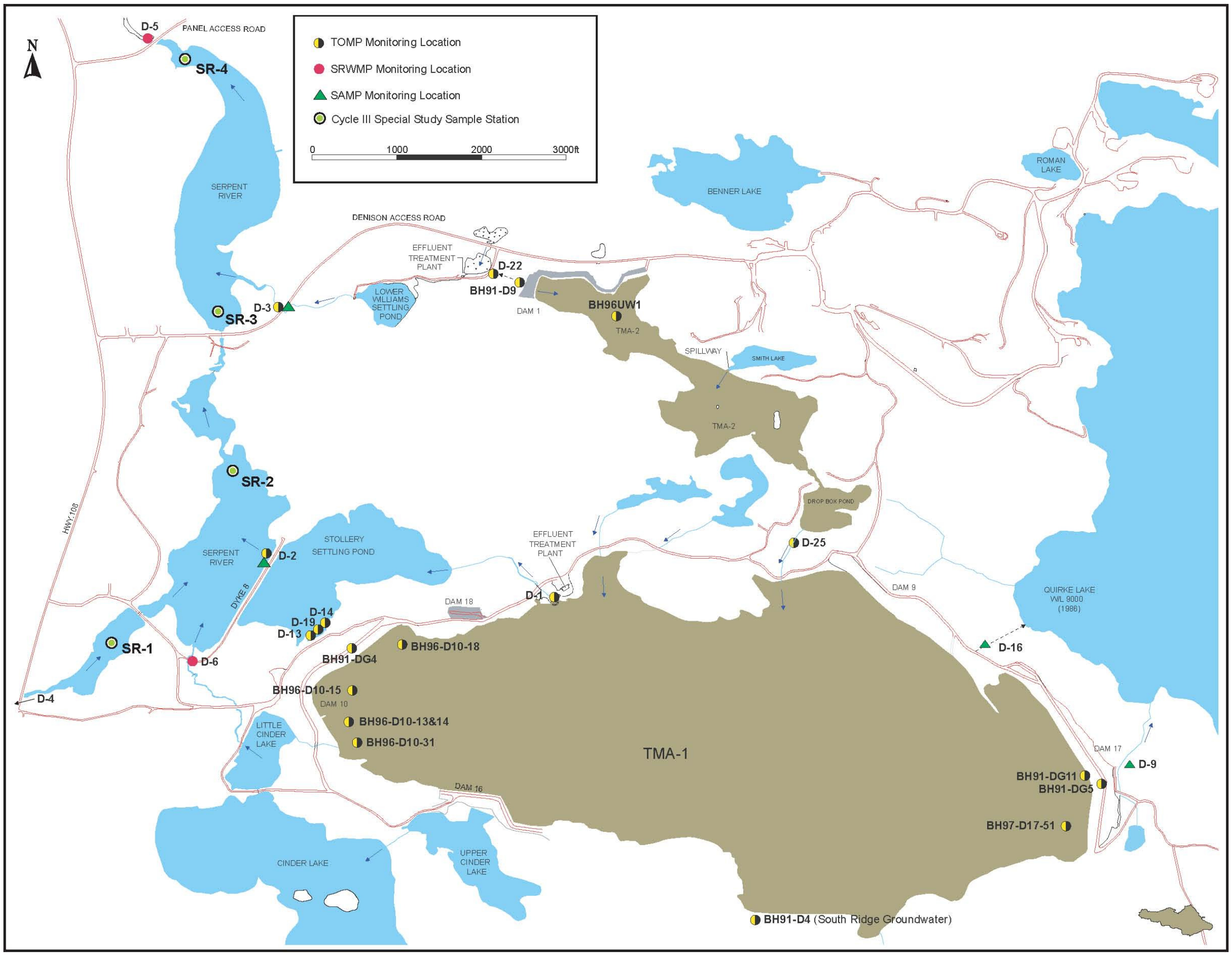

Figure 2: Configuration of the Denison Tailings Management Area

The Denison tailings were typical of those from the Elliot Lake ore body. The ore was a Precambrian conglomerate similar to the gold deposits in South Africa. The uranium grade was on the order of 0.2% U. Pyrite was an accessory mineral with typical sulphide contents in the range of 5 to 10 % S. The ore was milled with a sulphuric acid leach process that removed any potential carbonate or other neutralizing minerals. The only neutralization potential (NP) in the tailings originated from residual traces of carbonate minerals in the lime that was used to neutralize the tailings prior to deposition in the TMAs. Studies of other tailings deposits in the region suggested that the NP of Elliot Lake tailings was less than 0.1% $CaCO_3$ or 1 kg-$CaCO_3$/t (Dubrovsky et al 1985).

Acidic water in the Denison tailings was recognized in the 1980s and water treatment plants were constructed to manage the effluents from each of the TMAs separately. The treatment systems were designed for pH control as well as for the removal of radium-226, a daughter isotope of uranium that has a prescribed effluent release limit of 0.37 Bq/L (10ρCi/L).

The Decommissioning Concept

The decommissioning plans for four Elliot Lake mines, including Denison, underwent an environmental assessment under the Federal Environmental Assessment Review Organization (FEARO), the predecessor of the Canadian Environmental Assessment Agency (CEAA). An assessment panel was appointed and after Denison submitted the Environmental Impact Statement (EIS) in 1995, public hearings were held between 1995 and 1996. The primary federal authority responsible for the nuclear safety aspects of the mine was the Atomic Energy Control Board (AECB), the predecessor of the Canadian Nuclear Safety Commission (CNSC) that was formed under the Canadian Nuclear Safety Act in 2000.

The proposed decommissioning plan for the TMAs was based on the concept of using mitigation to lessen the need for active management in the long-term, in accordance with the principles developed by AECB and later by CNSC for closed uranium mines. While the decommissioning plan considered all mine facilities and infrastructure, the tailings represented the main focus for water quality effects, and therefore, is the focus of this discussion.

Pyrite oxidation and ongoing acid generation in exposed on-land tailings was identified as the key concern with the need to develop chemical stability for the protection of water quality in the long term. Therefore, flooding and permanent underwater storage of the existing tailings was selected as the preferred closure option at Denison, as well as several other TMAs at Elliot Lake. Although dams were in place to contain tailings in TMA1 and 2, they were generally not suited to raise water levels sufficiently to flood the beached tailings. Flooding was achieved through a combination of modest dam raises and upgrades to hold water at appropriate elevations, as well as the relocation of some beach tailings to lower elevations. Some beached tailings in TMA2 were relocated to TMA1 and some were sent underground. Some drainage redirection in the watershed was also required to have a positive water balance and to maintain a water cover on TMA1.

A cornerstone of the decommissioning plan for Denison, and for other TMAs at Elliot Lake, was the follow-up monitoring plan that consisted of three tiers of surveillance. These included a range of physical scales from the footprint of the tailings facility to the greater watershed that receives water from most of the TMAs. The Tailings Operational Monitoring Program (TOMP) focused on site-specific operational data to demonstrate compliance and evaluate treatment effectiveness and, where appropriate, dam performance. The Source Area Monitoring Program (SAMP) focused on the release of constituents of potential concern (COPC) and conformance with expected performance predicted in the EIS. The Serpent River Watershed Monitoring Program (SRWMP) was developed as an ecosystem-based aquatic surveillance program to assess the overall effects of TMA discharges to the Serpent River Watershed and to compare measured effects to those predicted in the EIS (Beak, 1999). While the TOMP and SAMP programs focus on water quality, the SWRMP program incorporates environmental effects monitoring on a 5-year cycle. Water sampling has a frequency that is consistent with one-half of the residence time of targeted water bodies. The SWRMP is comprehensive for ecological pathways that include water, sediment, benthos, fish and other aquatic organisms and has included other special studies to assess effects on other biota and humans.

Water Quality Before and After

Acidic conditions had developed in the beached tailings in TMA1 and TMA2. The acid conditions were observed in the effluent from the Denison tailings. More detailed investigations at other Elliot Lake TMAs showed that the shallow tailings pore waters were commonly characterized by pH values less than 3 with elevated sulphate and acidity, iron and other metals (Dubrovsky et al 1985). In fine-grained tailings, the acidic zones were generally limited to the top few metres of tailings while in coarser tailings acid zones had developed to depths of 10m. At Denison, about 1.7Mm^3 of the most acidic tailings in TMA2 were relocated during decommissioning with about 50% sent to underground workings and 50% to TMA1. During relocation, lime was added to the acidic tailings to raise the pH.

The acidity loads generated in the TMAs can be estimated from the quantities of lime and/or sodium hydroxide used in the treatment plants that received runoff and seepage from the tailings. Prior to flooding TMA1, typical lime consumption was on the order of 4,000 tonnes per year (t/a) of CaO (Figure 3a). Lime consumption declined dramatically during the decommissioning process by three orders of magnitude (99.9%). Similarly in TMA2, sodium hydroxide consumption prior to decommissioning was on the order to 1.5 t/a and declined to zero post decommissioning (Figure 3b).

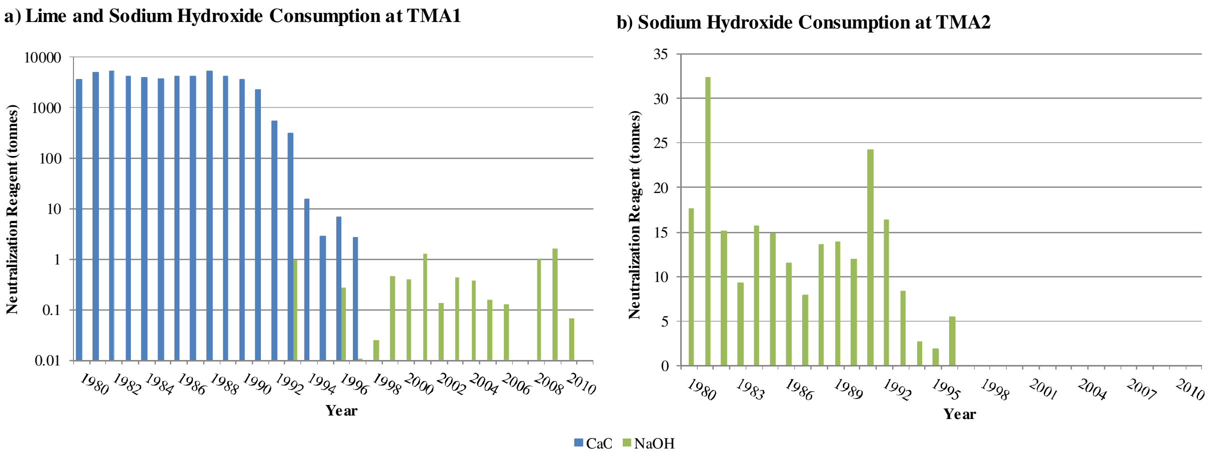

Figure 3: Lime and Sodium Hydroxide Consumption at TMA1 and TMA2 at the Denison Mine

The water quality in the TMAs immediately after flooding was affected by the accumulated soluble products of sulphide oxidation as shown by the sulphate, acidity and iron concentrations in the influent to the treatment plant (Figure 4). All measured parameters that were elevated prior to flooding decreased after flooding. The acidity and iron concentrations in the treatment plan influent were lower than those in the TMA because the chemistry of the tailings basin water was altered by addition of lime directly to the TMA ponds while treatment was occurring.

The overall reduction in pyrite oxidation, however, is clearly evident from the decrease in sulphate concentrations from values near 2000 mg/L to values between 20 and 100 mg/L over the 10 year period since flooding. The lower concentrations of sulphate are expected to persist for an extended period because of the presence of gypsum ($CaSO_2 \bullet 2H_2O$) in the tailings that dissolves and releases sulphate to pore water in the absence of pyrite oxidation. Subsequently, sulphate in the pore water is released to the overlying water as a result of diffusion at the water-tailings interface. In the tailings at the Denison site, gypsum originated from two sources. It formed when the sulphuric acid (H_2SO_4) in the leach solution in the mill was neutralized with lime (CaO) and when sulphuric acid was produced by pyrite oxidation and reacted with available calcium in the exposed tailings where prior to flooding.

The effects of decommissioning are also observed in the Serpent River, immediately downstream of the Denison effluent discharge, which is illustrated in Figure 6. While the pH values have become more consistently in the range of 6.5 to 7.5, the sulphate, acidity and iron concentrations have all declined to low levels. For example, prior to 1994, sulphate concentrations as high as 1,000 mg/L were commonly measured in the river while the average value from 2010 to 2011 is less than 20 mg/L.

Quirke Lake is the largest waterbody immediately downstream of the Denison TMAs in the Serpent River chain of lakes, with a volume of 803.0Mm^3 and an annual average outflow of 183Mm^3/a. Quirke Lake also receives treated effluent from the other TMAs that were also decommissioned and flooded at about the same time as the Denison TMAs. In the 1960s, Quirke Lake had pH values near 4 as a result of early milling practices that did not include complete neutralization of mill process water prior to tailings discharge. Neutralization of tailings was started in the 1970s and subsequently the pH in Quirke Lake increased. The water quality at the outlet of Quirke Lake from the late 1980s to 2011 is summarized in Figure 7. The pH was typically in the range of 5 to 6 in the early 1990s and has since increased to values consistently near 7. The concentrations of sulphate have declined from about 200 mg/L in 1991 to less than 50 mg/L in 2011. Similarly, concentrations of acidity and iron have declined since decommissioning of the Denison and other upstream TMAs.

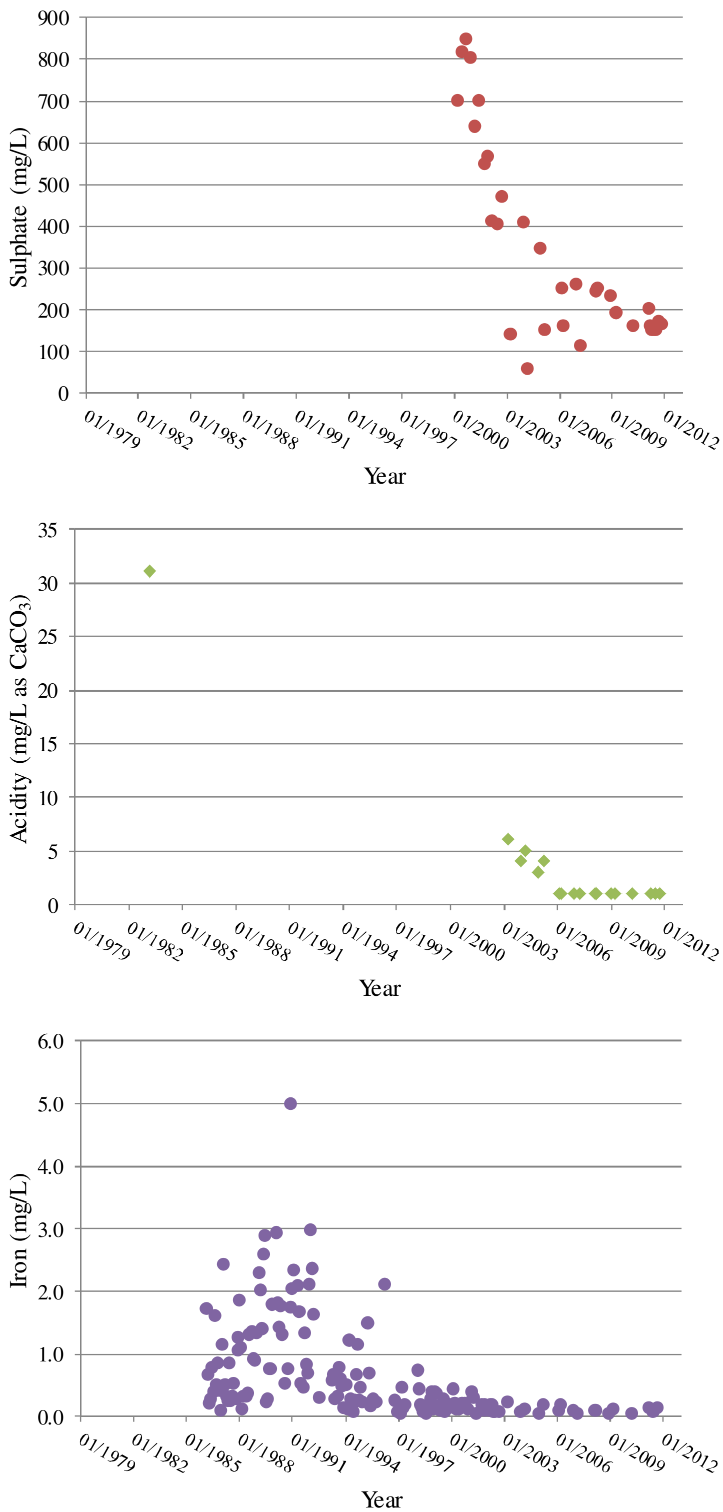

Figure 4: Water Quality in the Influent to the TMA1 Treatment Plant

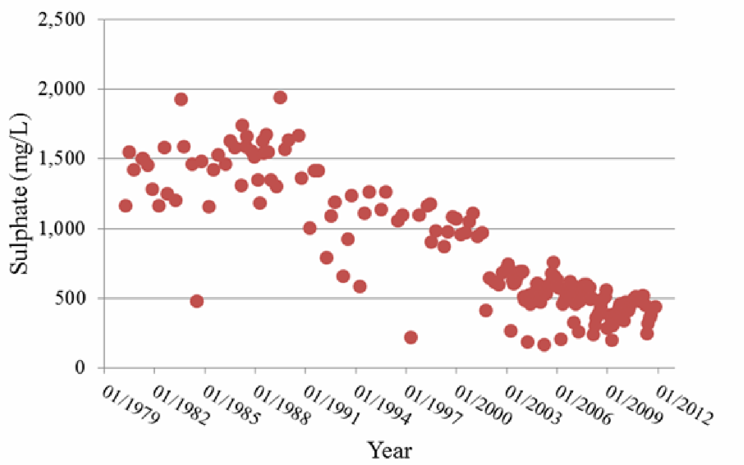

Figure 5: Sulphate Concentrations in Effluent from the TMA1 Treatment Plant

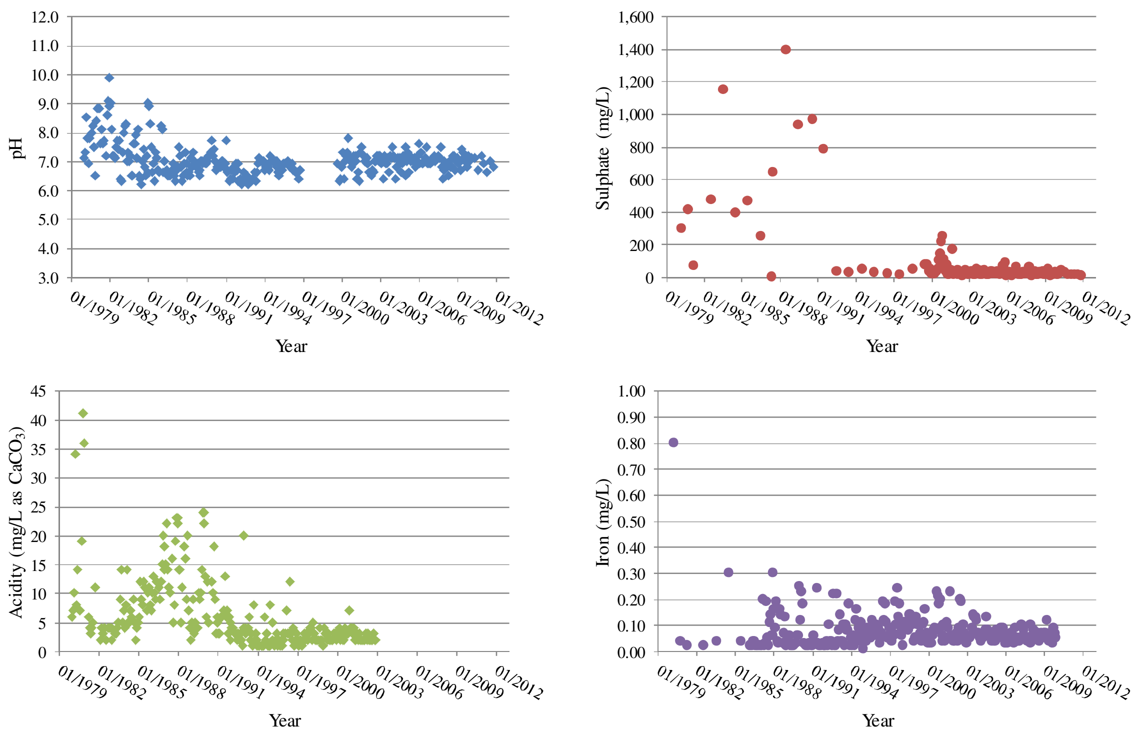

Figure 6: Water Quality in the Serpent River Downstream from the Denison Effluent Discharge

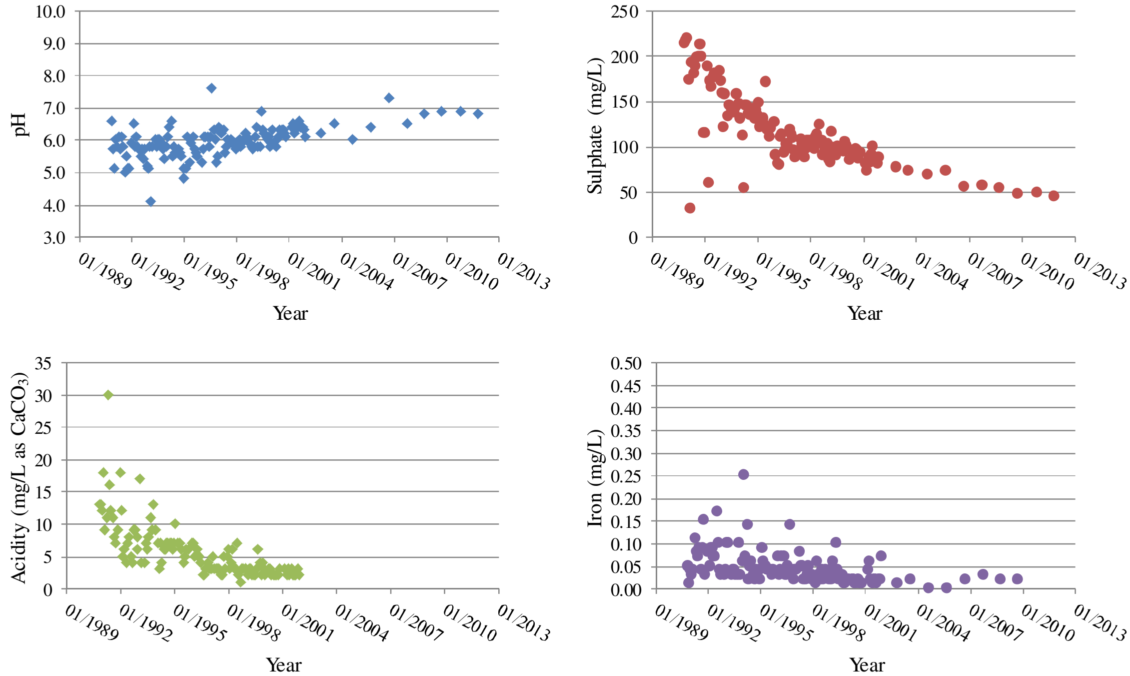

Figure 7: Water Quality in Quirke Lake Outflow

The Serpent River Watershed

The SRWMP was first implemented in 1999 and has undergone three sampling cycles. The first cycle occurred during the period of 1999 to 2002. Cycles 2 and 3 were completed in 2004 and 2009, respectively. The monitoring program was designed to be adaptive (Beak, 1999) and each successive cycle has been modified to respond to the results from the previous cycle (Russell *et al.*, 2011). Typically, consistent results with no or declining effects have provided rationale for reducing sample locations and/or sampling frequency. The results of the SRWMP have shown consistent declines in concentrations of pyrite oxidation products and continual improvement in ecosystem conditions in the watershed since decommissioning. Monitoring of the TMAs has shown that water quality has improved dramatically at all sites that have been flooded and that observed conditions are generally in good agreement with EIS predictions.

Water quality in the Serpent River has also improved dramatically since decommissioning of the sites. The concentrations of tailings-related COPCs throughout the watershed have attained levels that can support aquatic life. The concentrations of COPCs in lake sediment continue to exhibit effects from past mine and tailings-related influences with elevated concentrations of cobalt, iron and manganese. Results from successive monitoring cycles suggest that concentrations in sediment are not increasing over time (Minnow, 2008) and it is anticipated that gradual declines in concentrations will be observed in the future, perhaps on a time scale of decades. Benthic sampling showed improvements to benthic invertebrate communities to the point that effects were near the limit of detection for mine-related influences. Where effects in mine influenced lakes were measurable, the benthic metrics fell within the range of those observed in reference lakes. The trends suggest that benthic health will continue to improve as water and sediment concentrations continue to decline. Although some signatures of mine–related effects were observed in fish tissues, concentrations were below established limits for human consumption and no risk to humans from eating fish was anticipated.

Conclusion

The uranium mines in Elliot Lake were developed and operated over decades at a time when environmental effects from sulphide oxidation and acid generation on water quality were not clearly understood. Planning for decommissioning and mitigation of acid generation was therefore only considered in the late stages of operation, prior to mine closure. During closure planning, sulphide oxidation and tailings acidification were recognized as the most important influences on future water quality and ecological health of the watershed. Despite the ad-hoc development of closure and decommissioning plans, the implementation of effective mitigation strategies for potentially acid generating tailings produced excellent results for water quality improvement at the individual TMAs and in the watershed, overall. The case study of the Denison TMA and results for other flooded TMAs in the Serpent River Watershed represent excellent examples of the reversibility of environmental effects from mining operations that were not initially designed to mitigate acid generation. The commitment by Denison Mines Inc. and other former uranium mine operators at Elliot Lake has clearly demonstrated that historic mines need not represent a negative environmental legacy for future generations.

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Acronyms

AECB	Atomic Energy Control Board
CAD	Canadian
CEAA	Canadian Environmental Assessment Agency
CNSC	Canadian Nuclear Safety Commission
EIS	Environmental Impact Statement
FEARO	Federal Environmental Assessment Review Organization
MEND	Mine Environment Neutral Drainage
NP	Neutralization Potential
NUTP	National Uranium Tailings Program
RATS	Reactive Acid Tailings Sulphides
SAMP	Source Area Monitoring Program
SRWMP	Serpent River Watershed Monitoring Program
TMA	Tailings Management Area
TOMP	Tailings Operational Monitoring Program