Development of a Technical Guidance Document for Cover System Design in Cold Regions

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Abstract

The contaminated sites program of Aboriginal Affairs and Northern Development Canada (AANDC) is responsible for closure of contaminated sites on Crown land throughout the Canadian north. A significant percentage of the closure liabilities faced by AANDC are associated with abandoned mines. Of these mine-related liabilities, at least one third involve the need to construct earthen cover systems over potentially reactive tailings and waste rock. AANDC will be implementing cover systems at some sites in the very near future and therefore requires information on key physical, chemical, and biological processes that may affect long-term risk to these cover systems. This paper outlines the technical guidance approach for cover systems in cold regions that is being developed by AANDC with the assistance of a Technical Advisory Group (TAG). Cover system design philosophy is discussed including the need to develop site-specific closure objectives and criteria, mine closure planning and progressive reclamation, utilizing attributes of cold regions, designing for sustainability, importance of final landform design, and assessment period and design life. Additionally, construction and implementation issues for covers in cold regions are described, including availability of cover materials, revegetation issues, and considerations for designing surface water management systems.

Introduction

The contaminated sites program of Aboriginal Affairs and Northern Development Canada (AANDC) is responsible for remediation of contaminated sites on Crown land throughout the Canadian north. A significant percentage of the remediation liabilities faced by AANDC are associated with abandoned mines. Of these mine-related liabilities, at least one third involve the need to construct soil (earthen) covers over reactive tailings and waste rock.

AANDC anticipates that cover systems will be implemented at some sites in the very near future, and therefore they require additional information on key physical, chemical, and biological processes that affect long-term risk to these cover systems. The appropriate design and long-term effectiveness of earthen covers in cold regions is therefore of central importance to AANDC, as well as to local and regional stakeholders.

The Mine Environment Neutral Drainage (MEND) program recently completed a Phase 1 review of soil covers on mine wastes in cold regions (MEND 1.61.5a 2009). Several dozen cold regions processes were identified as potentially significant for soil covers. The most widespread are ground freezing and ground ice formation, ground thawing and associated settlement, and freeze-thaw cycling. Combinations of these processes with specific soil or hydrologic conditions can change soil properties, such as compaction and permeability, or lead to the development of macroscopic features, such as solifluction, cracking, mounding or hummocks, or mudboils. These effects can develop slowly enough that they may not be obvious in current observations of soil covers, but quickly enough that they might have significant effects over a cover's design life.

Following on the findings and conclusions of MEND 1.61.5a (2009), a Phase 2 of the study was undertaken (MEND 1.61.5b 2010), which involved various tasks in support of advancing the state of cold regions cover research. These tasks included:

- Characterizing the cold regions phenomena identified in the Phase 1 report as 'observed', 'suspected', 'expected' or 'not expected' to affect the performance of various types of soil covers;

- Reviewing the role of vegetation on cold regions covers, including available literature on cold regions evapotranspiration and rooting depths;
- Reviewing the state-of-the-art computer modelling of cold regions soil covers and related hydrologic processes;
- Examining possible applications of convective cooling in both rock piles and cover systems using a series of bounding calculations;
- Examining the potential for insulating layers to limit freeze-thaw effects on low-permeability barrier layers; and
- Identifying and tabulating ongoing soil cover trials or research programs in locations that might experience cold regions effects.

AANDC's next course of action was to lead the development of a guidance document for covers in cold regions. This document not only outlines the current state-of-knowledge of cover design in cold regions but the expectations of AANDC on how a cover design process should be conducted and what information AANDC expects to receive during the design process so that an informed decision on the best cover design can be made. In particular, AANDC requires that critical questions in regards to cold region cover systems be addressed: i) what are the key processes that will affect performance of different types of cover systems within a cold regions context; ii) how should the design process incorporate these issues; and iii) what are the risks to long-term performance as a result of these cold regions phenomena. The present paper describes the cover design philosophy and discusses construction and implementation issues that apply to the cover system design in cold regions. These topics are part of the technical guidance document.

Key Attributes of Cold Regions

In the context of mine waste covers, an appropriate definition of cold regions would include any area where there is a regular occurrence of ground frost sufficient to affect cover performance. Actual data on frost depth is limited (Andersland and Ladanyi 2004). Therefore, frost depth is often estimated from the freezing index, which uses only meteorological data to assess the combined duration and magnitude of below-freezing air temperatures during a year (Brown and Kupsch 1974). Freezing indices can only be used to approximate frost penetration as many other factors such as soil mineral and textural composition, snow cover and vegetation also affect frost depth. To generalize, most regions where ground frost affects cover performance are areas with significant seasonal frost and/or discontinuous permafrost as well as areas with continuous permafrost. A permafrost map of Canada is shown in Figure 1.

Cold regions typically experience extreme climate, the most obvious of which is prolonged cold air temperatures. Site climate is extremely important to the performance of cover systems, and along with the availability of cover materials, is one of the two key inputs to cover design. In temperate regions, the importance of climate relates predominantly to moisture transfer between the atmosphere and the ground. In cold regions, the importance of climate extends to heat transfer between the atmosphere and the ground. Other cold regions climate factors affecting cover performance include snow cover, surface radiation, convective heat flow, evaporation, and condensation.

In cold regions, there is a distinct link between climate and the ground surface. Extreme climatic conditions result in the ground surface reacting in ways not experienced in other temperate regions of the world. Washburn (1973) stated that where a climate is sufficiently cold it will leave physical evidence of its influence. Common terrain features associated with cold regions include:

- Ice wedges,
- Pingos and palsas,
- Thermokarst,
- Patterned ground,
- Boulder fields / pavements,
- Mounds and/or hummocks,
- Mudboils, circles and diapirs, and
- Involutions.

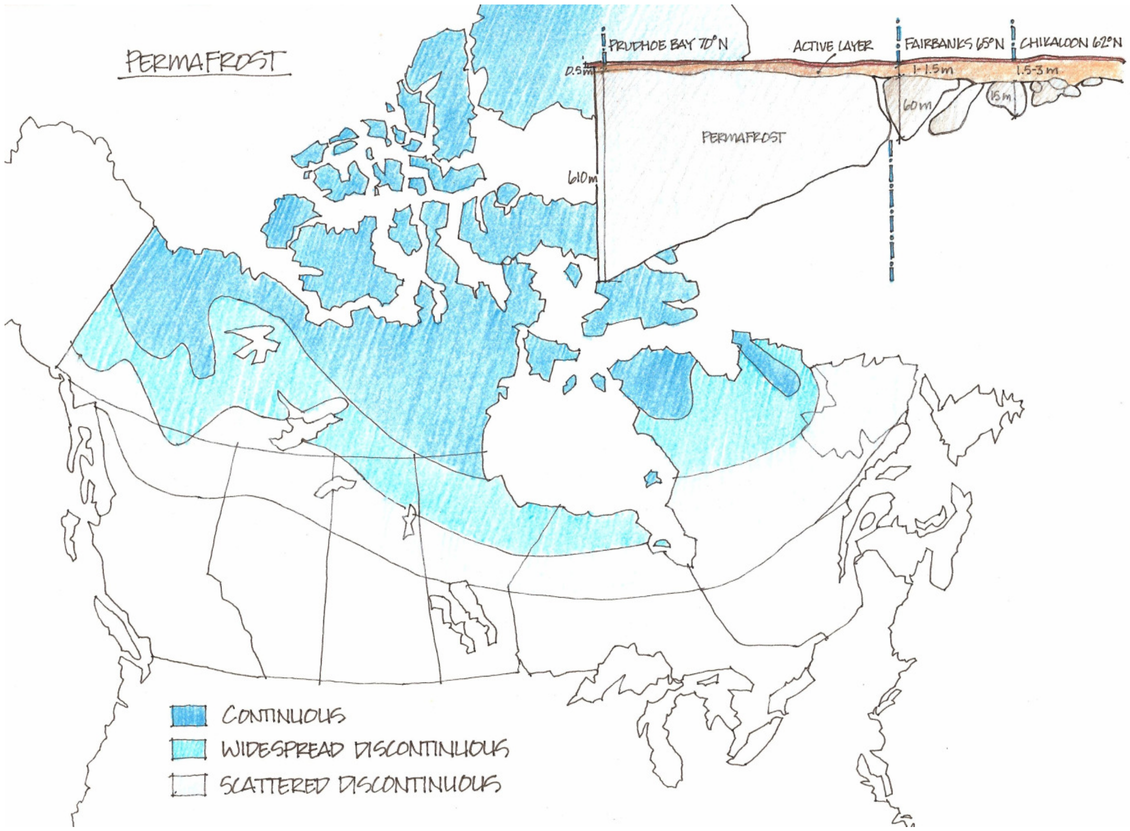

Figure 1. Permafrost regions in Canada.

MEND 1.61.5a (2009) includes a description of each of the above terrain features. The significance of frozen ground phenomena for cold regions covers will depend on the time scales under consideration. Some of the features and processes that have the greatest impact on cover design in cold regions are illustrated in Figure 2.

Cover Design Philosophy for Cold Regions

Cover design objectives

Several factors influence and often dictate the design objectives of a cover system. The key factors for covers in a cold region include:

- Surface energy balance,
- Surface water balance,
- Geochemical and geotechnical characteristics of the waste material, and
- Hydrogeological setting of the waste storage facility.

The ground surface undergoes constant exchanges of mass and energy. In cover design, mass fluxes are largely water and vapour fluxes and are commonly evaluated using a water balance. In cover design for warmer climates, energy balances are usually only considered pertaining to movement of water vapour through the cover profile. However, for colder climates, energy balances are of greater importance to estimate ground freezing and thawing. The depths of ground freezing and thawing strongly influence the hydrological processes that occur, such as infiltration and redistribution of meltwater (Zhang *et al*. 2008).

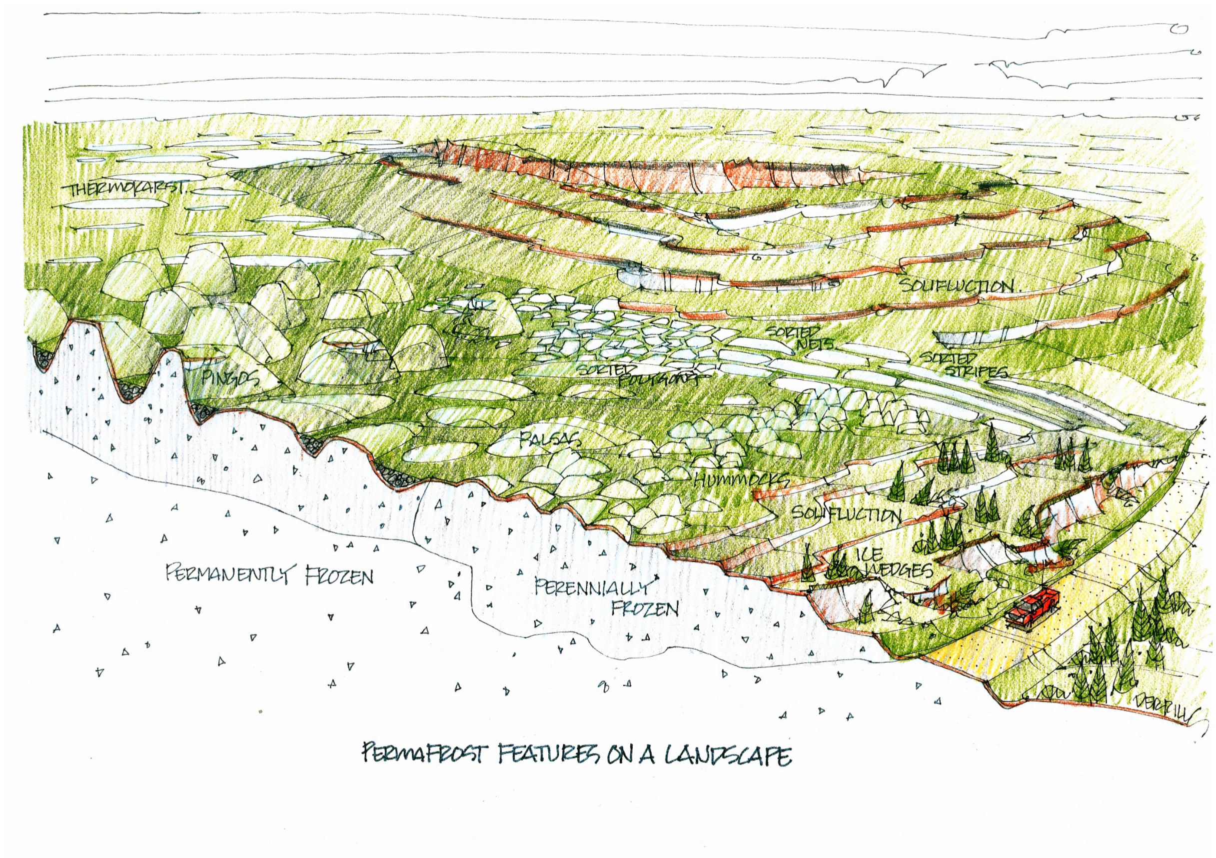

Figure 2. Cold regions processes affecting cover performance in cold regions.

Yamazaki *et al*. (1998) reported that the daily frost depth in the ground depends much more on the temperature profile inside a snow cover than on soil water content (at least when the volumetricwater content was more than 0.1) or on vegetation. Solar radiation, thermal radiation, sensible heat flux, latent heat flux including phase change, soil heat flux, and advection are key processes for energy exchange between soil covers (land) and atmosphere. These factors vary temporally and spatially, which leads to temporal and spatial variability of a surface energy balance, and hence cover design objectives, in cold regions.

The surface water balance of a soil cover in all climates is associated with precipitation, runoff, evapotranspiration, and infiltration. Surface water balance evaluation is crucial for soil cover design because maintaining low infiltration rates can result in low contaminant loading to the environmental receptors. Cold regions generally experience seasonal precipitation with large snowfall in winters. Snowmelt in spring and/or summer may result in high water infiltration into the underlying wastes; therefore, cover design in cold regions should consider surface water balance for extreme climates.

The geochemical and geotechnical characteristics of the waste material could have significant influence on cover design objectives. For example, controlling contaminant release and provision of a growth medium may be the cover design objectives for a reactive waste rock pile while providing a growth medium could be the main objective for non-reactive tailing such as oil sands tailings.

The hydrogeological setting of the waste storage facility provides pathways for contaminants released from the waste material to the final environmental receptors. A relatively sealed hydrogeological setting could reduce the risk of the contaminant moving to the environmental receptors, thus benefiting the cover design and design objective.

The objectives of a cover system may vary from site to site but generally include:

1. Dust and erosion control,
2. Chemical stabilization of mine waste (through control of oxygen or water ingress),

3. Contaminant release control (through control of infiltration), and
4. Provision of a growth medium for establishment of sustainable vegetation.

Dust and erosion are typically minimized through placement of a material layer suitable for growth of vegetation to stabilize the soil. In cold regions, vegetation establishment is slow and may or may not be of sufficient density to control erosion in the long term. Mulch can be used to temporarily stabilize the surface; however, long-term erosion control in cold regions may require alternative controls such as placement of gravel to resist wind erosion and coarse rock riprap to resist water erosion.

The principal mechanism used to inhibit oxygen ingress is to utilize the low rate of oxygen diffusion through water. Cold regions processes and material availability reduce the ability to design a cover based on the development of tension-saturated conditions within a cover layer. Water covers in cold regions were outside the scope of the technical guidance document.

Limiting the net infiltration of water into the waste in cold region covers follows most of the same guidelines as in more temperature climates. The processes of creating a low hydraulic conductivity layer and/or utilizing the store-and-release concept are typically considered. In cold regions, the limitations on these designs are material availability processes affecting barrier layer integrity. A method of limiting infiltration can be taken advantage of in cold climates where the waste material can be frozen into the permafrost. At freezing temperatures, most of the soil water changes to ice and subsequently has a lower hydraulic conductivity. The applicability of this method is a function of the local climate.

Establishment of vegetation is generally more challenging on reclaimed sites in cold climates than in warmer regions, as short frost-free periods restrict the window for revegetation activities, the rate of vegetation establishment, and the range of plant species capable of colonizing and persisting on a site. Primary challenges in cold region revegetation include: (1) limited species selection and availability, (2) slow rate of vegetation establishment, and (3) restricted or negligible availability of growth medium materials.

The cover design objectives should be site-specific. Site-specific objectives allow the needs of all the stakeholders to be included in the design process from the beginning. With clearly defined objectives, the cover designer has a more defined scope to proceed with the site and material characterization and the development of the conceptual cover designs. The cover objectives may need to be revised based on field and performance information.

Utilizing attributes of the Canadian North

Historically, many cold region covers have been designed based on experience and technologies developed for temperate regions. It is then hoped that the cover design will not fail over time due to differences in the climatic and geologic setting between the north and south. Where possible, cold region covers should be designed to take advantage of the climatic and geologic setting inherent to the north. Key attributes of the Canadian north pertinent to the design of a mine waste cover system include:

- Low precipitation in the form of spring snow-melt and summer storm events relative to most other parts of Canada;
- High actual evapotranspiration (AET) rates compared to typical rainfall amounts during the summer months due to warm temperatures and long daylight hours;
- Prolonged, cooler temperatures during the winter months that can result in deeper frost penetration;
- Glacial deposits of relatively coarse-textured soils, which are less susceptible to frost action and may be suitable for a capillary break layer;
- High runoff coefficient in the spring when only the upper surface has thawed; and
- Surfaces are covered by snow and ice most of the year, thus limiting exposure.

Taking into account the above attributes, where possible, designers should consider incorporating the following elements into a cold region cover design:

1. Divert snow-melt waters to the greatest extent possible by incorporating topographic relief in the final landform design and/or incorporating a seasonally frozen layer;
2. Maximize AET rates during the summer months by establishing vigorous vegetation covers (where possible). This establishment and subsequent water removal can be enhanced by incorporating

organics or fine-textured mineral materials, where available, in the upper cover profile to increase the amount of available soil water for plant and atmospheric demands;

3. Encourage deep freezing of the waste material where possible to minimize percolation of meteoric waters through the waste material;
4. Use compacted coarse-textured materials to achieve relatively low hydraulic conductivity due to the negative effects of frost action on fine-textured materials such as compacted silt / clay or compacted sand-bentonite within the active zone;
5. In tailings covers (saturated waste), address the potential for post-cover construction deformation due to freezing of contaminated water;
6. If required, liners must be installed where they are not subject to freeze-thaw processes; and
7. Consider the cost benefit of post-closure sustainability into upfront cover investment in relation to proposed design life.

Designing for sustainability

The longevity of a cover design in cold regions should be evaluated in relation to site-specific physical, chemical, and biological processes that will alter as-built performance and determine long-term performance (See Figure 3). Some physical processes include erosion (water and wind), frost heave, frost degradation (thermokarst), slope instability, wet/dry cycles, freeze/thaw cycles, consolidation, extreme climate events, and brushfires. Chemical processes include osmotic consolidation, dispersion, dissolution, sorption, acidic hydrolysis (chemical weathering), oxidation, salinization, and mineralogical consolidation. Biological processes include root penetration, burrowing animals, bioturbation, human intervention, bacteriological clogging, vegetation establishment and physiology. It is noted that, in many respects, the impact of biological and chemical processes specific to a site on long-term cover performance can only be evaluated from a qualitative perspective. In contrast, many of the physical processes affecting long-term performance are quantifiable using state-of-the-art technology, provided that adequate material characterization data are available. Recent reviews based on 10 to 15 years of cover performance data indicate that covers may limit, but do not stop, infiltration and sulphide oxidation (Wilson 2008, Wilson *et al.* 2003, Taylor *et al.* 2003). However, the achieved reduction in oxidation (and ARD and metal leaching) may be sufficient to meet design goals and, at a minimum, would reduce water treatment requirements.

An additional consideration for the long-term sustainability of cover system performance in cold regions is reduction of permafrost associated with climate change, more specifically warming in northern latitudes. Melting of permafrost has raised concern in the scientific community; in relation to cold region soil covers, permafrost offers several benefits for cover performance, which include impediment of vertical drainage, negatively affecting infiltration rates and increasing levels of runoff (Carey and Woo 2001). If permafrost and its associated benefits were to disappear, it is unlikely that the cover would fail. In this instance, failure is an iterative process and should be viewed as a probability curve that highlights the probability of the cover system being able to 'supply' the appropriate conditions to support the desired vegetation and achieve cover performance objectives (Elshorbagy and Barbour 2006). A warmer northern climate and associated permafrost melt would most likely result in conditions more suitable for a larger variety of vegetation and/or vegetation that transpire water at a higher rate (taller shrubs and trees). As such, increased soil moisture and available water holding capacity (AWHC) due to permafrost melt could shift the site capability to a wetter system, where another community could occupy the site over another operative edatopic range.

Importance of final landform design

Final landform design is an important consideration for designing cover systems for waste storage facilities located in cold regions. Poor surface water management and landform instability are common factors leading to failure of cover systems around the world (MEND 2.21.4 2004). The primary reason for this is a design approach that attempts to build engineered structures to oppose natural processes rather than developing engineered systems based on natural analogues that integrate rapidly with the surrounding hydrologic and ecosystems following implementation (Ayres *et al.* 2006). Careful consideration must be given to the planned final landform for a waste storage facility to ensure that performance of a given cover system can be sustainable over the long term.

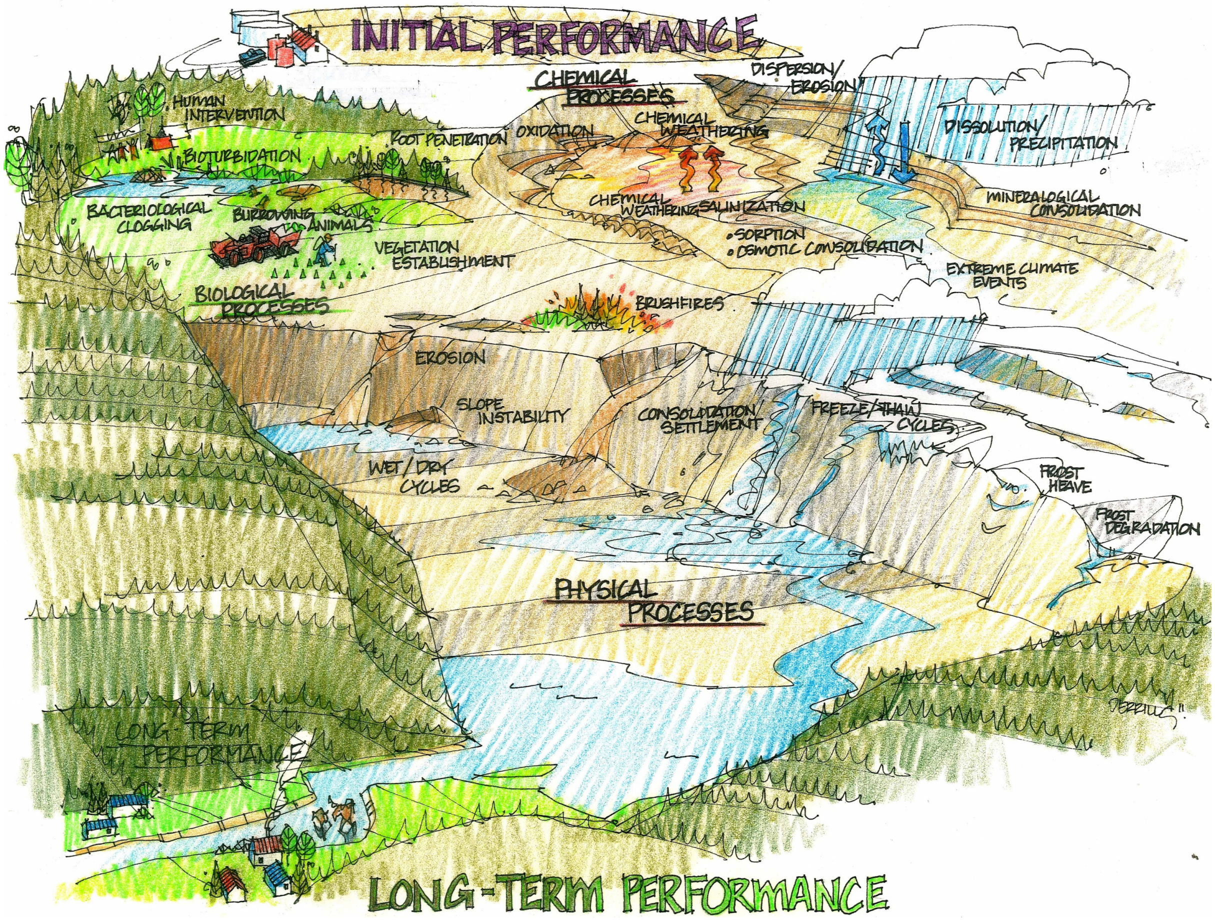

Figure 3. Conceptual illustration of processes affecting long-term performance of cover systems in cold regions.

The final landform design (including the cover system) depends greatly on the mine closure objectives established by the stakeholders. Generally, the reclaimed landscape must be returned to a productive land use. Examples include wildlife habitat, traditional uses by aboriginal communities, and commercial forestry. Successful reclamation will not 'restore' a landscape but rather provide conditions for a landscape to 'develop' towards a capability equivalent to that existing prior to mining (MEND 2.21.5 2007). The priorities of general landform design are to create a stable landform, and have the landform meet slope and shape criteria determined by the land-capability requirement. After these criteria are met, additional details can be incorporated, such as the cover system and drainage channels.

Landscape design is dependent on numerous factors, including climate, geology, soils, local hydrogeologic patterns, topography and final land use (MEND 2.21.5, 2007). A large challenge concerning landform design is the long timeframe of interest, in the order of hundreds to thousands of years. The changes that will occur during this period are difficult to predict and quantify, yet will affect the system. Often, the methods to achieve a stable landform in a cold regions climate have more complex consequences than in more temperate climates. For example, it would be ideal to limit snowpack development on a waste storage facility from an environmental loading and erosion perspective; however, this results in the cover profile being more susceptible to freeze/thaw cycling, which could have detrimental impacts on long-term performance. Increasing the thickness of snowpack through reduction of wind drifting will reduce the thickness, and thus construction cost, of a growth medium layer designed to prevent frost penetration into an underlying barrier layer. However, this creates a challenge in dealing with large spring melt runoff.

Assessment period and design life

Cover design practitioners, through consultation with AANDC and regulatory agencies, need to determine an appropriate period for assessing post-closure performance of various cover design alternatives. Philosophically, remediation of a mine waste storage facility should generate a 'walk-away' solution, with an infinite lifespan. However, as with all engineering, anything that is 'designed' is also subject to failure and therefore has a fixed lifespan. Cold regions, in general, have a lower population density and are more remote than warmer climates. Therefore, the ability to perform long-term monitoring is decreased and the ability to provide mitigating measures, should they be necessary, is also decreased and more expensive. For this reason, the assessment period for a cold region site should be longer compared to that typically used for sites in temperate regions.

The concepts for the assessment period and design life are different. The design life of a product or structure is the period of time during which the item is expected by its designers to work within its specified parameters; in other words, the life expectancy of the item. While the assessment period is a timeframe during which the designed product or structure is evaluated with extreme events and no catastrophic failure is expected to happen. In general the design life is shorter than the assessment period. For example, a cover system may be designed for 100 years but assessed for 1000 years; in other words, the cover system is expected to maintain performance for 100 years and will not undergo catastrophic failure (high hazard) for 1000 years. The purpose of the assessment period is to evaluate the necessary maintenance on the basis of the assessment period for the probability of catastrophic failures and/or other high hazards. Funds need to be set aside to repair the product for the duration of the assessment period, if necessary.

The selection of the assessment period and design life depends on the regulatory requirement, cover design objectives, closure planning, and cost. It should be noted that the cost should be evaluated for the whole assessment period.

Cover Construction and Implementation Issues for Cold Regions

The cold regions guidance document addresses issues applicable to most cover system designs and practical implementation / construction issues for cover systems in cold regions, which are summarized below.

Availability of Cover Materials

The availability of potential cover materials and the distance to borrow sources is a key factor when developing a cover system design, with transport and placement costs evaluated against the benefits of using greater volumes and/or more suitable materials. Ideal cover materials for the project location, climate, and waste may not be readily available in the immediate area, while other materials in the vicinity may be less than ideal but more feasible to use due to cost and/or logistical considerations. Material scarcity can be an important factor in decision making in cold regions. Licensing may also be required to access/use borrow materials, which can add substantial, perhaps prohibitive, time to the process.

Scarcity of natural materials often goes hand-in-hand with increasing variability of material properties within a given deposit. This variability must be accounted for in the prediction of cover system performance.

The environmental impact of material borrows and transportation should also be evaluated to ensure that the use of the material provides a net benefit to the project. This is particularly important in northern regions as areas sensitive to disturbance of permafrost and vegetation communities may not recover or have a long recovery process.

Short-term Erosion Protection

In cold regions, the time required to establish sufficient vegetation to provide erosion protection may be excessive (many years), leading to unacceptable erosion rates prior to full establishment, particularly for highly erodible materials. In these instances, short-term erosion protection in cold regions can be provided by the use of landform design features (e.g. micro-topography) and/or mulch materials to reduce erosion until vegetation can be fully established; or by placing an erosion-protection gravel or riprap layer over the cover. In the latter case, the material must be sufficiently coarse that is not susceptible to erosion. Ideally, this layer should also support vegetation, if vegetation establishment is desired as a long-term objective, although the material is likely to support only species adapted to establishment and growth on coarse-grained substrates.

Revegetation

Revegetation may be a cover design objective required to meet end land-use goals and/or to improve cover system performance through evapotranspiration (ET). Establishment of vegetation on growth mediums in cold regions is largely influenced by soil type, local terrain, moisture regime, ecology, and climate (Slaughter and Kane 1979, Gibson *et al*. 1993). In addition to facilitating water removal through evapotranspiration, the growth medium layer serves as protection against physical processes, such as wet/dry and freeze/thaw cycling, as well as various chemical and biological processes.

Topsoil, where available, can be used as a source of nutrients and vegetation propagules, but, as noted above, must be protected from surface erosion (through surface preparations to control surface drainage), and is often available in limited volumes, such that its use must be carefully matched to cover system design and overall site objectives. Initial fertilizer treatments may be necessary for successful vegetation establishment, but continued fertilizer applications may be detrimental to native species establishment (as most cold region native species are adapted to low-nutrient conditions). Treatments that increase the creation of micro-topography (e.g. surface landform creation, placement of woody debris and/or large rocks) can be effective in increasing establishment and diversity of vegetation on reclamation covers, provided that they are consistent with other cover system design objectives.

Need for Proper Management of Surface Water Drainage

As discussed above, one of the most common failure modes of cover systems in general, and for cover systems in cold regions in particular, is the failure of the surface water management system to safely convey runoff off the landform. Surface water management systems must be robust, as any failure is visible to stakeholders. Even if the failure does not result in increased contaminant loading or other critical failures, the surface drainage system is visible and even small glimpses of erosion give the impression of poor design and management.

A surface water management system will be successful if it manages to convey all the required surface water and does not suffer greatly from erosion, sedimentation, and turbidity. This success is largely based on choosing a reasonable design storm event during planning. In cold regions, care must be taken to consider spring snowmelt in conjunction with the design rainfall event, as well as glaciation of surface water conveyance channels. Glaciation of surface water channels and ditches, particularly near the 'outlet' area of the landform, is a very common failure mechanism of cover systems in cold regions.

Erosion can result in stream water with high turbidity and large sediment loads. If sediment gets into surface water onsite, it may become an environmental contaminant requiring treatment. The best approach is to reduce or eliminate suspended fines rather than removal and treatment which can be difficult and costly. Key factors are to prevent raindrop erosion and slow surface water velocity in bare areas. This can be done through establishing adequate vegetation, proper grading of contours, berms, and swales, diversion ditches, and rock armouring (Norman *et al*. 1997).

Reclamation of large waste storage facilities should include the construction of small catchment areas and wetlands upstream of final surface water discharge points when compatible. This will attenuate surface runoff to reduce peak flows and increase sedimentation prior to reaching receiving streams. In some cases, products such as silt fences or straw wattles are recommended to provide temporary sediment control until the cover surface stabilizes.

Placement of Cover Material on Soft Tailings

The use of construction equipment to re-grade tailings surfaces and place cover material requires sufficient dewatering of the upper tailings profile to provide adequate shear strength and improve trafficability conditions. Drain-down of tailings can be achieved by collecting and treating supernatant and seepage waters over a period of time. A staged advancement of several thin layers of cover material may be required with provision to allow consolidation and strength gain at each stage, to avoid a rotational failure (slumping) or a bearing capacity failure near the advancing edge of the cover material (Wels *et al.* 2000). Use of geosynthetic products, such as a geogrid or geotextile, and wick drains, are often required to improve strength conditions and accelerate consolidation of tailings, respectively.

Placement of the initial cover layer during winter when the upper tailings are frozen is another option, particularly where tailings are finer textured (see Ricard *et al.* (1997) or MEND 2.22.4a (1999) for case study of winter tailings cover construction). However, it is fundamental that an understanding of the potential for settlement, and differential settlement, following thaw of the tailings is developed. Sustainability of any surface water management system on top of the cover system of a tailings storage facility is intimately linked to settlement characteristics of the tailings.

Summary

Compared to soil cover design in temperate climates, the development of soil cover design technology in cold regions is just in its infancy. Although some knowledge and experience obtained from cover design and cover performance in temperate sites may be applicable in cold regions, special features such as extreme climate and relatively coarse-textured material in cold regions require specially-developed technical guidance for cold regions cover design. The cover design philosophy presented in the paper describes the main aspects for designing soil covers in cold regions. Application of the cover design philosophy should be incorporated in the site-specific settings. The development of the technical guidance document is intended to be a resource for guiding cover designers to consider all possible solutions. From AANDC's perspective, the lowest cost option for a cold region cover may not be the best alternative when all issues surrounding long-term performance and liability are considered.

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References

Andersland, O.B. and Ladanyi, B. (2004) Frozen ground engineering, John Wiley & Sons, Inc., Hoboken, New Jersey, 363 p.

Ayres, B., Dobchuk, B., Christensen, D., O'Kane, M. and Fawcett, M. (2006) Incorporation of natural slope features into the design of final landforms for waste rock stockpiles, in Proceedings of the 7th International Conference for Acid Rock Drainage, 26-30 March , St. Louis, MO, USA, pp. 59-75.

Ayres, B.K., O'Kane M. and Barbour, S.L. (2004) Issues for consideration when designing a growth medium layer for a reactive mine waste cover system, in Proceedings of the 11th International Conference on Tailings and Mine Waste, 10-13 October, Vail, Colorado.

Brown, R.J.E. and Kupsch, W.O. (1974) Permafrost Terminology, Natural Research Council of Canada, Ottawa, Ontario, 62 p.

Carey, S.K. and Woo, M.K. (2001). Spatial variability of hillslope water balance, Wolf Creek basin, subarctic Yukon. Hydrological Processes 15: 3113 – 3132.

Elshorbagy, A. and Barbour, S.L. (2006). Risk and uncertainty-based assessment of the hydrologic performance of reconstructed watersheds. Paper submitted to ASCE Journal of Geotechnical and Geoenvironmental Engineering, (under review).

Gibson, J.J., Edwards, T.W.D. and Prowse T.D. (1993) Runoff generation in a high boreal wetland in northern Canada. Nordic Hydrology 24: 213 – 224.

INAP (International Network for Acid Prevention) (2003) Evaluation of the long-term performance of dry cover systems, final report. Prepared by O'Kane Consultants Inc., Report No. 684-02, March.

McFadden, J.P, Chapin III, F.S. and Hollinger, D.Y. (1998). Subgrid-scale variability in the surface energy balance of arctic tundra. Journal of Geophysical Research, 103(22): 947 – 961.

MEND 1.61.5a (2009) Mine waste covers in cold regions, Mine Environmental Neutral Drainage (MEND) Program, March 2009.

MEND 1.61.5b (2010) Cold regions cover research – Phase 2, Mine Environmental Neutral Drainage (MEND) Program, November 2010.

MEND 2.21.4 (2004) Design, construction and performance monitoring of cover systems for waste rock and tailings, Mine Environmental Neutral Drainage (MEND) Program, July 2004.

MEND 2.21.5 (2007) Macro-scale cover design and performance monitoring reference manual, Mine Environmental Neutral Drainage (MEND) Program, July 2007.

MEND 2.22.4a. (1999) Construction and Instrumentation of a Multi-Layer Cover—Les Terrain Aurifères (LTA), Mine Environmental Neutral Drainage (MEND) Program, February 1999.

Norman, D.K., Wampler, P.J., Throop, A.H., Schnitzer, E.F., and Roloff J.M. 1997. Best management practices for reclaiming surface mines in Washington and Oregon. Washington Division of Geology and Earth Resources. Open File Report 96-2. Revised Edition December 1997.

Ricard, J.F., Aubertin, M., Firlotte, F.W., Knapp, R., McMullen, J., and Julien, M. 1997. Design and construction of a dry cover made of tailings for the closure of Les Terrains Aurifères Site, Malartic, Quebec, Canada. In Proceedings of the 4th International Conference on Acid Rock Drainage (ICARD). May 31 – June 6, 1997, Vancouver, BC., pp. 1515–1530.

Slaughter, C.W. and Kane, D.L. (1979). Hydrologic role of shallow organic soils in cold climates. In Proceedings, Canadian, Canadian Hydrology Symposium 79-Cold Climate Hydrology. National Research Counsil of Canada: Ottawa; 380 – 389.

Taylor, G.; Spain, A.; Nefiodovas, A.; Timms, G.; Kuznetsov, V.; Bennett, J. (2003) Determination of the reasons for deterioration of the Rum Jungle waste rock cover, Australian Centre for Mining Environmental Research: Brisbane.

Vourlitis, G.L. and Oechel W.C. (1999) Eddy covariance measurements of CO_2 and energy fluxes of an Alaskan tussock tundra ecosystem. Ecology 80 (2): 686 – 701.

Washburn, A.L. (1973) Periglacial processes and environments, Edward Arnold Ltd., London, England, 320 p.

Wels, C., Robertson, A. MacG., and Jakubick, A.T. (2000): A review of dry cover placement on extremely weak, compressible tailings. Paper published in CIM Bulletin, Vol. 93, No. 1043, pp. 111-118, September.

Wilson, G.W. (2008) Why are we still struggling with ARD? Geotechnical News, BiTech Publishers Ltd., Vancouver, Canada, June 2008, pp. 51-56.

Wilson, G.W., Williams, D.J. and Rykaart, E.M. (2003) The integrity of cover systems - An update, in Proceedings of the 6th International Conference for Acid Rock Drainage, 12-18 July, Cairns, North Queensland, Australia, pp. 283 - 291.

Yamazaki, T., Nishida, A. and Kondo, J. (1998) Seasonal frost depth of grounds with the bare surface, snow cover and vegetation, Journal of Japanese Society of Snow and Ice, Vol. 60, pp. 213–224. (in Japanese with English summary).

Zhang, Y., Carey, S.K. and Quinton, W.L. (2008) Evaluation of the algorithms and parameterizations for ground thawing and freezing simulation in permafrost regions, Journal of Geophysical Research, Vol. 113, D17116, doi: 10.1029/2007JD009343.