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Use of engineered landfills for arctic mine site reclamation

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Abstract

One of the objectives of any mine site reclamation should be to minimise long-term environmental risk. Tailings and waste rock are typically the most problematic wastes generated during mining that must be addressed during closure. However, mine site reclamation generates many other types of solid waste including; hazardous waste, contaminated soil, and demolition debris. Hazardous waste such as fuel and process chemicals can be packaged and transported off-site for treatment and disposal at licensed facilities. However, demolition debris may have to be managed on-site because transportation of recyclable materials to market may not be economic. At remote mine sites, construction of an engineered landfill to manage solid non-hazardous waste may be required to minimise long-term risk to human health, wildlife and water quality. Design and operation of a solid waste landfill in an arctic climate presents some unique challenges. Recognising the short construction season in the arctic, it is important to not only carefully plan the site reclamation program but also have a technically suitable landfill design that can be constructed, filled and closed quickly. Depending on the size of the mine site and projected volume of solid waste requiring disposal in a landfill, it may be necessary to complete some foundation preparation and construction material stockpiling in advance of landfill construction. Siting options at a closed mine site that can be considered for construction of an engineered landfill include; open pit mine excavations, quarries, borrow areas, tailings areas, waste rock dumps, and natural topographic containment. If permafrost is present, it may be utilised to either create an impermeable liner or encapsulate the waste in ice. Finally after construction, annual post-closure geotechnical inspections should be carried out to demonstrate that the landfill is physically stable. Two case studies will be presented where engineered landfills were constructed and utilised for onsite disposal of solid waste generated during mine site reclamation in the Canadian Arctic.

1 Introduction

Mine development and operation generates many different solid waste materials. At closure these solid waste materials must be managed or rehabilitated to minimise long-term environmental impact and protect surface and groundwater quality. Most jurisdictions have regulations that specify minimum requirements for waste management during mine closure. For example, the Ontario Mine Closure Regulation specifies that:

> *All landfill sites and other waste management sites shall be rehabilitated; all tailings, rock piles, overburden piles and stockpiles shall be rehabilitated or treated to ensure permanent physical stability and effluent quality; and that closure plans shall include details of measures to rehabilitate all landfill sites and other waste management sites (O. Reg. 240/00).*

Solid waste landfills at mines do not always get much attention during the operating phase of the mine. Typically the risk of acidic drainage and metals leaching from waste rock dumps and tailings storage facilities overshadows the environmental risk of a solid waste landfill at mine sites. Existing solid waste landfills at mines are not always properly designed, constructed and operated making it is even more important for them to be properly rehabilitated at closure. Sometimes construction of a new engineered landfill is preferred over rehabilitation of an existing landfill to reduce post-closure monitoring and maintenance requirements. Furthermore, an engineered landfill minimises risk to human health, wildlife and water quality so may be more acceptable to regulators and stakeholders including First Nations.

Management of solid waste during closure of a remote, arctic mine site presents many unique challenges. This paper will review and discuss how engineered landfills can play a critical role in arctic mine site reclamation. For the purposes of this paper, references to solid waste do not include mine waste (e.g. tailings and waste rock) but include all other non-hazardous waste materials including demolition debris.

2 Waste management in the arctic

In addition to solid waste generated during operation of the mine, site reclamation generates other waste materials including; hazardous waste, contaminated soil, and demolition debris. Mine closure must efficiently and effectively manage both historic solid waste from operations and waste materials generated during site reclamation.

In accordance with regulatory requirements, hazardous waste such as fuel and process chemicals are typically packaged (Figure 1) and transported off-site for treatment and disposal at a licensed facility. It should be noted that some hazardous waste materials such as batteries, used oil and coolant can be recycled so transportation to a processing facility is not only necessary from a regulatory standpoint but has an added environmental benefit. Burning used oil for heating may also be an option with appropriate regulatory approval.

Figure 1 Hazardous waste prepared for transport to a southern licensed receiving facility (photo courtesy Aboriginal Affairs and Northern Development Canada (INAC, 2006))

However, it may not be economic to transport non-hazardous recyclable materials long distances from remote, arctic sites to market. Although there may be significant economic value in metal, steel and other recyclable materials recovered from demolished buildings, demolition debris generated at remote sites will probably need to be managed on-site because of high transportation costs. Furthermore, burning of wood from demolition may not be possible if it was painted with products containing lead or polychlorinated biphenyl (PCB). However, disposal of PCB-amended and lead-based painted wood in an engineered landfill is an environmentally responsible option. Management of demolition waste at a remote, arctic mine site may necessitate construction of an engineered landfill to minimise long-term risk to human health, wildlife and water quality.

3 Arctic landfill design

3.1 Design and operation of solid waste landfills in the arctic

Design and operation of a solid waste landfill in an arctic climate presents some unique challenges. A short summer construction season and extremely cold weather make constructing an engineered landfill very difficult in the arctic. Construction of a conventional compacted soil liner and then protecting the soil liner from freeze-damage can be very difficult in a cold climate. Furthermore, welding of geomembrane liner is not recommended in cold weather and therefore must be carried out during the very short construction season. In fact, during the winter months with extremely cold winter weather it may not even be possible to operate a typical engineered landfill with environmental controls. A solid waste landfill design and operation plan should always consider site-specific conditions including climate. Finally, because of the expense to operate a remote camp it is often advantageous to complete mine site reclamation, including solid waste landfill construction, over a one or two year period.

For these reasons it may be practical to construct, fill and close a landfill for mine reclamation waste over a single summer construction season. Recognising the short construction season in the arctic, it is important to not only carefully plan the mine site reclamation program but also have a technically suitable landfill design that can be constructed, filled and closed quickly.

One of the most important influences on landfill design in the arctic is the availability of construction materials. If suitable granular construction material is not available then bedrock may have to be quarried, crushed and screened to generate the required materials. If suitable low permeability soils are not available for liner or cover construction then consideration should be given to using a geomembrane liner or cover. Alternatively, frozen ground may provide a suitable containment barrier and/or cover if the mine site is located in an area with continuous permafrost. The following sections discuss various arctic landfill design considerations.

3.2 Waste inventory and landfill sizing

Prior to designing any landfill, an inventory of all waste materials and estimated volumes requiring disposal should be carried out. Estimates of waste volumes generated from demolition of buildings and mine structures, e.g. the headframe shown in Figure 2, must be included in the waste inventory taking into account an appropriate allowance for voids during placement in the landfill.

Figure 2 Former discovery mine headframe, Northwest Territories, Canada (photo courtesy Aboriginal Affairs and Northern Development Canada)

Properly estimating the volume of waste materials requiring disposal is important not only so the landfill is sized properly but also so that sufficient construction materials are prepared (e.g. granular stockpiles) and transported to sites (e.g. geomembrane) in advance. Also important to landfill design is quantifying the waste composition, physical characteristics and expected contaminants of concern. The type of solid waste being disposed in a landfill will determine the landfill design, environmental controls and post-closure monitoring required to protect the environment from landfill-related impacts.

3.3 Environmental controls

3.3.1 Base liner and/or final cover

Protection of surface water and groundwater quality are the primary purpose of environmental controls for an engineered landfill. Leachate is generated when precipitation is allowed to infiltrate into the solid waste. Leachate can be contained by placing a low-permeability soil or geomembrane liner beneath the waste however collection and treatment of leachate at a closed mine site is not preferred because it is an active option requiring long-term operation and maintenance of a water treatment system. It should be noted that typical mine water treatment systems for metals are not likely suitable for treatment of solid waste landfill leachate which contains both organic and inorganic contaminants. In general, the preferred option at remote mine sites is to prevent leachate generation in the first place by placing a low-permeability cover over the waste that minimises infiltration.

At arctic sites with continuous permafrost, landfills must be designed to protect surface water quality from leachate impacted runoff and shallow groundwater quality in the active thaw zone that discharges to surface water. Therefore minimising the generation of leachate is particularly important at arctic landfill sites. If permafrost is present, it can be utilised in landfill design three ways:

1. To create an impermeable frozen layer of soil beneath the waste.
2. To encapsulate the waste in ice.
3. To create an impermeable frozen cover to minimise infiltration.

If permafrost is not present or discontinuous, placing a low-permeability cover over the waste that minimises infiltration will minimise leachate generation. Placement of a low-permeability base liner can be combined with a cover to contain leachate and minimise leachate discharge to the underlying groundwater.

3.3.2 Landfill gas ventilation

The decomposition of solid waste normally generates landfill gas that must be considered in landfill design. However, landfill gas generation rates decrease at cold temperatures and may be negligible in frozen waste. This means that solid waste landfills located at an arctic mine site will not likely generate sufficient gas volume and quality to justify gas collection and utilisation, e.g. for heating or power generation. Nevertheless, provision of passive landfill gas ventilation pipes should be incorporated into any landfill design as a precautionary measure to prevent the accumulation of explosive concentrations of methane gas within the waste and beneath the final cover. Landfill gas ventilation pipes are particularly important where geomembrane liners are used as final cover to prevent the development of large bubbles of gas beneath the geomembrane. Passive landfill gas ventilation systems are preferred for closed mine sites to minimise long-term maintenance requirements.

3.3 Landfill siting options at a closed mine

After the required landfill size and environmental controls have been determined, the preferred site must be selected. All potential landfill sites should be considered and ranked against various criteria to select the preferred site. A landfill site should be located in close proximity to the waste requiring disposal to reduce haul distance but it should also have favourable geotechnical and hydrogeological conditions to mitigate environmental impact. Solid waste should not be placed into ponded water so a landfill site should be above the groundwater table and not prone to flooding. Ideally the bottom of waste should be well above the groundwater table so that aerobic natural attenuation of organic contaminants can occur beneath the waste.

Landfill site options that could be considered at a closed mine may include:

- Open pit mine excavations.
- Quarries.
- Borrow areas.
- Tailings areas.
- Waste rock dumps.
- Natural topographic containment.

Landfill design and environmental controls for the selected site must ensure protection of surface water and groundwater quality. At a closed mine where suitable landfill site options are limited, it may be necessary to mitigate potential environmental impact with engineered environmental controls.

4 Arctic landfill construction considerations

4.1 Construction schedule considerations

The arctic has long, cold and dark winters that are not suitable for earthworks construction or geomembrane placement. However, during the summer months there can be almost 24 hours of daylight in the arctic. This means that there may be opportunities to work more than 12 hours a day in the arctic with sufficient work crews. At remote sites where demolition of all existing mine facilities is planned, provision of a temporary camp may be required for the duration of the mine closure program. In addition, mobilisation and rotation of work crews to a remote site requires significant logistics and planning.

Construction progress at a remote site can be significantly impacted by the availability and efficiency of construction equipment. An operating mine that is being closed may have excavators and haul trucks that can be used for mine closure earthworks including landfill construction. If older construction equipment that is near the end of its operating life is available then allowances for increased maintenance and lower productivity should be made. However, reclamation of an abandoned mine site that has not operated for many years may require mobilisation of construction equipment at significant cost. In this case, the construction schedule may be limited by equipment availability, e.g. fewer haul trucks.

4.2 Site and construction material preparation

Depending on the projected volume of solid waste requiring disposal and the required landfill size it may be necessary to complete some foundation preparation and construction material stockpiling in advance of landfill construction. Particularly if filling the landfill and final cover construction is planned during a single summer construction season. Suitable granular and bedding material may have to be manufactured by crushing quarried rock or screening gravel pit borrow material. To meet the proposed construction schedule it may be necessary to generate sufficient stockpiles of processed aggregate the year before landfill construction is planned. It may also be possible to so some preparatory clearing, grubbing and foundation excavation at the proposed landfill site in advance.

4.3 Transportation of imported construction materials to remote sites

Purchase and transport of imported geotextile and geomembrane liner to remote, arctic mine sites must be planned well in advance of the construction season, particularly if access to the mine site is by winter ice road or by water during a short ice free shipping window where imported construction materials may have to be purchased and transported to site more than one year in advance of construction. If special imported materials are being transported to site in advance of construction, care must be taken to ensure they are not damaged during unloading and storage at the mine site.

If transport by road or water is not possible then it may be necessary to fly some imported construction materials to site by fixed-wing aircraft at significant cost. When construction materials are being flown to site consideration must be given to maximum aircraft cargo dimensions and weight. For example, it may not be possible to fly large rolls of geotextile or geomembrane to site by fixed-wing airplane. Some more flexible geomembrane liner materials, such as polyvinyl chloride (PVC), can be folded and rolled to fit into wooden crates that can fit into small fixed-wing airplanes, if required.

5 Post-closure inspection and monitoring of engineered landfills

Finally after landfill construction is completed, annual post-closure geotechnical inspections should be carried out to demonstrate that the landfill is physically stable. The primary objective of post-closure geotechnical inspections is to assess the physical condition of landfill for evidence of slope instability or erosion that could expose waste and present a safety hazard to either humans or wildlife.

Environmental monitoring at arctic sites where there is permafrost typically focuses on surface water quality as groundwater only exists in the seasonally thawed active zone. Surface water quality monitoring may be a condition of water and land-use permits associated with northern mine projects.

If the landfill design relies on permafrost then ground temperature monitoring should be carried out with thermistors to confirm encapsulation of waste and final cover in permafrost as intended by the design.

6 Case studies

6.1 Former Polaris Mine, Nunavut, Canada

The former Teck Cominco Polaris Mine produced 25 million tonnes of lead-zinc ore between 1981 and 2002. Prior to being decommissioned in 2003 and 2004, Polaris was the most northerly base metal mine in the world located on a remote island 80 km north of Resolute Bay, Nunavut. Decommissioning and reclamation of the site involved demolition of all structures including removal of a deep sea marine dock and excavation of soils contaminated by metals and hydrocarbons (Donald, 2010).

Demolition waste and contaminated soil was either placed underground, i.e. in the mine workings, or into two engineered landfills at surface. One landfill, referred to as the Little Red Dog Quarry Landfill (Figure 3), was sited in a limestone quarry that was excavated during mine development and operation. Closure of an existing landfill, referred to as the Operational Landfill (Figure 4), involved relocating solid waste generated during mine operations upslope more than 80 m away from the ocean shoreline and covering the waste with a thick rock fill cover. Both of the landfills at the Former Polaris Mine were designed to utilise permafrost to encapsulate waste in ice beneath a thick rock fill cover and ensure that the decommissioned mine site does not present long-term environmental risk.

Post-closure geotechnical inspections have been carried out to visually assess the physical condition of the two engineered landfills at the former Polaris Mine for evidence of slope instability or erosion that could present a safety hazard to either humans or wildlife. Ground temperature data measured by thermistors installed at the two landfills indicate that the waste is frozen and that permafrost has extended up into the overlying rock fill cover as designed. Seven years of post-closure annual geotechnical inspections and ground temperature monitoring have demonstrated that the landfills are physically stable and functioning as designed.

Figure 3 Rock fill cover, Little Red Dog Quarry landfill, former Polaris Mine, Nunavut (photo courtesy D. Johnson (with permission of Teck Resources Ltd.))

Figure 4 Rock fill cover, operational landfill, former Polaris Mine, Nunavut (photo courtesy D. Johnson (with permission of Teck Resources Ltd.))

6.2 Former Discovery Mine, Northwest Territories, Canada

The former Discovery Mine, located approximately 80 km northeast of Yellowknife in Northwest Territories (NWT), was operated from 1949 to 1969. When mining operations ceased in 1969, acid-generating tailings containing mercury, mine buildings containing asbestos and lead-based paint, unsealed mine openings and hydrocarbon contaminated soil remained at the mine site that posed health and safety risks. The initial remediation work occurred between 1998 and 2000 and involved the capping of the tailings using a low-permeability clay cover and waste rock as well as some general clean-up of the site (INAC, 2008).

Nearby Aboriginal communities were involved with subsequent environmental site assessment and development of a closure plan that was implemented during the summer of 2005. The primary goal of the mine closure plan was to return the site to a safe condition for hunting, trapping, and fishing, and for the protection of wildlife and the environment.

Hazardous waste materials were collected, consolidated, and transported to Yellowknife on a winter road for offsite disposal at licensed facilities. Buildings and mine structures were demolished and non-hazardous waste materials were placed in an engineered landfill constructed, filled and closed during the 2005 construction season. Heavy construction equipment, rolls of geotextile for the landfill cover and temporary camp facilities were mobilised to the site via a winter road. Large stockpiles of granular aggregate were manufactured in advance of landfill construction. Because the site is in an area of discontinuous permafrost a geomembrane cover was selected to minimise infiltration into the waste rather than rely on permafrost to encapsulate the waste and minimise infiltration. Drainage ditches were constructed around the landfill to divert surface water and further minimise infiltration into the waste.

Factory fabricated panels of polyvinyl chloride geomembrane liner specially formulated to remain flexible at cold temperatures for the landfill cover were placed over the waste to minimise infiltration of precipitation into the waste. Figure 5 is a photograph of a PVC geomembrane panel being unrolled over an underlying geotextile cushion layer. The geomembrane panels were field welded together and then covered with a second geotextile cushion, a granular bedding layer and an inert armour stone layer to resist erosion and protect the geomembrane from damage. Passive landfill gas ventilation pipes were installed through the final cover to prevent accumulation of methane gas beneath the geomembrane.

Figure 5 Unrolling geomembrane panel for landfill cover at the former discovery mine, NWT (photo courtesy D. Johnson (with permission of Aboriginal Affairs and Northern Development Canada))

7 Conclusion

As exploration activity continues to identify new mineral deposits in remote, arctic locations there will continue to be new mine development in the far north. Global warming is expected to open shipping channels through the Canadian Arctic Northwest Passage that will also improve access for mine development. Closure plans that consider solid waste management are a requirement for approval of these new mines. In addition, historic and existing mines that have not been closed will require future reclamation.

However, as fuel and transportation costs increase, responsible disposal of solid waste generated during mine reclamation in engineered landfills is expected to become a more important aspect of successful mine closure. Engineered landfills have already played an important role in the successful reclamation of several mine sites in the arctic offering valuable experience that can be applied to future mine closure in the arctic.

A low-permeability landfill cover that has been properly designed for the site-specific conditions and climate will minimise leachate generation and should prevent surface water quality impacts. Geotechnical post-closure monitoring of a landfill site can provide regulators and other stakeholders with increased confidence that the landfill cover is physically stable and functioning as designed. Surface water and groundwater quality monitoring down gradient of a landfill provides further assurance that leachate is not being discharged from the landfill and impacting the environment. With proper design and post-closure monitoring, engineered landfills can play an important role in the reclamation of remote, arctic mine sites.

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