KEY FACTORS IN DEVELOPING AND IMPLEMENTING A SUCCESSFUL MINE RECLAMATION PLAN – DENISON SITES 20 YEARS AFTER CLOSURE

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ABSTRACT

Developing and implementing a successful reclamation plan is dependent on a number of key factors, including defining clear objectives, assessing available options to meet those objectives, gathering adequate and accurate data for evaluating options, revising the selected reclamation plan during implementation if required, and developing a focused and integrated monitoring network to track performance and effectiveness of the plan over time. Successful reclamation can be defined as ensuring effective protection of health, safety, environment and community, with measures of effectiveness driven by regulatory requirements, corporate policies and stakeholder expectations. A successful reclamation plan must also be flexible, adaptive and cost effective in both the short and long term. This paper illustrates how these key factors were and continue to be essential in the success of the reclamation plans designed and implemented at the Denison Mines Inc. uranium mine sites in Elliot Lake, Ontario, over the past 20 years.

Key Words: Closure, Decommissioning, Rehabilitation, Uranium, Elliot Lake.

INTRODUCTION

Mine closure planning and implementation of reclamation measures have evolved over the past twenty to thirty years as "planning for closure" has transitioned from a concept in the early 1980s (Culver et al. 1982) to standard practice in modern mine development (McKenna 2011). As closure and reclamation considerations have become routine aspects of mine development from the earliest stages of the mining life cycle, mines that were previously developed in the absence of closure plan legislation have also designed closure plans for current operations, as well as planned expansions, with many initiating progressive reclamation while still in operation. Historic mines that developed, operated and closed or were abandoned prior to the legislated requirement for closure planning face greater challenges in designing and implementing successful reclamation plans as generally no measures were taken to minimize the operational footprint and prevent and/or mitigate impacts to surrounding land, water and air. Often these sites have limited funds available for closure plan design and implementation of reclamation activities, as they are no longer generating profits for the mining company or the site has been abandoned and reclamation efforts have become the responsibility of the government.

Regardless of the stage of the mining cycle during which the closure planning process is initiated, there are key factors to consider in designing and implementing a successful reclamation plan. These include defining clear reclamation objectives, assessing available options to meet those objectives, gathering adequate and accurate data for evaluating options, having a flexible and adaptive plan that can be revised during implementation if required, and developing a focused and integrated monitoring network to track performance and effectiveness of the plan over time. The stage of the mining cycle during which this process is initiated will; however, determine the reclamation options that are available, as well as the time frame and cost of achieving success. Measurements of successful mine reclamation are also different for mines developed before and after reclamation legislation was adopted; therefore there is a need to develop site-specific performance indicators based on closure plan objectives established through collaboration with regulators, local community stakeholders and affected First Nations. This will allow for a balance of expectations and viewpoints on what can and cannot be achieved during the stages of mine closure. Although the closure plan objectives and performance indicators may be specific to each mine site, there is general consensus that the overall goals of mine reclamation are to restore mine sites and affected areas to self-sustaining ecosystems that are compatible with a healthy environment and human activities.

HISTORY OF DENISON SITES

The discovery of uranium in the region of Elliot Lake, Ontario during the post-World War II era led to the development of 12 mines between the years 1955 and 1958 (Figure 1), three of which, Denison, Stanrock and Can-Met, are owned by Denison Mines Inc. Most of the uranium was produced for contracts with the United States Atomic Energy Commission during the late 1950s and early 1960s; however, following the cancellation of these contracts, most mines in the area closed. Denison mines continued to operate, supplying uranium to electrical power generating utilities in Japan and Ontario from the early 1970s to the early 1990s. By 1996, due to diminishing ore grades and high production costs, all the Elliot Lake uranium mines had ceased operations and begun the decommissioning process, which included design and implementation of closure plans for each of the facilities.

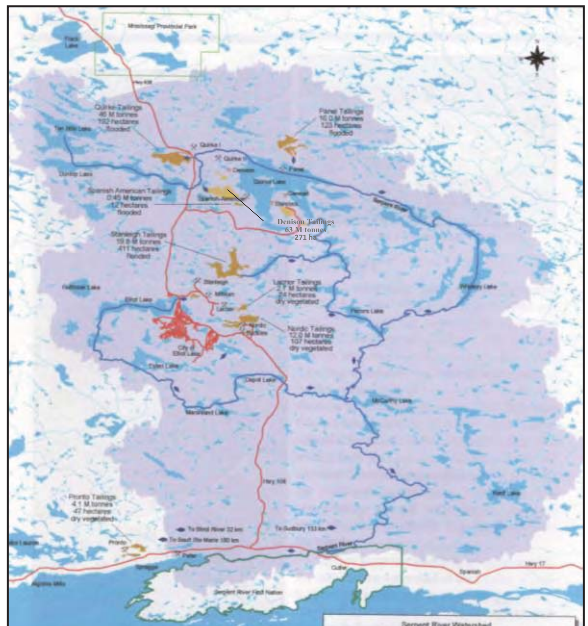

Figure 1. Locations of Former Mine Sites in the Serpent River Watershed

Denison Property

Denison Mine, located 16 km north of the City of Elliot Lake, consisted of a conventional mill and underground mine that operated between 1957 and 1992. Over this time, Denison generated a total of 63 million tonnes of uranium tailings that was deposited into two bedrock lined basins, which are now referred to as tailings management areas (TMA-1 and TMA-2).

Stanrock and Can-Met Properties

The Stanrock property, located 21 km northeast of the City of Elliot Lake, was also developed in the 1950s and consisted of a mine, mill and TMA. The underground mine used conventional milling to recover uranium from 1958 to 1964. From 1964 to 1970 and from the late 1970s to 1983, a mine water recovery operation was used to extract uranium from water that was allowed to flood the underground workings. During the latter period, the mine was rehabilitated and a small amount of ore was hoisted to surface and hauled to the Denison mill for processing.

The Can-Met property is located adjacent to the Stanrock property and was operated (both a mine and mill) from 1957 until 1960. Tailings from both the Stanrock and Can-Met facilities were discharged into the natural basin of a small lake located immediately south of both mines. This became the Stanrock tailings basin (TMA-3), which contains approximately 5.7 million tonnes of tailings.

PLANNING AND DESIGN OF CLOSURE PLANS

Prior to closure, the mines operated in accordance with stringent licensing requirements by the Atomic Energy Control Board of Canada (AECB), now known as the Canadian Nuclear Safety Commission (CNSC), in consultation with other Federal and Provincial regulatory agencies. When closure of the mines was announced in the early 1990's, the Canadian regulatory framework governing mine closures was still in the process of being finalized, and the decommissioning process for the uranium mines was the largest privately-owned, multi-mine closure program seen up to that time in Canada (Payne et al. 2004). Over the course of three years, extensive Environmental Hearings were conducted to evaluate the proposed closure plans and potential environmental and socio-economic impacts. The approvals process was facilitated by the establishment of a Joint Review Group (JRG) comprised of more than 15 Federal and Provincial regulatory agencies with the CNSC as the lead regulatory agency. This collaborative effort allowed for coherent responses and decisions on all issues during the hearing process.

Both companies (Denison Mines Inc. and Rio Algom Ltd.) involved in the decommissioning process shared common overarching objectives for the reclamation of all sites, which were to protect public health and safety, minimize long-term environmental impacts from the decommissioned facilities and ensure the decommissioned sites would not prejudice the survival of affected communities after the mine closures. Fortunately, since the 1970s, the physical, chemical and radioactive characteristics of the Elliot Lake tailings had been studied by both companies in conjunction with government agencies such as the Canada Centre for Mineral and Energy Technology (CANMET) and the Mine Environmental Neutral Drainage Program (MEND), as well as various university research groups. This work provided the companies with a significant database of information that was essential in planning, design and implementation of the closure plans (Payne et al. 2004).

The Elliot Lake uranium deposits are classified as low grade (< 0.1% U_3O_8). Although the radioactive characteristics of the tailings are a concern, detailed radiological modeling conducted as part of the National Uranium Tailings Program has confirmed that exposures and risks to the public from the Denison facilities are very low (Denison Mines Ltd. 1995). However, in addition to radioactive elements, the tailings contain an average pyrite content of 6%. When pyrite is exposed to air it reacts with oxygen to produce sulphuric acid, which in turn mobilizes metals and radioactive isotopes having a detrimental effect on receiving waters if not treated. All of the water from the TMAs drains into a network of rivers and lakes that eventually discharge into Lake Huron. Acid generation was deemed to be the most significant issue for consideration during the development of decommissioning options, although long-term physical stability of the sites and achieving radiation doses as low as reasonably achievable were also important (Denison Mines Ltd. 1995).

A number of closure options were considered and evaluated against the established design criteria and objectives prior to selecting the final reclamation plans for each site (Table 1). Site specific probabilistic risk assessments were also completed to examine the likelihood and consequences of failure resulting from discrete disruptive events such as earthquakes, floods or droughts having return periods of up to 1 in 10,000 years. In addition, the risk assessments considered the expected costs of environmental releases resulting from discrete events together with the cost of on-going care and maintenance (Belore et al. 1999; Kam et al. 1999a,b; Welch et al. 1996). The ability of each option to meet the specified design objectives and criteria for each TMA was assessed on the basis of the option's potential environmental, economic, and social impacts. The evaluation also took into account the guidelines for environmental assessment laid out by the Federal Environmental Assessment Review Organization (FEARO) Panel and the recommendations made at public hearings. Following thorough evaluation of all the options and consideration of the risk assessment results, the Panel concluded that the final approved reclamation plans were designed and constructed with the best available technology to address the problem of perpetual containment (CEAA 1996). The decommissioning plans that were selected and implemented at the Denison and Stanrock sites are described in the following sections.

Table 1. Options Considered for Decommissioning of TMAs (Denison Mines Ltd. 1995)

Option	Description
Base Case	• long-term collection and treatment of contaminated seepage and run-off water
Water Cover	• use of natural precipitation and run-off water to flood the exposed tailings • water retaining perimeter dams required
Soil Cover	• use of non-acid generating soil material to cover the exposed tailings and encourage a raise in the water table elevation
Complete Removal	• hydraulic relocation of tailings • underground disposal • deep lake (Quirke Lake) disposal
In Situ (Stanrock only)	• a modification to the base case • construct new, low permeability dams to establish and maintain an elevated water table near the tailings surface • similar advantages to a water cover

IMPLEMENTATION OF CLOSURE PLANS

Denison Property

A water cover was selected as the most suitable option for decommissioning of TMA-1 and TMA-2 at the Denison site (Figure 2) based on the following reasons:

- elimination or near elimination of acid generation,
- elimination of airborne releases (i.e., dusting),
- geography of the area is well-suited to flooding,
- risk of structural failure is very remote,

- flooded tailings would result in no requirement for new lands,
- limited burden on future generations,
- basins are returned to a use very similar to what they were like pre-mine development,
- radiation dose to receptors will be much less than anticipated limits, and
- water cover is an effective barrier to intrusion by man.

The decommissioning of the Denison site was completed in 1996 (SENES 1998) using the water cover option at both TMA-1 and TMA-2; however, the process of implementation was unique to each TMA. Constructing large dams would not have been economical in TMA-2 nor sustainable within a small watershed. As a result, tailings were removed from TMA-2 to lower the elevation and meet the requirements of a water cover. The tailings were relocated to two areas (TMA-1 and the underground workings) using hydraulic monitors and slurry pumping. The appearances of TMA-1 and TMA-2 before and after decommissioning are illustrated by pairs of photographs (Figure 3).

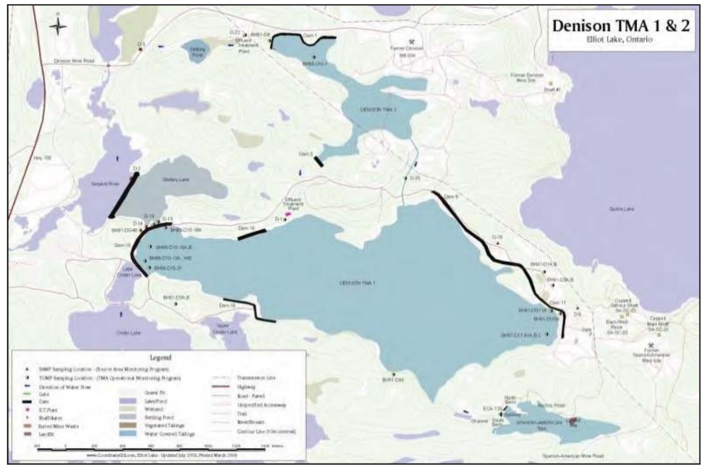

Figure 2. Denison Site Map (TMA-1 and TMA-2)

All surface facilities at the Denison site were demolished and the site was revegetated, with the exception of the Executive Lodge, the two effluent treatment plants, and roadways required for long-term access. Prior to demolition, equipment was removed for sale when possible, and scrap steel was removed for recycling. Asbestos was removed and placed into the Denison landfill located at the northeast end of TMA-2, which was subsequently graded, capped with a till cover and revegetated. All other hazardous materials, such as laboratory chemicals, were disposed of by a firm licensed to undertake that work.

<u>Stanrock Property</u>

The "*In Situ* Management Plan" was chosen as the preferred option for decommissioning the Stanrock TMA (Figure 4). The reasons for selecting this option included:

- the majority of the acid generating tailings would be stored below the water table,
- airborne dust and radon releases would be reduced,
- surface water quality would be within accepted loadings, no new areas were required,
- the basin would be returned to conditions similar to those of pre-mine development,
- cost effective option that addressed all concerns within the existing TMA, and
- the future risks of major system failures were minimal.

Figure 3. Denison Before and After Decommissioning: TMA-1 in (a) 1992 and (b) 1998; TMA-2 in (c) 1992 and (d) 1998

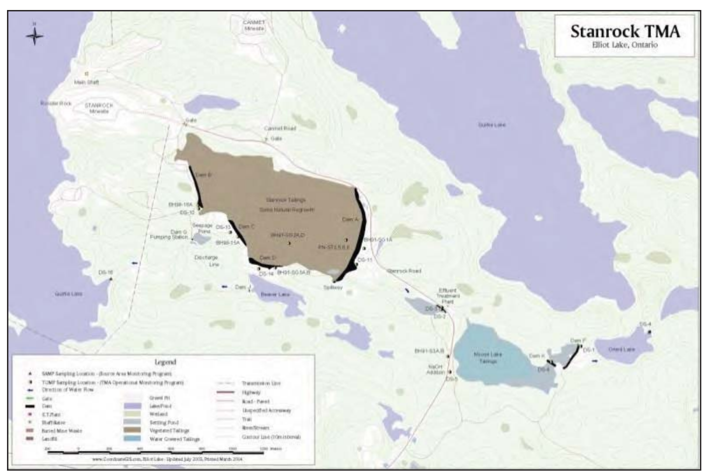

Figure 4. Stanrock Site Map

The decommissioning of the Stanrock and Can-Met sites were completed between 1992 and 2000 (Ludgate et al. 2005). New containment dams were constructed downstream of the existing structures to raise the water table. The dams incorporated a water retaining core of compacted till with a bedrock foundation beneath the dam core that was grouted to minimize seepage. Filter drains were provided to prevent internal erosion and a build-up of porewater against the dam. Although there is a small headpond, water is generally not impounded in the TMA, but drains from the surface and passes through a spillway in Dam A which flows, along with seepage collected from all of the dams, to a treatment plant southwest of the plant. Although building the dams raised the water table, it could not be raised high enough to completely cover all of the tailings, as anticipated in the planning process (SENES 1997). Unoxidized tailings above the water table still react to form additional acid, which is flushed out along with the acid already present. Modelling has shown that it may take up to 50 years to deplete the entire contained acid inventory.

The demolition of the Stanrock surface facilities was carried out in 1992 and 1993 (SENES 1997). Facilities that were demolished included: the mill complex, head frames, mine offices, workshops, warehouse, mine hoist rooms, pumphouses and sewage plant. The demolition excluded some power lines, an electrical substation, the Effluent Treatment Plant and the Dam G pumps, trestle and pipeline, as these services are required for ongoing treatment of acid water. Prior to demolition, equipment and material were sold for reuse or recycling when possible and all hazardous materials were removed and disposed of appropriately. The underground crushing and grinding plant, located 200 ft below the surface, was used as a disposal site for solid waste and was completely filled with demolition material.

LONG-TERM MONITORING, CARE AND MAINTENANCE

General Care and Maintenance Programs

Each of the TMAs were upgraded to ensure that they meet current standards for the protection of health, safety and the environment. There are a number of programs in place to ensure the continued safe operation, care and maintenance of these decommissioned sites. The general programs include: Site Security, Radiation Protection Programs; Health and Safety Programs; Inspection Programs; Tailings Management Operating Programs; Monitoring Programs; Reporting Programs; and Emergency and Contingency Response Programs.

In addition to routine monitoring of all site infrastructure by care and maintenance staff, annual inspections are also completed by professional engineers in order to verify that the facility is performing as designed; confirm that routine care and maintenance activities are being completed as required; and identify any potential areas of concern that may require remedial action. To date, there have been no issues at any of the structures and the TMAs and basins are operating as designed.

Environmental Monitoring Programs

Denison has undertaken extensive environmental monitoring programs since the early 1970s. At the time of closure, each mine had its own environmental monitoring program conducted under an operating licence from the AECB (now CNSC) or a Certificate of Approval (now Environmental Compliance Approval) from the Ontario Ministry of Environment (MOE). In 1997, both Denison Mines Inc. and Rio Algom Ltd. reviewed their existing monitoring requirements in terms of their relevance to current environmental data and predictions of changing conditions associated with decommissioning as outlined in the Environmental Impact Statement (Denison Mines Ltd. 1995). The evaluation resulted in the development of a focused and integrated monitoring network to track the performance and effectiveness of the reclamation plans over time. The integrated strategy is subdivided into four programs that supersede the monitoring requirements listed in the licenses and Certificates of Approval for the TMAs. The monitoring programs include:

- Serpent River Watershed Monitoring Program (SRWMP) – replaced the various mine-specific receiving environment monitoring programs with one comprehensive program focused on water and sediment quality, benthic invertebrate and fish communities, as well as radiation and metal doses to humans and wildlife (Beak 1999; Minnow and Beak 2001a, Minnow 2002a).

- In-Basin Monitoring Program (IBMP) – companion program to the SRWMP to assess the health risks to biota potentially feeding at each of the aquatic and vegetated management areas (Beak 1999; Minnow and Beak 2001b, Minnow 2002a)
- Source Area Monitoring Program (SAMP) – monitors the nature and quantities of contaminant releases to the watershed (Minnow 2002b)
- TMA Operational Monitoring Program (TOMP) – generates the data used to track TMA performance and supports decisions regarding the management and discharge compliance of the TMAs (Minnow 2002c)

Each program was designed to directly complement the other three programs in terms of monitoring locations, parameters, and sampling frequency, and thus ensure that the overall monitoring framework is comprehensive and interpretable. These programs are objective-driven and allow for modifications to be made over time in response to changes in the conditions at the sites.

<u>Source Areas</u>

Data collected under TOMP and SAMP demonstrate the effectiveness of decommissioning activities at both the Denison and Stanrock sites. Since decommissioning, there have been substantial reductions in the amounts of reagents used at the effluent treatment plants or directly within the TMAs. For example, at the Denison site, the liming of the surficial tailings and the use of water cover has resulted in circum-neutral pH in both TMA-1 and TMA-2. As a result, the need for caustic treatment has been modest and generally only required to treat acidic rain and meltwater. (Figure 5). Decommissioning activities were also effective in reducing the concentrations of heavy metals, and sulphates in the TMAs, as indicated by the trend of decreasing concentrations present in pre-treated water collected from TMA-1 between 1992 and 2012 (Figure 6). However, with the reduction in sulphate concentrations, there has been a slight increase in radium concentrations. This observation is not surprising based on initial modeling and additional studies have shown increased mobility and release of radium in pyritic uranium tailings when sulphate ion mobility control has been depleted for both on-land and underwater disposal scenarios (Davé 1999a,b; Davé et al. 2002). The decommissioning of TMA-1 and TMA-2 has been successful in addressing the primary concern of acid generation and has resulted in improved water quality; and on-

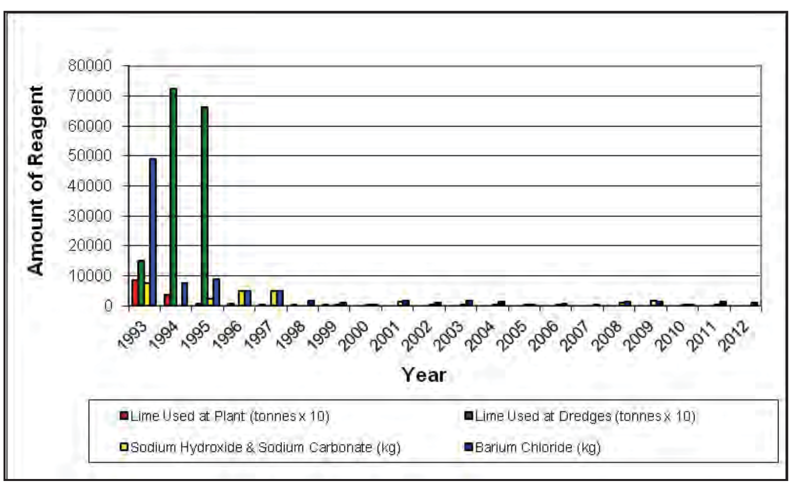

Figure 5. Annual Reagent Consumption at Denison TMA-1

going and future management of the TMAs is focused on the possibility of increased radium mobility with the depletion of sulphate over time within the basins (Ramsay et al. 2013).

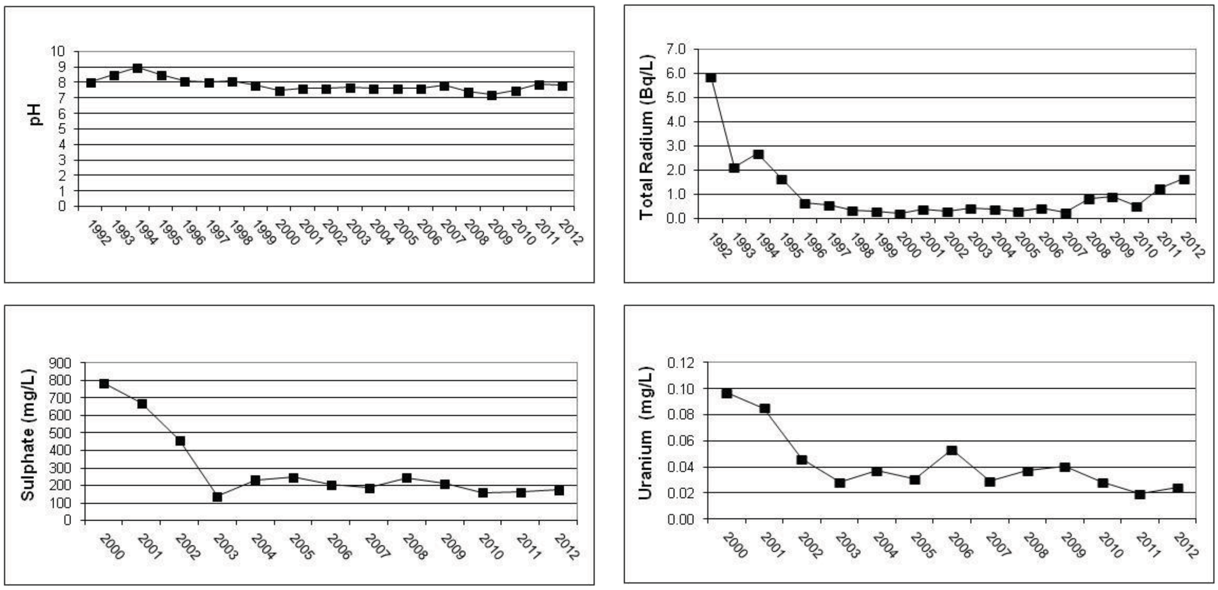

Figure 6. Annual Average Water Quality in TMA-1 Prior to Treatment

At Stanrock TMA-3 there have also been great improvements in the reagent requirements for water treatment as result of decommissioning activities. Prior to the construction of the new dams, the TMA surface run-off and the combined seepages required large quantities of lime to neutralize the water before it was released. Since dam construction and decommissioning, the consumption of neutralizing agents and barium chloride has decreased substantially (Figure 7) due to decreased tailings water acidity and radium concentrations in the influent water.

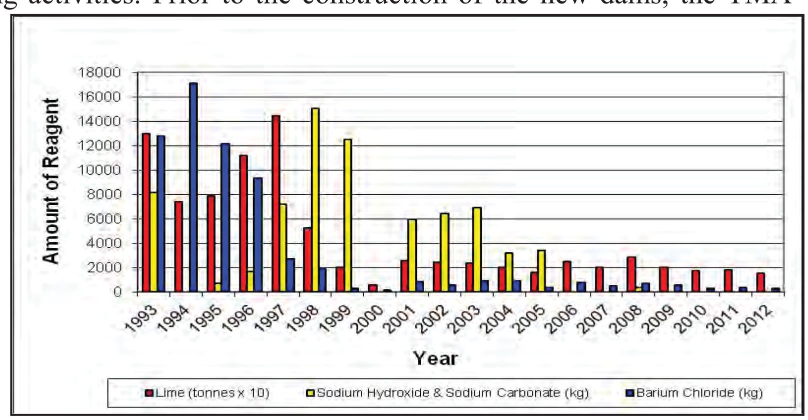

Figure 7. Annual Reagent Consumption at TMA-3

Receiving Waters

The SRWMP is conducted on a five year cycle with three cycles of the program having been completed to date (1999, 2004 and 2009). Water quality in receiving waters is better than criteria established for the protection of aquatic life and in most cases, the concentrations of "mine indicator" parameters have improved or remained consistent over time. Sediment quality is below upper limits established for the protection of aquatic life, but remains above lower limits and background concentrations. Benthic invertebrate density and community structure in exposure lakes are different from those in reference lakes, but the magnitude and number of differences are decreasing over time indicating a gradual recovery. Public radiation doses are below Health Canada Guidelines of 0.3 mSv/y (Minnow 2011).

Public Information Program

Denison Mines Inc., in association with Rio Algom Ltd., has developed an extensive Public Information Program to ensure effective communication of site activities with local residents. A more intensive program was deemed necessary because of the changing demographics of the community. Elliot Lake is no longer a mining town, but it has become a leading provider of Retirement Living services. At mine closure, both Denison and Rio Algom were instrumental in establishing the Elliot Lake Retirement Living Program. A significant part of the population is now elderly and from outside of the Elliot Lake area.

The public information program includes; annual site tours (in conjunction with the annual Elliot Lake Uranium Heritage Days held in early July), public presentations, public awareness meetings, development of an information web site, newsletters and the release of reports. An Elliot Lake Rehabilitation Information Web Site link (www.denisonenvironmental.com) was developed and provides both historical information and current monitoring results. Bi-annual presentations are made to City Council and public meetings are held periodically to inform the public of important events. An annual newsletter is distributed through the local paper and is also available on the web site. All significant reports are provided to the City and are available to the public at the local library.

CONCLUSIONS

Despite the significant challenges faced by Denison Mines Inc. when the mines ceased operations in the early 1990s, the decommissioning process in Elliot Lake has been successful. Reclamation objectives were established through collaboration with regulators, local communities, and affected First Nations. Options available to meet the objectives were determined by drawing upon an extensive database of information that was established in conjunction with government and university research groups. Reclamation options were evaluated against design criteria and objectives, and risk assessments were completed with the final reclamation plans approved by the FEARO Panel (CEAA 1996). During implementation of the reclamation plans, a focused and integrated monitoring network was developed, which allows tracking of the performance and effectiveness of the plans over time. This monitoring network also allows for adaptive plans to be created and implemented if required to ensure the objectives of the reclamation plans continue to be met.

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Overcoming Northern Challenges

Proceedings of the 2013 Northern Latitudes Mining Reclamation Workshop and

38th Annual Meeting of the Canadian Land Reclamation Association

Whitehorse, Yukon September 9 – 12, 2013

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Northern Latitudes Mining Reclamation Workshop

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NORTHERN LATITUDES MINING RECLAMATION WORKSHOP

The Northern Latitudes Mining Reclamation Workshop is an international workshop on mining, land and urban reclamation and restoration methods. The objective of the workshop is to share information and experiences among governments, industry, consultants, Alaska Natives, northern First Nations and Inuit groups which undertake reclamation and restoration projects, or are involved in land management in the north or in comparable environments.

The first Workshop was held in Whitehorse, Yukon Territory, Canada in 2001 and it has been held every two years since, alternating between Canada and Alaska. The primary sponsors of the Workshop include the Yukon Geological Survey, Indian and Northern Affairs Canada, Natural Resources Canada, US Department of the Interior Bureau of Land Management, and the State of Alaska Department of Natural Resources.

CANADIAN LAND RECLAMATION ASSOCIATION

The CLRA/ACRSD is a non-profit organization incorporated in Canada with corresponding members throughout North America and other countries. The main objectives of CLRA/ACRSD are:

- To further knowledge and encourage investigation of problems and solutions in land reclamation.
- To provide opportunities for those interested in and concerned with land reclamation to meet and exchange information, ideas and experience.
- To incorporate the advances from research and practical experience into land reclamation planning and practice.
- To collect information relating to land reclamation and publish periodicals, books and leaflets which the Association may think desirable.
- To encourage education in the field of land reclamation.
- To provide awards for noteworthy achievements in the field of land reclamation.

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- The Conference Organizing Committee: Alissa Sampson, Andrea Granger, Bill Price, David Polster, Diane Lister, Justin Ireys, Linda Jones, Mike Muller, Neil Salvin and Samantha Hudson.
- The Conference Papers and Posters Committee: Andy Etmanski, Bill Price, Chris Powter, David Polster, Diane Lister and Scott Davidson
- The Conference Sponsors (see next page)
- The Conference paper and poster presenters
- Dustin Rainey, Jocelyn Douheret and Brian Geddes for permission to use their photos on the Cover, Papers and Posters pages, respectively

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