MINIMIZING ENVIRONMENTAL IMPACTS IN REHABILITATING SMALL REMOTE ABANDONED MINE SITES IN MANITOBA

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ABSTRACT

One of the main requirements of rehabilitating an old mine site is to safely secure and cap mine openings to ensure public safety. For remote sites, current options (such as concrete caps) are less effective from an economic perspective, and are generally associated with important environmental impacts mainly related to construction of access roads and development of working areas. This paper presents a relatively novel approach for shaft capping which was implemented in Manitoba at a large number of orphaned and abandoned mine sites, using polyurethane foam as sealant for mine openings and workings, such as shafts, adits, exploration trenches, and steep excavations that pose a threat to public safety. The paper presents criteria used in establishing a safe sealant medium, and presents a summary of the laboratory testing completed to confirm material performance, its physical, structural, and chemical characteristics. The paper also provides a comparison between the use of this technology and the more traditional concrete capping option. For remote sites, the new technology is significantly more efficient. Several case studies from Manitoba are presented where the use of polyurethane foam proved to have minimal negative impact on the surrounding environment, the solution being less invasive and resulting in minimal

ecosystem and ground disturbance. Recommendations for future uses and limitations of this technology are also provided.

Key Words: mine closure, polyurethane foam, shaft capping, adits, exploration trenches, rehabilitation

INTRODUCTION

In the year 2000, Manitoba's Orphaned and Abandoned Mine Site Rehabilitation Program was established in response to the Mine Closure Regulation adopted in 1999. The Orphaned and Abandoned Mines Program's (OAMS) mandate is to address public safety and environmental concerns associated with abandoned mine sites in Manitoba. The program received C$2 million initial funding to address safety issues and identity environmental concerns at five pre-established large high priority sites, and at another 148 inactive (orphaned and abandoned) mine sites (Priscu et al, 2010), as defined by the National Orphaned and Abandoned Mine Sites Initiative (NOAMI, 2001). For all these sites, ownership has been reverted back to the Crown, as former mining companies no longer exist or do not have the financial capacity to carry out rehabilitation work. The sites include sealed and open shafts, adits and accesses to underground workings, exploration trenches, open pit excavations, subsidences, unsafe derelict buildings and infrastructures, waste rock dumps and tailings disposal sites. Public safety hazards and environmental degradation are present at most of these sites.

A program was initiated by the Manitoba Mines Branch in 2001-2002 to identify location, ownership, previous inspections, availability of historical documents, and site conditions for the 148 sites, scattered throughout the Province. A priority-based rehabilitation program was needed, and a hazard-based framework model was developed, implemented and completed from 2005 to 2007 to rank the Manitoba sites and prioritize work in a consistent way, eliminating biased decisions as much as practically possible (Priscu et al, 2009). A total of 31 High hazard sites were prioritized for rehabilitation; a total of 14 small sites were rehabilitated from 2007 to 2009, another site was identified as having an owner and rehabilitation studies or construction work at an additional 16 sites is currently underway. The 14 mine sites rehabilitated from 2007 to 2009 had several similar characteristics and features in common: they were remotely located and with no major road access to the sites (though close to small communities and touristy/cottage country areas), all had old openings to the surface that posed major public safety hazards, and were away from major infrastructure (power, water, industrial zones, etc).

In trying to rehabilitate the sites, it became evident that a novel approach was required to seal and secure the openings, other than the traditional concrete capping methods that require construction equipment and vehicles to reach the site. In addition, many of these small sites are located in Provincial Parks or areas with dense vegetation; minimizing the footprint of the environmental impact and implementing sustainable environmental practices while rehabilitating the sites became a priority and a necessity. This is also in line with the green remediation initiatives recently identified and promoted by the U.S. Environmental Protection Agency (EPA, 2008). Manitoba Mines Branch and its consultant have evaluated and successfully implemented an alternative capping method using polyurethane material, which proved to be a more effective way of sealing the old underground openings and site features, as described hereafter.

BACKGROUND INFORMATION

Overall Project Context

A screening-level review and identification of all orphaned and abandoned mine sites in Manitoba was undertaken by Manitoba Mines Branch and AMEC Earth and Environmental (AMEC) from 2005 to 2007. A total of 148 Crown-owned mine sites were identified and located in Manitoba, although it is acknowledged that the exact number varies as ownership could change within a short period of time, especially during periods with high commodities prices such as the one experienced in the last several years. The vast majority of the mine sites are located in the Precambrian Shield, which is a major geological subdivision in central Canada that hosts gold deposits and producing gold mines. Most of the Crown-owned inactive mine sites reviewed as part of this project were identified as gold mines, with copper and nickel being secondary products at a limited number of sites. The majority of the Crown-owned inactive mine sites covered in this project were discovered, starting as early as the late 1890s, and most of them operated between 1911 and the late 1970s (Richardson and Ostry, 1996).

Throughout the course of this project (2005 to 2007), AMEC, the consultant retained to undertake the work, has reviewed and examined an extensive number of documents and sources of information, including discussions with residents of local communities around the old mine sites, exploration teams, trappers and hunters, geologists, miners, active mining and forestry companies, Rural Municipalities and Non-governmental agencies (NGOs), elders in near-by First Nations communities. This proved to be an invaluable source of information for identification of several old mine sites and their history. The project team also gathered information from various other jurisdictions (Federal and Provincial governments) on implementing similar projects (NOAMI, 2006). The purpose of this review was to research methodologies utilized elsewhere and, together with AMEC's own expertise, to establish and adopt the most relevant and efficient assessment and evaluation protocols for the Manitoba specific conditions.

Site Locations and Characteristics

Of a total of 149 inactive, Crown owned mine sites listed for Manitoba, 131 sites were identified in the field and visited, and included in a database. Most of the abandoned mine sites have limited access, due to their remote location, overgrown vegetation, or access roads in poor condition (swamps, dense bush, etc.). Field personnel used a variety of methods accessing the sites from trucks, ATVs to helicopter and floatplane. The outcome of the field reconnaissance program, carried out in conjunction with the desktop review of the 148 sites, was the following:

- A total of 131 individual mine sites were found, identified, and located;
- A total of 15 sites (or 12% of total) were extensively searched in the field but could not be found;
- Two sites were found in the Mines Branch files to be listed under two different names.

During the course of the project, a total of 31 sites were rated as having a High hazard rating for public safety and the environment. Of these, a total of 14 were rehabilitated to date: 10 sites from 2007 to 2008 and five additional sites from 2008 to 2009. One for the 14 sites was located in the Flin Flon region, while the rest were all clustered in Southeastern Manitoba in the Bissett, Bernic Lake, Long Lake, West Hawk

Lake, and Wanipigow Lake mining areas. All sites had at least one opening to the surface, from an operating shaft or vent raise, an adit or even exploration trenches that were up to 3.5 m deep. Openings varied in size and shape, most being rectangular. Some were fenced with some visible signage, but most were not fenced and had no signage. Fencing of open shafts or exploration trenches is not considered an acceptable long term solution for ensuring public safety, and capping or sealing of the features was required.

In terms of terrain morphology, it was noted that most were located in areas with undulating, gently sloping terrain; however, some were close to hidden ravines and terrain with steep slopes, sudden drops in elevation, unstable and unraveling material, and with limited visibility (heavily vegetated areas). Potential for ground subsidence was also noted as some locations.

Figure 1. Clinton Shaft, in Wanipigow Mining Area, Southeastern Manitoba

Figure 2. Packsack Shaft in the Bissett Mining Area Southeastern Manitoba

Accessibility to the site varied from very remote, reached through long hikes (minimum 1-2 hours through dense bush, to sites accessible by biking or hiking trails or back country roads, to ATV, boat, floatplane or helicopter access. Most sites were located close to small towns, cottage areas or tourist attractions (leisure activity centers, camping grounds, etc.). High hazard ratings were obtained for these sites mainly due to concerns related to public safety (from local community members to tourists and cottagers, including hunters, trappers).

Sites were therefore prioritized for immediate rehabilitation, including permanent capping and sealing of the mine openings and exploration workings.

SHAFT CAPPING AND SEALING OPTIONS

Several technologies were evaluated to be applied at these particular Manitoba sites for capping or sealing mine openings; these included concrete capping, metal capping, backfilling, or sealing using man-made materials. Concrete capping includes either cast-in-place or precast concrete cap placement. While these methods provide long life span (up to 60 years) and increase strength, they were not preferred at these sites because of various factors, discussed hereafter.

- Concrete capping of any kind requires a concrete batch plant in the area (or in close proximity from where concrete mix can be shipped), in order to obtain a good quality, long lasting concrete structure. This was not the case at most of the 14 remote sites. Concrete placement involves a detailed site preparation of the shaft collar, requires heavy equipment and transportation access to the site, detailed rebar reinforcement placement and solid support on the perimeter of the opening. For openings with irregular shapes, this also becomes a design and installation issue. Main concern in applying this technology was the lack of access roads to the sites and the established densely vegetated areas that needed complete removal around the mine feature. While some were accessed by ice roads, most sites had limited access in the summer months. The negative effect of vegetation removal, tree clearing and access road building for tens of kilometers weighted heavily against using this option.
- Metal capping is generally used as a temporary method and is not considered to provide a long term safe solution. For openings requiring large structural spans, the capping becomes very expensive and intricate designs are required. As for the concrete capping method, limited site accessibility and negative environmental impacts during construction were considerations against applying this method.
- Backfilling using waste rock or other loose fill materials was not considered a safe, long term solution. Potential for subsidence or settlement of the backfill would create additional hazards and expensive maintenance would potentially be required. Cemented backfill was not considered as an option, a batch plant would have been required, with a very strict quality control program being implemented during placement time.
- Sealing of the openings was considered using man-made materials. One of the options included cellular or foamed concrete, a light weight concrete (density around 800 kg/m^3, or 50 lbs/ft^3) which contains stable air or gas cells uniformly distributed in the mix. Use and placement of this material would have required heavy equipment access to the site, as well as a fresh water source with a suitable pH and chemical composition. Formwork requirements for shafts would also have been fairly complex. Use of polyurethane foam (PUF) as a sealant was also considered, as explained hereafter. Extensive experience with capping and sealing of mine openings at many abandoned mine sites in the United States of America (USA) provided a good understanding of material characteristics, application, and performance.

Given the remoteness of the sites and the limited access available, it became evident that an alternate capping and sealing technology was needed in order to avoid vegetation clearance and tens of kilometers of road construction in difficult terrain (swamps, creek crossings, steep terrain, dense brush), most of it in a Provincial Park setting. Based on comparison of all options available, the use of PUF material as a

sealant was selected and applied. The portability and effectiveness of the method proved to be crucial in its selection, helping to minimize the environmental footprint of the rehabilitation works.

POLYURETHANE FOAM (PUF) TECHNOLOGY

Composition

Polyurethane foam (PUF) was invented in the 1930s by Otto Bayer, and its early uses were to replace balsa wood as insulation material in airplanes and refrigerators. PUF is obtained by mixing two components: an isocyanate with a polyol resin.

PUF is a thermoset plastic, meaning that once the reaction is complete, the molecules are cross-linked and set, and the expanded material would retain its shape regardless of changes in temperature. Once reacted and protected from ultra-violet light (UV) and fire, PUF has an unlimited life expectancy.

PUF can be modified to have different densities, rigidity and closed cell content. Various degrees of fire resistance can also be achieved. The reaction characteristics can also be varied. The typical measured characteristics are:

- “cream time”: the time it takes to mix and start the reaction;
- “gel time”: the time the foam remains liquid;
- “rise time”: the time until the foam stops expanding; and
- “tack free” or de-mold time.

Being both exothermic and an insulator, care must be taken during installation to minimize the risk of scorching, melting or even burning the foam. The amount of UV degradation depends on density and the actual application, but in general UV will degrade foam. Based on that, most PUF installations are coated or covered with a light blocking material, which often doubles as a fire insulator.

PUF for mine closures is rigid and its typical density ranges between 2 and 3 pcf (32 to 48 kg/m^3). It is almost always produced from a binary liquid that can either be mixed by hand or with a machine known as a plural component sprayer, or pump.

The biggest change to the foam chemistry in the last two decades was probably slowing the back end reaction (gel and rise) down so the foam would flow better and fill a large, irregular void without blinding off and leaving gaps, especially at the perimeter of the feature. Spray foams usually have gel and rise times of a few seconds, but times of a few minutes might be more suitable.

There was also a move away from solvent blowing agents, which at the time, were ozone depleting. To achieve the required dimensional and altitudinal stability from water blown foam, higher densities were required, moving up from 2.0 to 2.6 pcf (32 to 41.6 kg/m^3). This had an added benefit of significantly increasing the strength and also brought the observed strength very near to the computed strength. Both in the field and the lab, load bearing capacities of 20-30 tons (196 to 294 kN) were achieved. Also with the

move toward 100% water blown foam, lightweight packaging became possible and two-part foam was made available in pre-metered plastic bags that can be easily transported to a remote site.

Figure 3. PUF raw two-part material delivered in 55 gallon drums.

Figure 4. Hand mixing and placing of PUF in an opening.

Over the past 25 years PUF has been used to plug shafts, adits, raises and portals. It has also been used to secure culverts for bat gates and to seal subsidence features.

Spraying foam is an equipment intensive process. The set up includes a generator, compressor, two 55 gallon drums (Figure 3), transfer pumps, a plural component proportioner, heated hoses and a mixing nozzle or gun. The gun must be capable of purging and cleaning itself of any chemicals or reacted foam. Still, when the volumes are large and features reasonably accessible, spraying or pumping the foam can be faster, and more cost effective than hand mixing and placement (Figure 4).

APPLICATION OF PUF AT MANITOBA MINE SITES

PUF technology was applied at 12 of the 14 sites rehabilitated to date, the remaining two sites not needing sealing of openings. In constructing the shaft seal or the exploration trench backfill, the following steps were followed:

- the required depth (thickness) of the PUF sealant was at least 1.5 times (sometimes up to 1.8 times) the largest dimension of the opening at surface;
- in general, two slightly different methods were used for hole preparation and bottom support. The first one was used in dry holes and involved lowering a tarp or tarps down to the proper level to provide a base for the foam to react on. The second was used on waterlogged holes and involved pumping out the water to the desired level and placing large pieces of reacted foam on the surface of the water to provide the base. Water was therefore used as base support;

- A 4 inch (150 mm) diameter pipe was placed vertically in the empty hole, its end reaching below the bottom/underside of the future PUF plug, to provide upward pressure relief both during construction and for long term; a prefabricated steel post was also placed in the opening, its bottom portion to be locked into the foam (post to serve later on as signage support);
- PUF was placed in layers and enough time was allowed between pours (usually between 15 and 20 minutes) to ensure the foam expanded and cured, i.e. the "rise time" was completed;
- Subsequent pours were completed up to about 0.2 m (8 in) below ground surface or collar elevation; all applications were done with spray equipment except for Le Vasseur which was hand poured;
- A thin layer of ReadyMix (non-structural, 100 mm thick) was placed and randomly mixed with larger pieces of waste rock found around the site to act as (an uneven) fire protection layer;
- Peat moss was spread over the site and its immediate vicinity, and tree branches and vegetation was placed randomly to allow some vegetation growth in the future;
- Pre-designed signage (as approved by the Mines Branch) was installed at the end.

There were numerous challenges associated with site access and placement of the PUF, some of which are described hereafter.

At Gatlan Shaft, the first and foremost issue was site access. As the site was on the shore of a lake, the original plan was to reach it by ice road. Unfortunately, due to climatic conditions and the time of year, this was not feasible. Therefore, all the product, equipment and personnel had to be flown in by helicopter or floated in by boat. On average this added approximately 2 hours of time each day to get back and forth from the site. Site access also hampered our ability to efficiently clear the site as it was impossible to get any heavy equipment to the site. Debris in the trenches and openings consisted of deadfall up to 200 mm (8 in) in diameter and dense brush. Since the contractor did not have anything suitable to lift the deadfall out, it required cutting it all up with a chainsaw and manually lifting it out, which was labor intensive. Foam placement on this site proceeded quicker than the other sites due to the fact that the trenches had a large surface area and were fairly shallow. It also helped that the trenches and the holes were close to one another, as this eliminated the time delays between applications. PUF was placed in one area, and the contractor would move on to the next one, while the foam was rising.

At Cryderman site, the work had to be done in two separate stages, one in the winter and one in the summer. This was due to the fact that one of the holes was in a low lying area and water management became an issue. Access to the site in winter time was straight forward, as access was provided by a narrow, pre-existing winter road. In the summer, however, access was a little more challenging as the winter road became muskeg. Equipment had to be ferried via swamp buggy and skid, and personnel had to go by quads. Winter foam placement was also relatively straight forward, the only minor challenge being the hoarding and heating of the hole. The site had to be kept fueled, which meant an extra trip to the site each evening to fill up the diesel heaters. In late spring, we found that water was a major concern. Excess surface water from the melting snow and the rain was entering the hole and there was a concern that this would disturb the application of the foam. A solution of installing weeping tile on one side of the hole to allow water to bypass the plug was proposed by the contractor and the engineer and was successfully implemented, thus concentrating flows in a small area of the perimeter of the hole.

(a) Pre-construction condition (b) Hoardings and heating (c) Completed

Figure 5: Winter rehabilitation at Cryderman Shaft, Long Lake mining area, Southeastern Manitoba

Le Vasseur Shaft, located in the Flin Flon mining area, was accessed by an ice road. At this site, the main challenge encountered was again from runoff collected from the surrounding snow which was freezing at the top of the road, making it so rough that any speed above 5 km/h was unfeasible. Since this opening was relatively small, and the ice road access was so rough, it was decided to mix and pour the foam by hand with a paint mixer rather than bringing heavy equipment to the site. While this proved to be adequate to get the job done in a less invasive manner for the environment, it was physically intensive. In hindsight, this method should be used only if necessary, and where small volumes of foam are needed at fairly remote sites. PUF application at Manitoba sites using spray equipment proved to be easier, safer, and resulting in a far more consistent product.

PUF field samples were collected at the above-noted mine sites and were tested in AMEC's laboratory. A summary of the laboratory test results obtained on the field samples is presented in Table 1 and indicates the ranges of values (minimum and maximum) for each property tested.

Specimens were taken at various locations below grade, and location, on site density measurements, air temperatures, and date were recorded. PUF material properties which are relevant for the application include density, compressive strength, tensile strength, shear strength and water absorption, with density and compressive strength being the most critical. The test results were used for quality control of the material installed in the field. All the densities and compressive strengths measured were within, or exceeded the typical PUF range reported by the manufacturer, regardless of the manufacturing location and pouring environmental conditions.

Table 1. Summary of the laboratory test results obtained for field EFS samples and comparison to manufacturer's data.

Property	Direction	Unit	Field sample		Manufacturer data	
			Min.	Max.	Min.	Max.
Density[1]	Average	kg/m^3	36.84	40.51	36.84	41.65
Compressive strength[2]	Parallel	kPa	151.75	217.57	151.68	227.53
	Perpendicular		141.52	210.86	68.95	179.26
Tensile strength[3]	Parallel	kPa	260.27	367.00	-	-
	Perpendicular		272.98	402.03	-	-
	Isotropic		-	-	137.90	206.84
Direct shear strength[4]	Parallel	kPa	74.18	93.76	-	-
	Perpendicular		70.87	82.18	-	-
	Isotropic		-	-	193.05	275.79
Water absorption[5]	Isotropic	%	0.46	6.24	0.05*	0.20*

Notes

[1] ASTM D1622

[2] ASTM D1621

[3] AMEC modified ASTM D1623

[4] AMEC modified ASTM D3080, Manufacturer ASTM C273

[5] AMEC ASTM D2842 Procedure B, Manufacturer ASTM D2842 Procedure A.

* kg/m^2

LESSONS LEARNED FROM THE MANITOBA EXPERIENCE

Advantages of Using PUF

There are many advantages for using the PUF over concrete or steel or other hydrating materials for sealing or backfilling mine features and surface openings (shafts, adits, vent raises), and some of them are discussed hereafter.

- Portability. PUF is very easy to transport and use at remote sites. It can be trucked to a near-by site, then it could be transported to the site using snowmobiles (in the winter), ATVs in the summer, or placed on a wooden pallet and dropped off using helicopters at the location of the opening. It could be delivered to the site either in bags or in drums. The typical expansion rate is in the range of 25-30 to one; for example, a pair of 55-gallon drums could hold enough chemical to make over 15 yd^3 (or 11 m^3) of PUF.
- Limited environmental impact at installation. For remote sites with poor access, seasonal narrow roads, or no access roads at all leading to the site features, this technology required limited or no vegetation or tree clearance. Based on the Manitoba experience, the impact footprint of the shaft sealing and trench backfilling operations was minimal in terms or road construction or upgrades, vegetation removal, and overall ground disturbance.

- Positive seal. Unlike backfilling, there is no need to fill the entire shaft, rather just build the plug at or near the surface. This also reduces surface water infiltration and maintains the integrity of the collar, providing a positive seal (through the expansion process). When this occurs, fractures and fissures in the rock are also sealed at the same time. PUF does not shrink and would not fail under its own weight.
- Light weight. Forming, mixing and pouring PUF proved to be easy and, because its internal cohesion is very good, pours can be completed in increments. PUF has a high strength to weight ratio and is essentially isotropic. At approximately one 50th the weight of concrete, it still has nearly half the tensile and shear strength of concrete.
- Inert material. PUF is an inert material, it does not erode, and it resists corrosion. Preliminary testing in acidic and basic environments (pH from 2.5 to 10.0; data not included in this paper) showed minimal, surficial impact and no impact on the structure of the final, expanded material.
- Overall strength. Although PUF strength is significantly lower than concrete strength, under vertical load, half the load is transferred horizontally. Therefore a plug exhibits adhesive, mechanical and frictional resistance. If loaded to or beyond its maximum compressive strength, PUF exhibits creep and a slow deformation rate, rather than a sudden, brittle failure. This is particularly important as the material is able to show an early warning in case a PUF plug is subjected to very high loads.
- Temperature resistance and freeze-thaw. Raw materials can be stored in sub-zero temperatures for longer period of time, provided that the two-part chemicals are brought and poured to at least + 5 ºC. Given the very small moisture gain due to its closed cell structure, freeze-thaw cycles will only affect the surficial portion of a plug. Materials tests conducted on PUF samples prepared both in the laboratory and in the field have shown that casting and curing temperature, especially low temperature, has an effect on the majority of the properties evaluated.
- Equipment-less placement. For small applications, PUF can be brought to the site, mixed and placed by hand, with limited (basic) tools and equipment. There is no need for water, power, or aggregate sources at the site location.
- Cost. When compared to traditional concrete capping of mine shafts, the overall costs of implementing PUF technology was estimated to be anywhere between 30% and 60% of a traditional method. Major cost items of concrete capping would have included a more detailed site preparation for a solid ground foundation, formwork, reinforcing rebars, as well as construction of access roads for most of the sites. Even with a very conservative life span estimate of 25 to 30 years for the PUF, the costs of installing and maintaining a polyurethane foam shaft seal would be equivalent to or cheaper than the ones for a concrete cap of its life span of 50 to 60 years. Even for an equivalent cost, PUF installation at remote sites was preferred in Manitoba, being less invasive and more environmental friendly application.

Disadvantages of PUF Technology

Based on the Manitoba experience in the last three years in implementing PUF technology, several disadvantages were noted.

- PUF is a flammable product. This is particularly important when rehabilitating mine features in heavily vegetated areas, where the risk of forest fires is much greater. For this reason, a fire

retardant layer is required at the surface to ensure flames to not reach or come in direct contact with the PUF. Additional costs are incurred, although the exposed surface of the PUF is relatively small (in most situations).

- UV protection. PUF does degrade when exposed to UV, however the degradation is limited to the first 1/8-1/4" and denser foams, like those used for mine closures, appear to be less susceptible. At the Manitoba sites, the fire retardant layer also acts as UV protection layer.
- Increased worker safety awareness. When placing the PUF, some noxious gases may be released (such as residual MDI) and additional precautionary measures may be needed to ensure air quality standards are met at all time. Air quality monitors should be used by every worker in the immediate vicinity of the work area.

Limitations

Limitations of this technology, as noted based on the Manitoba experience include the following.

- Ambient temperature. When consideration is given to using PUF in a Northern climate, it is important to note that ambient air temperatures at pouring time are recommended to be above the + 5 ºC mark. Pouring in sub-zero temperatures may limit volume expansion and could result in a PUF product with heterogeneous / layered internal structure and lower strength characteristics.
- Groundwater conditions. Shafts, vent raises and other openings to surface that are located in a very wet environment may not be suitable for PUF application. Surface runoff also needs to be diverted away from the opening, to ensure water ingress along rock walls will not hinder or lower the estimated bonding strength of the foam-rock interface.
- Impact of chemicals and water quality. Limited testing was carried out to date to evaluate the impact of various chemicals and trace metals that could be found at a mine site with heavy Acid Rock Drainage (ARD) generation on the integrity of the PUF. Although the PUF was noted to be structurally sound and stable in pH solutions between 2.5 and 10.0, additional testing is recommended to evaluate its long-term resistance to chemicals.
- PUF Life span. Current evidence exists on PUF applications at remote locations in harsh environments (extreme warm or cold temperatures, freeze/thaw cycles, etc), particularly in the USA (Colorado, Nevada, Missouri, Alaska). The oldest applications in a mining environment are since 1982 (approximately 28 years old). Although PUF is expected to last for many years (at least 25 to 30 years estimated for Manitoba sites), the material and the integrity of the plug need to be monitored in the future to better understand its long term performance.

CONCLUDING REMARKS

The rehabilitation of 14 small orphaned and abandoned mine sites in Manitoba over the last three years was successfully completed. Novel technologies related to capping and plugging of the old mine workings and openings were implemented to minimize environmental impacts during implementation of rehabilitation measures. Polyurethane foam (PUF) material was used to plug shafts, vent raises, exploration pits and trenches that posed a hazard to public safety, therefore lowering the overall environmental liability for the Province. Due to the remoteness of the mine sites, the PUF technology proved to be a more environmentally sustainable alternative to traditional concrete capping, its

implementation allowing for increased protection of the environment. This was of particular importance at most Manitoba site locations since most of them were located in Provincial parks, thus construction of lengthy access roads through densely vegetated and forested areas, vegetation removal, and disturbance of habitat and ecosystem were minimized.

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