Development and Implementation of a Closure and Remediation Plan: A Case Study of the Faro Mine Closure Project, YT

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ABSTRACT
At the height of its production, the Faro Mine, located in south-central Yukon, Canada, was one of the largest producers of lead and zinc in the world. In 1998 mining operations ceased indefinitely after almost thirty years of activity, leaving behind over 360 million tonnes of waste rock and 55 million tonnes of tailings. In 2003, the governments of Canada and the Yukon and the affected Yukon First Nations collaborated to initiate a closure and remediation plan for the contaminated site. The purpose of this research project was to use the Faro Mine Closure Project as a case study to gain a comprehensive understanding of the processes involved with developing and implementing a closure and remediation plan for a mine that is no longer operating. An analysis of several government and technical reports as well as peer reviewed journal articles were used to complete this document. The main environmental challenges faced by the remediation project are the generation of acid mine drainage (AMD); water contamination by metals; metal-bearing dust from tailings and stability of existing structures such as tailings dams and diversion channels. Socio-economic concerns are also examined. Several remediation options were proposed for the site and are described in this paper. Some options favor the relocation of the waste rock and tailings to the excavated pits while other options involve an approach to stabilize the waste in place. Many technical reports and rounds of community consultation resulted in consensus on a plan that involves stabilizing and covering the waste in place. A brief discussion of the subsequent phases of the closure plan, including the design and regulatory phases, is included in this report.
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1.0 Introduction and Objective

The Faro mine was officially opened in 1969 when it began commercial production of lead and zinc ore. At the height of its production the Faro Mine, located in south-central Yukon, was the largest lead-zinc producer in the world and was at one time, the largest open pit mine in Canada. In 1998 the mine was closed after it was no longer deemed economical to develop any further. Since the last company that owned the Faro property went into receivership the mine fell into the hands of the federal government. By 2003, the Government of Yukon, Indian and Northern Affairs Canada (INAC) and affected Yukon First Nations had come together to collaborate on an initiative to develop a closure and remediation plan for the Faro Mine complex. Closure and remediation plans are implemented when a mine is no longer producing. In general, the goal of a closure plan is to eliminate any contamination related to mining activities and to return the site to its natural land use. The Faro Mine Closure Project is estimated to cost between $500M and $700M, making this one of the most expensive environmental clean-ups in Canada (FMRP, 2011). The project is to be funded by the Federal Contaminated Sites Action Plan.

The purpose of this research paper is to examine and gain an understanding of the processes involved with creating and implementing a closure and remediation plan after a mine has ceased operations. The Faro Mine was chosen as a case study to illustrate this process as it provides an example of a large scale closure project currently involving extensive remediation. This particular project also made for a desirable subject because of the significant involvement of the affected communities in the area of the mine. Additionally, an appreciation can be gained for the vast amount of time that is needed for a
contaminated site to be remediated as some predictions indicate that Faro Mine complex will only return to more natural conditions after several hundred years of remediation activities and maintenance (IPRP, 2007).

2.0 Methodology

Research for this project was conducted primarily through a review of a variety of sources that can be classified as “grey” literature. This includes government reports and technical reports prepared for the mining industry. A selection of peer reviewed scientific journal articles were also used to solidify understanding of certain concepts. Most of the literature used for this research project was published within the last ten years so as to provide the most current information available.

3.0 Location of the Faro Mine Site and Description of Nearby Communities

The Faro mine was a large open pit lead-zinc mine located in south-central Yukon, approximately 15km north of the town of Faro (see Figure 1). The site is relatively remote, situated approximately 350km northeast of the capital city of Whitehorse. The Faro property lies within traditional territory of the Kaska Nation.

The town of Faro was established in 1969 for the purpose of servicing the newly opened mine. The population of the town has decreased dramatically since the mine closed and is now home to...
approximately 400 residents (Government of Yukon, 2009). Presently, the town is developing in the eco-tourism industry, the arts, and as a retirement community. Ross River is a small community located approximately 65km east of the mine complex. It is home to the Ross River Dena who are members of the Kaska Nation. There are approximately 340 inhabitants who represent a community rich in Kaska culture and tradition (Government of Yukon, 2009).

Members of the Selkirk First Nation living in Pelly Crossing make up a third community strongly tied to the Faro Mine Closure Project. There are 290 people living in Pelly Crossing, which is located directly on the banks of the Pelly River, approximately 300km west of the Faro Mine (Government of Yukon, 2009). Rose Creek is a tributary of the Pelly River and flows through the Faro Mine site (see Figure 2). While Pelly Crossing is situated relatively far away downstream from the mine site, potential contamination of Rose Creek creates a direct concern for the people of Pelly Crossing.

### 4.0 Description of the Site

The Faro Mine complex has a total footprint of approximately 25km² and can be divided into three main areas: Faro Mine area, Rose Creek Tailings area, and the Vangorda Plateau (see Figure 2). Throughout the site two main types of mine waste have accumulated, waste rock piles and mine tailings. Material in the waste rock piles includes coarse rock that was excavated from the open pits but was not economical to process and extract the valuable metals. Mine tailings are very fine-grained waste that is generated when the processed rock is ground up to extract metals for economical purposes. Mine tailings are usually saturated with water. This is in contrast with waste rock, which is
usually dry. However, tailings can be dry and fine particles can be picked up and transported large distances by the wind (Spitz & Trudinger, 2009).

The Faro Mine area, labeled as 1 on Figure 2, consists of the Faro pit and the decommissioned processing mill with associated buildings. The Faro pit covers an area of approximately 1.06 km². Over 250 million tonnes of waste rock surround the Faro pit in several piles. A rock lined diversion channel was constructed around the northern edge of the pit in which the Faro Creek is currently flowing. The mill and associated buildings, which are no longer in use, are sited south of the Pit (FMRP, 2011).

The Rose Creek Tailings area is located south of the Faro Pit. Over 55 million tonnes of tailings were accumulated between 1962 and 1992. These tailings are currently stored in an unlined containment area within the Rose Creek Valley. Four dams were constructed in the area. Three are holding tailings and the fourth dam is retaining contaminated water. Another rock lined diversion channel was constructed to allow the Rose Creek to flow around the tailings area (FMRP, 2011).

The third area in the complex is the Vangorda Plateau. Within this section there are two open pits, the Vangorda pit and Grum pit. The Vangorda/Grum mining area is connected to the Faro mine area by a 13 km heavy haul road. This road was constructed to allow transportation of ore from the Vangorda Plateau to the Faro mill. Approximately 16 million tonnes of waste rock surround the Vangorda pit. The Vangorda Creek is diverted around the northwest side of the pit in a culvert. The Grum pit is surrounded by over 100 million tonnes of waste rock. The mining operations ceased before the Grum pit was developed to its original design specifications (FMRP, 2011).
The watercourses that flow through the mine site, including the Faro, Vangorda, and Rose Creeks, are all part of the Pelly River drainage system. The Faro Creek is currently diverted into the North Fork of Rose Creek. Rose Creek flows into Anvil Creek, which in turn flows into the Pelly River (see Figure 2).

![Map of the Faro Mine site showing relative location of the Faro Pit (1), Rose Creek tailings (2) and Vangorda Plateau (3). The drainage system of the area is also depicted.](http://faromine.ca/reference/library.html)

**5.0 Brief History of Production at the Faro Mine Complex**

In 1953 the prospector Al Kulan first discovered the Vangorda lead-zinc deposit. Prospector Airways obtained the newly discovered property and from 1953 to 1955 diamond drilling took place. Kerr-Addison Mines Limited ultimately acquired Prospector
Airways but their interest in the property diminished as the market for metals was declining due to low prices and also because the area was very remote. By 1962 Kerr-Addison began to explore the Vangorda plateau again. In 1963 a lead-zinc deposit southeast of Vangorda was discovered. At the same time an exploration program began on the Faro claims. By 1965 the Faro lead-zinc deposit was discovered. Cyprus Mines and Dynasty joined together to form Cyprpus Anvil and began to develop the Faro deposit. (FMRP, 2011)

By 1969 open pit mining had begun, moving up to 10 000 tonnes per day. In 1973 the Grum lead-zinc deposit was discovered and subsequently purchased by the Cyprpus Anvil Mining Corporation. By 1982 most of the production ceased due to the combination of a significant drop in metal prices, a drop in productivity, high operating costs, and the accumulated debt obtained through expansion of the property. By 1984 production was completely halted (FMRP, 2011).

In 1985 the Cyprpus Anvil assets were obtained by Curragh Inc who resumed operations at the Faro mine in 1986. The Vangorda Plateau began development in 1989 with the stripping of the Grum and Vangorda deposits. Ore removed from these two deposits contributed to the mill feed at the Faro mine area.

In 1991 Curragh began to strip the Grum deposit. 193.2 million tonnes of waste was required stripping from the Grum deposit. At this time the reserves in the Faro pit were being exhausted. By late 1992 enough material had been stripped in the open pit to expose the Grum deposit. Approximately 21.4 million tonnes of rock was removed before stripping in the Grum area came to a close in December 1992 (FMRP, 2011).
All of the mining operations stopped again in 1993 when metal prices fell below profitable levels. As a result, Curragh was forced into receivership. Subsequently, Anvil Range Mining was created and purchased the Faro properties from the receiver for $27 million dollars. ARM began production from the Grum and Vangorda open pits in 1995 and reached commercial production later that year. Mining operations were suspended once again at the end of 1996 when the Vangorda pit was diminished and because of low metal prices (FMRP, 2011).

1997 the mine reopened one last time and operated until January 16th, 1998, at which time Anvil Range filed for court protection from creditors. In 1998, Deloitte and Touche was appointed by the court as an interim receiver and is responsible for managing and maintenance of the site (Indian and Northern Affairs Canada, 2005). In 2003 the government of Yukon and the Department of Indian Northern Affairs Canada (INAC) established that the mine would not reopen. As a result, a long-term closure plan was to be designed under the responsibility of governments.

At the height of production, the Faro mine was the largest open pit mine in Canada (FMRP, 2011). According to the Faro Mine Closure (FMC) project website the mine site accounted for approximately 15% of the world’s lead and zinc production and contributed to 20% of the Yukon economy during the years of peak production (FMRP, 2011).
Figure 3 Timeline summarizing production and activity of the Faro Mine Site from 1953-2003. http://faromine.ca/mine/history.html

6.0 Challenges of the Faro Mine Remediation Project

6.1 Assessment of human health and ecological risks

An Independent Peer Review Panel (IPRP) was commissioned in 2006 to review the several remediation options suggested for the Faro Mine (discussed further in section 7.0). The Panel reviewed the several human health and ecological risk assessments that were conducted and agrees that under current management practices the site is being properly contained. However, it is strongly believed that if appropriate actions are not taken, there is potential for a great risk to human and ecological health in the future. One of the main
causes for concern is the wind blown dust from the tailings piles containing residual amounts of metals. Fine metal-bearing particles can be easily picked up by the wind and carried several kilometers from the site thereby expanding the areas of contamination. Some worries exist about the direct toxicity to humans from affected animal species and traditional food sources. As well, there are greater concerns about toxicity to fish in aquatic environments. This is especially true for the Pelly River and its tributaries: the Anvil, Rose, and Vangorda Creeks. In aquatic ecosystems, wind blown dust can bring about an accumulation of metals, which can severely impact the reproduction of fish populations (Franssen, 2009). In terrestrial environments metals can accumulate to toxic levels in animal species, many of which are important traditional food sources for some local residents. The wind blown tailings pose a threat to human health because of the potential uptake of the accumulated metals through the consumption of contaminated fish and game.

Another potential risk to human health and the environment could occur as a result of the instability of tailings dams during significant seismic events. If the tailings dams are not capable of withstanding a maximum credible earthquake for the region severe contamination could occur. The risk of failure of the dams however, was deemed low as these engineered structures are considered to be stable (IPRP, 2007).

Gartner Lee Limited was commissioned to collect data over a period from 2003-2005. SENES Consultants Limited (SENES) prepared a Human Health and Ecological Risk Assessment (HHERA) of the Faro Mine complex using this data. The SENES report focused on the probable impacts to both aquatic and terrestrial ecosystems as well as human receptors. Their report used four possible scenarios combined with three different projections of seepage chemistry. The purpose of these combinations was to encompass a
large range of potential environmental conditions in the future and describe a range from low to maximum risk estimates. The four scenarios are as follows: 1) the mine in its existing conditions; 2) the conditions of the mine if no human intervention occurs; 3) conditions of the site after implementing a hypothetical remediation scheme; and 4) the best possible scenario wherein all water flow from the mine site is collected and treated. Three sub-scenarios were created under scenarios 2 through 4. These sub-scenarios, termed Futures 1 through 3, were fashioned based on three different estimates reflecting the uncertainty involved with the chemistry of the future seepage. Assessment of human exposure was modeled based on the different possible land use patterns as well as the rate of traditional food use for adults, children and toddlers. However, there was no assessment made for the limited number of people who only consume traditional food. Even though the number of people who fall under these extreme circumstances is small it is still very important from the perspective of First Nations stakeholders for this group to be included in the assessment. The IPRP suggests that this receptor be included in future iterations of the HHERA (IPRP, 2007).

The IPRP report states that the sampling done by Gartner Lee was very thorough and comprehensive and is sufficient to support the HHERA. There are, however, sources of uncertainty due to a large number of non-detectable constituents in the samples. This issue is a common problem that is usually inevitable for analytical laboratories to deal with, especially with samples taken from remote locations. While the IPRP agrees that Gartner Lee was consistent with the non-detects, following the common protocol of using values of one-half the reported detection limits for analyses, there remains a question of the representativeness of the samples (IPRP, 2007).
6.2 Geochemical Issues: Sulphides and Acid Rock Drainage

One of the most significant impacts of mining is the degradation of nearby water systems. Acid Rock Drainage (ARD) is a term referring to the outflow of acidic water and is a common side effect of mining projects associated with metal sulphides (Spitz & Trudinger, 2009). The lead and zinc ore mined at the Faro site are associated with sulfide meaning that ARD is an immediate concern in the remediation process. Acid is generated when sulphide-rich materials from the mine site react with oxygen and water to form sulphuric acid. This process is illustrated in a simplified diagram in Figure 4 (Natural Resources Canada, 2008). The generation of sulphuric acid is a natural occurrence over periods of thousands of years as sulphide-bearing rocks are exposed to weathering processes. Small amounts of acid naturally released into the environment are usually neutralized in the environment or the organisms are adapted to handle the small amounts of acid. This natural process of acid generation is greatly accelerated when mining activities are taking place. Mining removes filtering topsoil layers and increases the amount of exposed, fragmented sulphide-bearing materials to the atmosphere (Spitz & Trudinger, 2009).

ARD develops in three stages including oxidation, leaching and drainage. Oxidation of the sulphide minerals occurs when they react with oxygen in the presence of water. The actual reaction is complex and is often catalyzed by bacterial activity. Leaching is the process where the oxidized sulphide minerals are dissolved in water and washed from
their source and discharged into the environment creating potential for adverse effects. Leaching usually takes place after a rainfall event. In open pit mines, such as the Faro Mine Complex, leaching occurs where rainfall runoff flows over the pit slopes. It also happens when rainfall percolates through oxidizing tailings and waste rock piles. There are several possible drainage pathways by which the oxidized materials are transported to the environment. For example, seepage of acidic water can emerge from the base of waste rock piles or tailings ponds. Drainage can also occur if there is an overflow from the tailings storage areas into the surrounding environment (Spitz & Trudinger, 2009).

ARD poses multiple threats to the environment, especially to freshwater aquatic ecosystems. The decrease in pH is likely to negatively impact the sensitive biota in the affected aquatic system. The sulphuric acid is also capable of dissolving other metals found in the surrounding rocks and can therefore contribute to the transport of metals in high concentrations to the aquatic environment. Many metals can accumulate in aquatic ecosystems to toxic levels.

Several geochemical studies were conducted at the Faro Mine site to aid in understanding the geochemical composition of the mined rock and to aid in predicting the future seepage quality. The 55 million tonnes of sulphide tailings and 32.4 million tonnes of sulphide waste rock pose the greatest concern because of the high concentration of sulphide minerals. There are also more than two hundred million tonnes of low sulphide waste rock and the mine walls that have potential to produce less acidic drainage (IPRP, 2007). These materials have been oxidizing for approximately 30 years and some of the seepage already contains toxic levels of trace elements. This water is currently being collected and treated before being discharged to the environment. Even though the
materials have been oxidizing for 30 years already the majority of the sulphide minerals at the Faro Mine site have not yet been oxidized. This means that as the mined rock remains exposed to air and water, the concentrations of the contaminants will continue to increase over time and the amount of acidic drainage will also increase (IPRP, 2007).

The SENES report proposed three geochemical scenarios, Future 1, 2 and 3, to demonstrate potential conditions of seepage chemistry for the waste rock found at the Faro Mine Complex. Future 1 is a scenario based on the average contaminant concentration of the current seepage. Future 2 is formulated based on the maximum contaminant concentration of current seepage. Finally, Future 3 is a scenario that predicts a worst-case seepage chemistry. The IPRP agrees that Future 2 seepage chemistry is a very probable situation due to the presence of the large mass of sulphidic rock at the Faro Mine site. Since Future 3 seepage chemistry is still a possible occurrence, the Panel suggests this scenario still be given consideration in subsequent assessments (IPRP, 2007).

### 7.0. Finding a Solution

The Faro Mine Remediation Project team was formed in 2003 when the governments of Yukon and INAC established the need to clean up the site. The team consists of several engineers and environmental scientists. The process of designing a closure plan was intended to be transparent and involve input from the affected communities. To begin, five objectives of the closure project were defined. These are:

1. Protect human health and safety
2. Protect and, to the extent practicable, restore the environment including land, air, water, fish and wildlife.
3. Return the mine site to an acceptable state of use that reflects pre-mining land use where practicable.

4. Maximize local and Yukon socio-economic benefits

5. Manage long-term site risk in a cost-effective manner (FMRP, 2011)

To start the process of meeting these objectives several technical studies and assessments were undertaken to classify potential environmental risks at the mine site. Over 100 technical studies were conducted since 2003 in order to find the most appropriate methods to reduce the major environmental concerns at the Faro Mine complex, which were previously discussed. In the spring of 2006 the results of the various studies were combined to come up with a range of engineered designs or alternatives for the closure project. Four alternatives or designs were created for each of the three distinctive areas of the site, the Faro Mine area, Rose Creek Tailings, and the Vangorda/Grum area. This made twelve alternatives in total. Each alternative was designed to meet five objectives of the Faro Mine remediation project (FMRP, 2011).

In October 2006, the Faro Project Management Team commissioned an Independent Technical Peer Review Panel to review the twelve alternatives. This panel was made of nine leading experts in mine closure procedures. The purpose of the panel was to assess the adequacy of the twelve proposed alternatives, determine if all remediation options have been identified and make note of any need for additional research (FMRP, 2011).

Based on recommendations by the Independent Peer Review Panel the twelve alternatives were refined to five closure options in 2007. The five options are broken into four options for the combined areas of the Faro Pit and Rose Creek Tailings impoundment and two options for the Vangorda/Grum mine area. A final closure plan would incorporate
one of the proposed options for the Faro/Rose Creek area and one option for the Vangorda/Grum area (FMRP, 2011).

7.1 Five Remediation Options
Certain reclamation activities are incorporated into each of the different options and would occur no matter which options are implemented in the final closure plan. These activities include: re-sloping and covering of waste rock piles; re-vegetation of soil covers and other areas within the site; diversion of clean water around the site; long term collection and treatment of contaminated water from the site; long term management of water treatment sludge; long term storage of water in pits; long term maintenance of remaining site facilities; long term monitoring of environmental conditions; avoid unacceptable risks to public health and safety; avoid unacceptable risks to worker health and safety; and meet appropriate environmental standards and guidelines (FMRP, 2011).

7.1.1 Remediation Options for the Combined Faro Pit and Rose Creek Tailings Area
Each of the options will also include certain processes to be undertaken at the combined Faro mine and Rose Creek tailings area. This includes re-sloping, covering and re-vegetating the Faro waste rock piles and upgrading the Faro Creek diversion. Upgrading the Faro Creek diversion would involve construction of a new diversion channel for the Faro Creek as well as building a lined channel for the North Fork of the Rose Creek. Water will need to be collected and treated from under the waste rock piles for an extended period of time. These pieces of the reclamation process are estimated to cost approximately $150M to build and maintain. It is estimated that this part of the project will provide approximately 230 person years of employment, which can translate to 230 jobs for one year or 115 jobs for two years, etc. Figure 5 is a depiction showing the Faro mine area in its
current condition and what the area is estimated to appear as in approximately forty years after the steps previously described are implemented.

In addition to the above project, three options were proposed to remediate the rest of the combined Faro and Rose Creek area. The first option involves the relocation of all the Rose Creek tailings to the Faro Pit. The second option is to leave the tailings and cover them in place. A third option is a combination of the first two alternatives where some of the tailings would be pumped into the Faro Pit and the remaining tailings covered in place (FMRP, 2011).

**Option 1: Move all tailings**

In order to move all the tailings from the Rose Creek tailings impoundment, the tailings would first be mixed with lime and water. This is an important step to increase the pH and decrease the acidity of the mixture. The tailings would then be hydraulically pumped from the impoundment into the Faro Pit. As with the remediated waste rock piles, contaminated water from under the tailings would need to be collected and treated for several decades. The existing tailings dams would be restructured and the valley would be re-vegetated. After the soils and waters are clean enough, a channel would be constructed in order for Rose Creek to be returned to its original position in the valley. Figure 6 provides an
illustration of what the remediated valley would look like should the tailings all be relocated.

Of the three proposed options for the combined Faro and Rose Creek areas, this first alternative is the most expensive, estimated at approximately $440M to construct and maintain. If this option were to be selected an estimated 745 person years of employment would be provided (FMRP, 2011).

Option 2: Cover the tailings in place

The second remediation option for the combined Faro and Rose Creek area is to cover the mine tailings in place with an engineered soil cover. The tailings dams would need to be upgraded to ensure long-term stabilization. The tailings would be regarded to improve stability. After the tailings are covered with soil they can be re-vegetated. Diversions, channels and spillways in the area would need to be upgraded in order to handle possible flooding events. Collection and treatment of contaminated water from under the tailings would need to occur for hundreds of years. Maintenance of the soil covers, dams, and channels would also need to be done for hundreds of years. Unlike the first option, the Rose Creek channel would remain in its current location. Figure 7 shows the current conditions of the tailings impoundment as well as what the area is predicted to look like after remediation activities have been
implemented. Remediation of the tailings in place is considerably less expensive than the option of relocating the tailings. It is estimated that this remediation option would cost approximately $260M and provide roughly 336 person years of employment (FMRP, 2011).

**Option 3: Move some tailings and cover some tailings with soil**

The third proposed alternative for the combined Faro and Rose Creek Tailings area is essentially a combination of the first two options already described. Some tailings would be mixed with lime and pumped to the Faro Pit while the remaining tailings would be re-graded, covered with soil and re-vegetated. As with the previous options, hundreds of years of monitoring, maintenance, and water treatment would be necessary factors. Once the tailings are covered with soil and deemed stable, a channel for Rose Creek could be constructed to allow the watercourse to return to its natural path in the valley. A depiction of what the valley might look like after implementing

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Figure 7 Comparison of current (top) conditions at Rose Creek Tailings impoundment and predicted (bottom) conditions after remediation. http://faromine.ca/reference/library.html7

Figure 8 Rose Creek tailings area before (top) and after implementation of option 3 remediation steps (bottom). http://faromine.ca/reference/library.html
this remediation option is shown in Figure 8. This third alternative has been estimated to cost $340M to construct and maintain and provide approximately 552 person years of employment (FMRP, 2011).

7.1.2 Remediation Options for the Vangorda/Grum Mine Area

Both of the proposed remediation options for the Vangorda Plateau involve resloping and covering the Grum waste rock in place which would be similar to the procedures used for the Faro waste rock as described earlier. As with each of the combined Faro and Rose Creek area options there will be a need for hundreds of years of collection and treatment of contaminated water as well as hundreds of years of maintenance of soil covers and the channel (FMRP, 2011).

Option 1: Relocate Vangorda Waste Rock into Vangorda Pit

In addition to covering the Grum waste rock, the first option proposed for remediation of the Vangorda Plateau involves mixing the Vangorda waste rock with lime and relocating it to the Vangorda Pit. The relocated waste rock would subsequently be covered with soil and vegetated. If this alternative were chosen a new channel for Vangorda Creek would be constructed over the filled Vangorda Pit. This remediation option is estimated to cost approximately $110M and provide roughly 225 person years of employment.
Figure 9 illustrates what the Vangorda Plateau might look like after implementation of this particular option (FMRP, 2011).

**Option 2: Cover Vangorda Waste Rock In-Place**

Alternative to relocating the Vangorda waste rock engineered soil covers could be used to cover the waste rock piles in their current locations. The rock piles would be re-sloped and shaped to increase stability and to adopt a more natural appearance. The re-sloped rock piles would be covered in soil and then re-vegetated. A new diversion channel would also be built for the Vangorda Creek. The cost of this process is estimated to be approximately $80M and provide employment for roughly 80 person years. This option is less expensive than the alternative involving the relocation of the Vangorda waste rock (FMRP, 2011). An illustration of what the area might look like after following this plan is depicted in Figure 10.
7.2 Relocating Tailings and/or Waste Rock as a Remediation Technique

Backfilling of open pit mines has been carried out extensively internationally, however it is only recently that backfilling closure programs have been created for the disposal of sulphide waste rock and tailings (MEND, 2001). The main objective in relocating the sulphide wastes to the open pit is to provide a suitable geochemical environment to prevent the generation of acid and reduce the negative impacts to groundwater and surface water resources. The addition of lime to the backfill material can be used to neutralize existing acidity or acidity that could potentially be generated in the future (MEND, 2001). In the case of the Faro Mine complex the addition of alkali materials would be essential to the backfilling process to promote an increase in pH levels. Once the pit was filled, the waste material would subsequently be covered as another control to prevent acid generation.

The proposed options involving the relocation of the mine waste material from the Faro Mine complex are generally less desirable because of the relatively higher costs and greater risks to human and environmental health (IPRP, 2007). In the case of the Rose Creek tailings facility, partial or complete relocation could be a practicable option. However, the Panel believes the environmental, economic, and engineering risks linked to this alternative have been underestimated. The several engineering assessments suggest that stabilizing the tailings in place presents an adequately low risk and can be implemented at an acceptable cost. Many engineering analyses and risk assessments had been conducted and demonstrate that the tailings and the associated dams will be stable under maximum credible earthquake (MCE) and probable maximum flood (PMF) events.
Based on these conclusions, the opinion of the Panel is that there is no technical reason for relocation of the tailings (IPRP, 2007).

The process of relocating the tailings would likely require two decades to implement. There are also several environmental and engineering risks connected with the intermittent character of the process throughout the year. There are also potential impacts from high precipitation or seismic events as well as possible worker related injuries (IPRP, 2007).

### 7.3 Soil Covers as a Remediation Technique

The favoured method of remediating the Rose Creek Tailings and the waste rock piles is based on an option to stabilize the material in place. A popular means of mitigating ARD in place is to use a dry soil cover to prevent infiltration of oxygen and water in the mine waste. Different types of materials can be used including natural soil or clay, non-reactive waste rock, crushed limestone, or geosynthetic materials (MEND, 2001). The selection of material to be used is based strongly on the budget of a project as well as what suitable materials are present locally. Covering the sulphide bearing material prevents precipitation and meltwater from interacting with the sulphides and creating ARD. Installation of soil covers over the tailings will also eliminate the dust problem at the Faro Mine site. The fine metal-bearing particles will not be exposed to wind and would no longer be transported outside the boundaries of the site. Another benefit of using dry covers is that they provide a substrate for establishing a vegetative cover, which can aid in returning the land to its previous state and add to aesthetic quality (Kavalench, 2010). As described earlier, one of the objectives of this remediation project is to return the mine site to a state
that reflects pre-mining land use. Vegetative covers also help to protect against wind and water erosion thereby increasing the long-term stability of the dry cover system (MEND, 2001). Dry covers can range from very simple, single layer designs to complex designs with several layers of multiple materials.

Fortunately, the Faro Mine Complex has adequate supplies of glacial sediments (till) that would be suitable for construction of dry covers for the tailings and waste rock piles. The most significant source of this material is the overburden which was removed when excavating the Grum Pit. Since the haul distance between this supply is relatively far from the Faro Mine area the efficiency of the cover design will be important to consider. A thinner but effective soil cover would help minimize the cost of the remediation project (IPRP, 2007).

When the soil covers are being designed, the thickness of the cover is largely based on the water retention capacity of the tills and the need to retain a certain percentage of the mean annual precipitation (IPRP, 2007). Three different soil covers have been considered for the waste rock piles. The first is a rudimentary cover of 50cm of lightly compacted till. This would reduce infiltration to 15-25% of mean annual precipitation. The second is a low infiltration cover of 150cm of lightly compacted till overlaying 50cm of compacted till which would reduce infiltration to 3-8% of mean annual precipitation. A possible example of a low infiltration cover is shown in Figure 11. The third option is a very low infiltration cover which would reduce infiltration to less than 2% of mean annual precipitation. One possible design for the very low infiltration cover is 150cm of lightly compacted till overlaying 100cm of compacted till. This cover could also consist of 100cm of till overlaying a geomembrane placed on a compacted subgrade. Upon review of these three
cover types, the Independent Review Panel considered each of the conceptual designs to be a sufficient representation of the range in performance that could be needed for soil cover function (IPRP, 2007).

The soil covers to be installed at the Faro Mine Complex will need to be functional for several hundred years and consequently will require ongoing maintenance to preserve their design function. Therefore, part of the remediation plan will need to incorporate a proactive maintenance plan that would detect, prevent and repair any deterioration of the covers due to settlement, weathering, desiccation, freeze-thaw cycles, erosion, and animal or human activity (IPRP, 2007).

7.4 Water Treatment

Any water that is discharged from the Faro Mine property must meet specific quality standards according to the water license granted to Deloitte and Touche by the Yukon Water Board. In order to abide by this requirement treatment of seepage, groundwater, and open pit waters at the Faro Mine site will need to be conducted in perpetuity. This will be a factor of the closure project no matter what remediation options are implemented within the Faro Mine Site (IPRP, 2007).

According to the Independent Peer Review Panel, the high density sludge (HDS) process would be the most appropriate treatment technology to implement at the Faro
Mine Complex both presently and in the future. The HDS process is proven to be reliable and has minimal sludge production relative to other treatment processes. In-situ biological treatments were also evaluated as a potential method of water treatment.

The high density sludge (HDS) process uses lime precipitation to treat water affected by acid mine drainage. Contaminated water is collected in a treatment tank and mixed with a lime slurry to increase the pH of the water to approximately 9. At this pH most metals of concern are no longer soluble and will precipitate out of solution. The mixture is then moved to a settling tank where metal precipitates, the sludge, fall out of suspension. The clean water can then be released while the lime sludge will be recycled for further use in the treatment tank. Since the lime sludge can be recycled in the HDS process this method is considered to be more efficient than other similar processes (Aube & Zinck, 2003).

A three year, full scale field trial within the Grum Pit was used to evaluate an in-situ biological treatment as an alternative to a conventional chemical treatment such as HDS. Examples of biological treatments can include the use of algae to uptake and remove metals and the use of sulphate reducing bacteria to consume acidity and precipitate metals. Biological treatments are often seen as passive applications, however this is usually not true. This technology requires extensive ongoing maintenance supplied by highly trained staff. Observations from the three year trial indicated that the biological treatment process was not successful in reaching the required standards for effluent quality as outlined by the water license issued by the Yukon Water Board, therefore this treatment option was not viewed as a viable primary treatment process (IPRP, 2007).
8.0 Community Consultation and Socio-economic Concerns

An important part of the Faro Mine Closure Project was to include input from local residents and consider any concerns raised by residents of nearby communities including the town of Faro and the communities of Ross River and Pelly Crossing. From the time when planning of this remediation project began, the federal and Yukon governments have been working in conjunction with the Ross River Dena Council and Selkirk First Nation to provide a strategy for the overall closure plan. The planning process for the project is meant to be transparent and able to provide information to aid in community understanding and involvement (FMRP, 2011). Fact sheets and newsletters providing regular updates to the communities continue to be distributed. The Faro Mine Remediation Project includes community-based First Nations offices in Ross River and Pelly Crossing. The project coordinators based in these offices have responsibilities that are directly involved with communications, field studies, and technical and information workshops. These offices provide a constant connection between the project and the members of the communities (FMRP, 2011).

Local stakeholders also had the opportunity to be involved with the assessment of the twelve closure alternatives in conjunction with the technical review conducted by the IPRP. Two rounds of community consultations were held in the Fall of 2006 and Spring of 2007. These were concurrent with the technical review of the twelve alternatives. The combination of recommendations made by the IPRP and feedback from the two rounds of consultation resulted in the twelve alternatives being refined into five closure options (FMRP, 2011).
In February of 2009, the governments of Canada, Yukon, and affected Yukon First Nations made public that they reached a consensus on a final remediation plan that focuses on a stabilize in place approach. This announcement marked the beginning of the next phase of the closure project which is the regulatory phase. This begins with environmental and socioeconomic assessments under the Yukon Environmental and Socio-economical Assessment Act (YESSA). YESAA is a process unique to the Yukon that uses public input to determine the possible effects a proposed project might have on the Yukon’s environment, people, and economy. This act is under federal legislation and was developed by the Council of Yukon First Nations, the Government of Yukon and the Government of Canada (YESAB, 2011). The effects of the Faro Mine Closure Project are generally expected to be beneficial since the project objectives were designed to restore the land to natural uses, protect the health of the environment and humans, and provide economic benefits for Yukoners by means of training, jobs and business opportunities.

A series of public meetings held in Faro, Ross River and Pelly Crossing took place in February of 2009 to begin the socio-economic assessment (SEA) process. Representatives from the government of Yukon, INAC, affected Yukon First Nations and technical advisors made up the team responsible for conducting these meetings. The purpose of the meetings was to provide an update and general understanding of the recommended closure plan for the Faro Mine complex. The meetings were also held in order to commence the collection of the people’s input on the socio-economic and environmental issues related to the plan. A summary of the communities’ questions and answers was compiled and presented at subsequent meetings that took place the following May. Additional input from the communities was encouraged at these follow-up meetings as well. Feedback from the
communities is regarded as fundamental for ensuring that the final closure and remediation plan will meet the needs and expectations of Yukoners (FMRP, 2011).

9.0 The Next Steps
Currently, the final design of the Faro Mine final closure and remediation plan is underway. Regular meetings between the project personnel and the communities occur as part of the regulatory process pertaining to the Yukon Environmental and Socio-economical Assessment Act. Upon completion of a detailed engineering design for the remediation project, the plan can be submitted for regulatory approval process. This includes the YESAA process as well as obtaining the necessary land and water licenses. Based on the size of the Faro Mine Closure Project, the entire regulatory process is estimated to last approximately three years before the project is granted all the necessary regulatory approvals and permits. According to these estimates, the final closure and remediation plan is expected to be put into action in 2013 (FMRP, 2011).

10.0 Summary of Main Conclusions
1. The Faro Mine complex is a large site contaminated mostly by acid rock drainage and high concentrations of metals.

2. After more than 100 technical studies were conducted and community consultation had occurred several remediation options were put under review. Based on recommendations by an Independent Technical Review Panel, five remediation options were proposed for the final closure plan.
3. Of the five remediation options the alternatives involving the use of soil covers to cover waste rock piles and tailings were deemed most appropriate compared to the options involving the relocation of the wastes.

4. The risk of failure of the existing structures at the site was assessed to be low.

5. Treatment of water and maintenance of structures from the site will need to be done in perpetuity.

6. Consideration of the input and concerns of members of the local communities were regarded as necessary to properly conduct the mine closure process.
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Works Cited


Franssen, C. (2009). The effects of heavy metal mine drainage on population size structure, and condition of Western Mosquitofish, Ganbusia affinis. Archives of Environmental Contamination and Toxicology, 57 (1), 145-156.


