Giant Mine remediation project

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Abstract

Following the discovery of gold in the Yellowknife, Northwest Territories, Canada, area in the 1930s, Giant Mine officially opened in 1948. Gold at Giant Mine was found locked in minerals, which needed to be roasted at extremely high temperatures. Unfortunately, this roasting process also released gases with a highly toxic by-product, arsenic trioxide. Throughout the 1950s, controls were put in place that minimised emissions to the air; however, this also resulted in the collection of 237,000 tonnes of highly toxic arsenic trioxide dust. At the time, scientists and government agencies agreed that storing the waste in underground stopes and chambers was an appropriate long-term management alternative.

When ore processing ceased in 1999, the care and control of the mine fell to the Department of Aboriginal Affairs and Northern Development Canada, and attention was focused on the environmental issues left behind, including the arsenic trioxide stored in underground chambers. The Giant Mine remediation project was created in 2005 with the overall goal to protect human health and safety, and the environment. To do so requires the long-term containment and management of the arsenic trioxide waste, ongoing water treatment and clean-up of the surface elements of the site. The main objectives of the Giant Mine remediation project are to minimise risks to public and worker health and safety, minimise the release of contaminants from the site to the surrounding environment, remediate the site in a manner that encourages public confidence, and implement an approach that is cost-effective and robust over the long term.

The project has recently completed an environmental assessment process under the Mackenzie Valley Resource Management Act, the governing legislation in the Northwest Territories for projects with the potential to have an impact on land or water. The project team is now proceeding with a clearly defined list of requirements established through the process of the project, but faces many challenges going forward, including technical considerations, regulatory and jurisdictional constraints, consultation and engagement requirements and resource pressures. It will require a great deal of ingenuity, planning and collaboration to address these challenges and deliver a successful project for the remediation of the Giant Mine site.

1 Introduction

Giant Mine was one of the longest operating and richest gold mines in Canadian history, producing more than 220,000 kg of gold between 1948 and 2004. While prospectors en route to the Klondike first discovered gold in Canada’s Northwest Territories (NWT) in 1896, accessibility limited exploration until the mid-1930s. Gold was first discovered at what is now the Giant Mine site in Yellowknife, NWT (see Figure 1), in 1935, by prospectors working for Burwash Yellowknife Mines Ltd., whose assets were acquired by Yellowknife Gold Mines Ltd. in 1937.
The mine operated under the subsidiary Giant Yellowknife Gold Mines Ltd. until 1940, when the company could no longer support operations. The mine was stagnant until 1944, when Frobisher Explorations took over the site based on promising exploration data. Giant Mine officially opened shortly after the end of World War II, and production began in earnest, with the first gold brick poured on June 3, 1948. From May to December of that year, the mine produced 8,152 ounces of gold from 49,985 tonnes of processed ore. The mine continued to produce gold under various operators until 1999, when it ceased operations after Royal Oak Mines Ltd. went into receivership. At that time, custodianship of the 950 ha site was transferred to the Department of Aboriginal Affairs and Northern Development (AANDC) on behalf of the Government of Canada. Miramar Mining Corporation continued to remove ore from the site and process it at the nearby Con Mine until 2004. The company terminated its obligations under the reclamation security agreement in 2005 and Giant Mine officially became an abandoned mine site, with responsibility for its closure and clean-up resting with the Government of Canada.

Owing to the length and period of operation, and the refractory nature of the ore at the site, the potential environmental impact of Giant Mine could be much greater than that of many other mining sites without proper management, care and maintenance. As with any mining operation, Giant Mine generated a substantial amount of contaminated waste during the extraction, handling and processing of ore at the site. There are four tailing ponds with an estimated 16 million tonnes of tailings, as well as an estimated 325,000 m³ of contaminated soils to be remediated or risk managed. The mine water requires treatment before it reaches the receiving environment of Great Slave Lake. There are numerous buildings in varying states of disrepair that pose a risk to human health and safety and must be dealt with as part of the remediation plan.

A problematic by-product of mining at Giant Mine is the significant quantity of arsenic trioxide dust. Gold at the site is found in the refractory mineral arsenopyrite; the ore must be roasted at extremely high temperatures to extract the gold. This converts the arsenic in the mineral to arsenic trioxide, which is highly toxic.

At the Giant Mine site, this arsenic trioxide gas by-product and other contaminants were released directly from the roaster stack, resulting in approximately 7,400 kg of arsenic emissions per day until 1951, when a Cold Cottrell Electrostatic Precipitator (ESP) was installed. This had the effect of removing a significant portion of the arsenic trioxide from the roaster emissions, reducing average daily arsenic releases to 2,900 kg per day by 1956. In 1958, a Dracco baghouse was added to great effect, reducing airborne arsenic emissions to 52 kg per day by 1959. Over the years, arsenic emissions would fluctuate based on production levels (SENES and SRK, 2010).

The dust produced at Giant Mine contains approximately 60% arsenic by weight and can be harmful even in very small amounts. It is water soluble, and can easily make its way into the environment if not managed.
properly. Over the operating period of the mine, it is estimated that approximately 237,000 tonnes of arsenic trioxide dust was collected and stored underground. When collection of the dust started in the 1950s, the mine operators, scientists and government officials had to decide what to do with the arsenic trioxide dust produced by the ESPs. They determined that placing it in mined-out stopes and chambers within the mine itself would provide the best overall storage solution. When the mine eventually closed, it was believed that the permafrost would eventually re-establish around these stopes and freeze the dust in place.

2.1 Response to the environmental issues

When AANDC was given care and control of the site in 1999, the department took steps to address the issue of the arsenic trioxide waste and other hazards at the site. The focus was on addressing the highest risks to human health and the environment first, with efforts directed at selecting the long-term management strategy for the dust stored underground, as well as remediation to mitigate immediate risks posed by tailings deposited along the shore of Back Bay. Over the next several years, AANDC retained specialists to conduct the necessary studies and options analysis, and presented the findings to both independent experts and the public for their input. After starting with an initial 54 possible remediation options, AANDC announced in 2004 its intention to proceed with the frozen block method to stabilise the arsenic trioxide in place as a way to effectively mitigate the risk to the environment while ensuring the protection of human health and safety.

2.2 Regulatory context

The site lies within the Mackenzie Valley watershed, and is regulated by the Mackenzie Valley Resource Management Act (MVRMA). The MVRMA is federal legislation aimed at protecting the lands and waters within the Mackenzie Valley watershed. Since the site is under the care and custodianship of AANDC, it is also subject to other federal acts, such as the Canadian Environmental Protection Act, the Fisheries Act and the Migratory Birds Convention Act, among others. It is also situated within the municipal boundaries of the City of Yellowknife, and so is impacted by the City’s bylaws and permitting requirements. Between 2005 and 2007, AANDC worked with experts to develop a remediation plan for Giant Mine that included a proposed approach to deal with the underground arsenic trioxide as well as the various surface features, such as the pits, tailings ponds, contaminated soils and surface water. In accordance with the regulatory requirements in the NWT, the project submitted a water licence application to the Mackenzie Valley Land and Water Board (MVLWB) in 2007 to seek approval for the remediation plan and secure a water licence to implement the project.

The MVLWB conducted a preliminary screening of the application and indicated that the project could proceed to the regulatory licencing process. However, the City of Yellowknife intervened under its own authority and referred the project to an environmental assessment (EA), a process intended to ensure it would not result in adverse environmental effects. The Mackenzie Valley Environmental Impact Review Board (MVEIRB) began the assessment process in April 2008. It took until the end of 2008 to finalise the scope of the assessment and until May 2009 to establish a terms of reference and work plan. At that point, the project commissioned the developer’s assessment report (DAR), which essentially formed the remediation plan that would undergo assessment, and then submitted the document to MVEIRB in October 2010. Information requests, responses and technical sessions took place throughout 2011 and into early 2012, resulting in a series of technical reports from interested parties later on that year. Public hearings were also held in 2012, and the public record was closed in October of that year. It was re-opened in February 2013 to address an additional information request from the MVEIRB, after which it was closed again. The MVEIRB released its EA report in June 2013 (MVEIRB, 2013). A number of conditions (measures as defined by the Act) contained in the report were reviewed, and alternate wording proposed. The MVEIRB responded with suggested modifications to the measures in February of 2014, and in August of 2014, the federal ministers responsible for the EA issued their final decision on the report of environmental assessment agreeing to 26 legally binding measures, eight of which were revised from those originally proposed.
A number of the measures will need to be completed, or substantially completed, prior to submitting an updated water licence application for the project. Specific components of the project require stakeholder input before being included in the updated consolidated project description, and the measures require the creation of an independent oversight body to provide input into options analysis as well as oversee research into a long-term solution for the arsenic trioxide dust.

In addition to the requirements from the EA, the project will require a land use permit from the MVLWB for specific project activities, and various development and demolition permits from the City of Yellowknife. Each process has its own consultation and engagement requirements that the project must follow in order to obtain the necessary permits. Consultation, while necessary, important and beneficial, will have an impact on the overall project schedule and could have cost implications depending on the final remediation plan that is approved.

It is also worth noting that the various regulatory regimes, while intended to be complementary, can work at cross-purposes. The MVRMA is intended to mitigate the environmental impacts of land use activities, while the city bylaws relate to ensuring land use activities occur in an orderly and planned manner. Section 98 of the MVRMA states that the MVLWB does not have jurisdiction “in respect of the use of land within the boundaries of a local government to the extent that the local government regulates that use” (Government of Canada, 2014). In 2011, the MVLWB and the Government of the Northwest Territories, represented by the Minister of Municipal and Community Affairs (MACA) made a joint determination that allows both the City of Yellowknife and the MVLWB to regulate the same activity under different processes, as they felt the city bylaws did not adequately cover the types of environmental considerations that would be addressed by a land use permit issued by the MVLWB. The only way to harmonise the two processes would be an amendment to the city bylaws, which could have a significant impact on smaller development projects.

Although the mine is no longer in operation, it is also subject to the metal mining effluent regulations (MMER) under the Fisheries Act because it continues to discharge mine water effluent. Even though the effluent is treated prior to release, it is a release of a potentially deleterious substance that could trigger the “harmful alteration, disruption, or destruction (HADD) of habitat” (Government of Canada, 2002). The effluent can be discharged as long as the mine “operator,” in this case, AANDC, conducts the required environmental effects monitoring (EEM). This includes the regular monitoring of effluent and water quality, and biological monitoring of the receiving environment.

Various other permits or authorisations may be required during the life of the project, such as research permits (wildlife, scientific, medical), archaeology permits and migratory bird permits.

2.3 Project components

The project has several major components that will form the overall remediation plan for the site, which are described in more detail in the following sections. The specific scope for each component will be determined through implementation of the EA measures and consultation with stakeholders.

2.3.1 Arsenic trioxide in the subsurface

As mentioned previously, an estimated 237,000 tonnes of arsenic trioxide dust are stored in stopes and chambers within the former mine workings. Considerable effort has gone into determining an appropriate method to manage the risk this material poses, resulting in the selection of the frozen block method. This approach is a means of freezing the rock around the chambers containing the arsenic trioxide dust and then maintaining this frozen state through the use of thermosyphons designed for either active or passive heat transfer. Thermosyphons are a type of heat pump designed to remove heat from the rock surrounding the arsenic stopes to create an impermeable frozen zone that will completely encapsulate the arsenic dust indefinitely.

To determine the design parameters for the final freeze system, a freeze optimisation study (FOS) was conducted on one of the arsenic chambers (Chamber 10). This study involved a full-scale installation of 38 drill holes and freeze pipes, as well as more than 30 instrumented drillholes to collect data during operation.
of the system. The FOS was constructed in 2009 and 2010, and testing was initiated in early 2011. The system was operated continuously during that time, testing active, passive and hybrid operation of the system, as well as various configurations for the system itself. The objectives of the study included:

- demonstrating large-scale ground freezing;
- estimating parameters needed for engineering design;
- testing implementation methods;
- developing monitoring and data handling methods;
- identifying constraints and opportunities related to procurement and project delivery;
- examining “unknown unknowns,” that is, project uncertainty and unexpected design issues.

The advantages and disadvantages of various design options identified through the FOS, as well as the EA process, were assessed through a series of trade-off studies. The following studies and variants were examined:

- wet vs. dry frozen blocks — freezing the dust with or without wetting;
- surface (vertical) and underground (horizontal) piping, or surface only;
- temperature of freezing coolant;
- conversion of system from active to passive
- active and/or passive freezing;
- application of surface amendments;
- requirements for bulkhead design.

The results of the FOS are being assessed at the time of this writing, and will inform the final design of the freeze system going forward in 2015.

### 2.3.2 Baker Creek

Baker Creek is a 2,520 m channel that traverses the site from the north to the south and discharges into Back Bay, which is part of Great Slave Lake. The channel has been altered significantly over the course of the mine’s operation to accommodate mining, processing and road construction. A description of each of the main reaches of Baker Creek is provided in Figure 2.
The alteration of Baker Creek has created a number of issues that need to be addressed by the project. Water and sediment quality are significantly impacted by historical spills, the discharge of treated mine water and offsite inputs upstream, which also impact habitat development and quality. As well, certain reaches of the creek pass close to pits, and there is a risk of flooding the pits, which could result in uncontrolled flooding of the mine during severe storm events (greater than one in 500 years). This could result in the uncontrolled release of arsenic into the environment. As well, the stability of the C1 pit wall adjacent to Baker Creek is deteriorating, the failure of which would increase the risk of uncontrolled flooding of the mine workings.

A number of options for Baker Creek exist, and it is a requirement of the EA to examine the options in consultation with regulatory authorities and stakeholders, and specifically with the input from an independent oversight body prior to making the final decision. The options span from re-routing the entire creek to a new route that avoids the mine site entirely, to making modifications to certain reaches that minimise the risk of uncontrolled flooding of the mine and maximise the quality of water and sediment that ultimately discharge into Great Slave Lake.

### 2.3.3 Water management

Mine records indicate that arsenic from the tailings effluent was controlled by treatment starting in the 1950s, but the details of the treatment and its effectiveness were not described. There was also a new water treatment circuit commissioned in 1967, using lime to precipitate arsenic from the mill tailings stream before discharging it into the tailings pond, thus reducing the concentration of dissolved arsenic in the tailings effluent. The precipitated arsenic was disposed of with the mill tailings.

Water from the mine was pumped directly to Baker Creek without treatment until 1981, when a new water licence required mine water to be treated to improve the quality of effluent released to the environment. Pilot scale testing completed in collaboration with Environment Canada resulted in a new effluent treatment plant starting operation in 1981. Ferric iron and lime were used to precipitate arsenic and other heavy metals. This was preceded by the destruction of cyanide using first alkaline chlorination, then hydrogen peroxide oxidation starting in 1990.

The need to regulate flows led to storing mine water in the tailings ponds prior to treatment, which significantly reduced the available tailings storage capacity. In 1997, a mine water treatment circuit was installed in the mill, which resulted in the treated water being used in the mill process, reducing the mine’s consumption of fresh water. Since 1999, when the processing of ore at the site was discontinued, mine water has been pumped to the south, north and northwest ponds for storage, and then treated in the existing water treatment plant prior to discharge to Baker Creek during the summer months.
The decision on the final configuration of Baker Creek will be impacted by, and will impact, decisions about other water management issues at the site. As indicated, surface water running onto the site can have moderate to high levels of arsenic that contribute to the overall loading of arsenic in water that eventually discharges from the site. It is also expected that mine water will remain impacted above acceptable levels that will prevent discharge without prior treatment. This is directly affected by the EA measures, which require mine effluent to be treated to Canadian drinking water standards prior to discharge into Yellowknife Bay. A new effluent treatment plant will be designed and built to meet the treatment standard. However, to minimise the costs of storing, handling and treating water, it will be necessary to limit the input of clean surface water into the mine. While runoff from tailings ponds and other areas may require treatment, the intent will be to divert as much water as possible from entering the mine and thus having to be treated. Capping systems for the tailings designed to maximise runoff efficiency and minimise contact with contaminated soils and tailings will also contribute to reducing the amount of water requiring treatment.

Storage of water prior to treatment is another decision point for the project, and is dependent on other factors such as the progress of the freeze. If the mine were to be used for water storage versus surface ponds, it would require allowing the water level in the mine to rise from its current level of 10 m below the 750 level (at C-Shaft). The decision to treat water year-round or seasonally is an important design consideration, because large fluctuations in the water level in the mine that would result from seasonal treatment could result in an increase in arsenic being discharged from the mine, and could impact the structural integrity of the backfilled chambers, bulkheads and crown pillars supporting the mine.

2.3.4 Tailings

Approximately 9.5 million dry tonnes of tailings were originally deposited in the north, central and south ponds, of which about 7 million tonnes of tailings remain. Between 1988 and 1990, 2.5 million tonnes of these tailings were reprocessed in the Tailings Retreatment Plant (TRP) and transferred to the Northwest Pond, to which another 6 million tonnes were added through conventional mill production. The tailings in these ponds cover a combined surface area of almost 100 hectares, with a maximum tailings thickness of about 22 m in the central pond.

The tailings are impounded by several dams, meant to contain the tailings and minimise seepage of pore water. Seepage collection systems were constructed at the perimeter dams where seepage did occur, and the dams are inspected annually. The performance and safety of these dams was formally reviewed in September 2004, and no immediate safety concerns were identified. Recommendations to assess dam performance in more detail and improve operating, maintenance and surveillance procedures have been implemented as part of the ongoing care and maintenance of the site.

The ultimate remedial concept for the tailings is a cover to prevent human or wildlife contact, and to encourage vegetation growth and shed runoff/prevent infiltration of surface water. The final design will be dependent on several factors, and will be determined once the final footprint of the tailings areas is identified. Tailings are currently being used in the production of paste used to stabilise the underground workings (further described in section 2.3.5), which also serves to reduce the final volume and aerial extent of tailings that will require covering.

2.3.5 Underground stabilisation

The mining activities at Giant Mine were meant to be temporary while extracting the gold-bearing ore, with the mine to be closed using standard practices of the day. However, the last owner went into receivership and left the site in an operable state, and AANDC took on care and control of the mine and eventual closure. The underground workings were safe while the mine was in operation, but since active mining ceased in 1999, the underground voids have started to weaken and have the potential to collapse, which has led to the appearance of sinkholes and subsidence on the surface. As discussed, the collapse of bulkheads or the surface into the underground chambers, stopes or tunnels could result in injury to workers or visitors to the site, loss of infrastructure, uncontrolled flooding of the mine and/or a release of arsenic trioxide directly to the surrounding environment.
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To increase the stability of the underground mine workings, the project has started to fill the voids using a paste backfill delivered through surface drillholes. This process has been used by operating mines for the last two decades, and as a component of mine reclamation for more than 10 years. The paste is a mixture of water, cement and tailings in a specifically designed ratio to provide underground structural support that, once hardened in place, will serve to stabilise the site (Caulfield, 2014).

Owing to the lack of detailed plans of the mine workings, and without the ability to physically verify the paste delivery for safety reasons, the process is being carefully controlled and monitored using remote video monitors. The stabilisation of the voids is necessary to secure the site as well as prepare the stopes containing arsenic trioxide for eventual freezing, and other areas for the potential controlled flooding of the mine.

2.3.6 Open pits and openings to surface

There are eight open pits and 35 openings to the underground mine, all of which present safety hazards. The overall mined volume of the pits is more than 2 million m³. Prior to addressing the pits, the openings to the surface will be sealed in accordance with the Northwest Territories Mine Health and Safety Act and regulations. The selection of methods must meet the regulations and achieve the objectives for strength and durability, and is primarily based on the physical characteristics of the opening (size, geometry, location, inclination) and the quality of the rock surrounding the opening. When the openings are no longer required for access or ventilation, they will be sealed with structures requiring minimal maintenance to remain stable and effective in the long term.

A number of the underground stopes are located directly below the pits, and so their long-term stability once backfilled is a primary consideration when determining how to address the risks the pits themselves pose as a site hazard. These include hazards related to the pit walls themselves, as well as risks related to water management: uncontrolled water from below (the mine) could form contaminated pit lakes, and from above (from Baker Creek) could enter the mine through the pits.

Waste rock will be used to seal up most of the lateral openings, including the portals located in the open pits. This may also be suitable for sub-vertical openings, such as the raises and shafts. In some cases a concrete cap may be placed over or inside the opening. The ground conditions would need to be inspected and assessed for competency as part of the cap design process. In openings where the bedrock is not competent, a reinforced concrete bulkhead may be constructed deeper inside the opening into sound bedrock.

2.3.7 Contaminated soils

There are considerable quantities of arsenic-impacted soil throughout the site, though the volumes that exceed the relevant industrial standard have not yet been fully delineated. The EA requires the completion of a human health risk assessment and quantitative risk assessment, which will help determine the final strategy for the various areas of impacted soil based on land use expectations. If soils require remediation, one potential solution will be to use the impacted material to backfill one or more of the existing pits.

3 Financial considerations

AANDC’s responsibility for the site includes financial liability for the care and maintenance and mitigation of environmental risks at the site. As the project has evolved, so have the estimated costs to address the issues at the site. The most recent indicative cost estimates for the project were developed in 2012, and indicated the total full-up project cost from 2000 to completion in the order of C$ 903 million. This number is subject to change as a result of the EA and the finalisation of the remediation plan, but is considered reasonable relative to the magnitude of the problems at the site. The primary challenge is to determine what funding mechanism(s) will be used to deliver the project.

In response to the issue of major environmental liabilities held by the Government of Canada, due in large part to abandoned mines sites like Giant Mine, the Federal Government announced the federal contaminated sites action plan (FCSAP) program in 2004. This 15-year, multi-billion-dollar program has the overall goal of
reducing the risk to human health and the environment, and the associated financial liability associated with these sites. To date, the project has received 100% of its funding from this program.

The limitation with this funding model is that Canada is a parliamentary democracy, and the sitting government cannot encumber future governments, so the program is approved in five-year phases, with funding approved on an annual basis. This makes it very difficult to secure long-term contracts for work and obtain better value for money. It also means that projects are competing for resources as priorities change, since there is no long-term commitment of stable funding.

As noted, the current funding program ends in 2020, which is when the Giant Mine project is expected to start remediation, so a new, long-term, stable source of funds will need to be secured prior to starting active remediation. This will be a major focus for the project team over the next few years, to ensure the overall plan to manage and mitigate risks at the site can be accomplished in a reasonable timeframe.

4 Conclusions

The Giant Mine remediation project is a complex technical undertaking in mine closure. It is further complicated by the variety of regulatory regimes under which it falls, the high profile it has in the public and the constraints within the Government of Canada project approval process.

The project components for both the surface and underground remediation are interconnected in various ways, and decisions made for one aspect of the project will impact the options available for other elements. The project team will follow the regulatory process to update the remediation plan, obtain a water licence and other required permits, and seek the necessary approvals to implement the project and reduce the risks to health, safety and the environment for the long term.

References


