Valued Component – Snow, Ground Ice and Permafrost (Final Draft)

STATE OF KNOWLEDGE – WHAT IS HAPPENING?

A very brief overview of the state of knowledge with respect to snow, ground ice and permafrost in the NWT is presented below. This overview is preliminary and not intended to be exhaustive.

⤷ **What are the baseline conditions with respect to snow, ground ice and permafrost?**

✻ Snow, ground ice and permafrost are integral components of the northern physical environment. This environment supports a diversity of ecosystems, traditional ways of life and it is the context within which northern development must be managed. The snow provides a store of water for spring runoff and serves as insulation that moderates the penetration of cold into the ground during winter. Several small mammals and birds rely on ameliorated temperatures of the subnivean environment for survival in winter. Permafrost is defined as "Soil or rock that remains below 0°C for at least two years". Permafrost is widespread in the NWT. Its presence limits infiltration, promoting runoff and causing existing moisture to be retained near the soil surface where it is available to vegetation. The amount of ice in near-surface permafrost determines the potential for instability if the sediments were to thaw. Ice-rich rich ground is a concern when planning northern development because surface disturbance can alter ground-temperatures causing near-surface permafrost to thaw leading to instability of slopes and subsidence of the ground surface.

KEY MONITORING INDICATORS

Snow water equivalencies	*Ground temperature*
Active layer depth	*Snow cover duration*

Snow

✻ In the Northwest Territories, snow data are collected at about 90 locations by DIAND and at about 40 Environment Canada weather stations. Snow accumulation is related to topography, weather systems, latitude, climate and vegetative cover. At DIAND sites in central and southern NWT the range of annual winter snowfall accumulation is 75 to 150 mm of snow-water equivalent. Inter-annual variations at each site range from 50 to 150% of normal. There is an abrupt decline in snow depths across treeline in the western Arctic. Typically more than 80 cm of snow accumulates in the boreal forest, but snow depths are less than half of this amount on windswept tundra uplands.

✻ In a few locations, the length of the snow record is almost 50 years, but for most areas, the record is too short to identify meaningful trends.

✻ Snow-water equivalency is the most important indicator for snow pack as it is the volume of water that is stored for release during the melt season. Snow depth and snow density vary as the snow pack ages over the winter and are also useful data for active layer/permafrost studies as they affect the ground thermal regime. The information is also used by wildlife biologists as animals are also affected by snow volumes and by forest managers for calculating forest fire indices.

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Permafrost

✻ Permafrost is widespread across the Northwest Territories. It may vary in thickness and in temperature as a function of local climate, soil thermal properties, geomorphic history, vegetation, slope aspect and snow cover. For example, south of Fort Simpson, permafrost is limited to areas of organic terrain and north-facing slopes and is usually only a few meters thick. Around Norman Wells, permafrost is widespread, absent only beneath deciduous woodlands and small areas of fen and is usually a few 10's of metres thick. In the Inuvik area, permafrost is continuous, usually over 100 meters thickness. Permafrost is considered to be discontinuous in the Mackenzie Delta due to the thermal effects of the numerous water bodies.

✻ In areas of permafrost, the active layer is surface layer of earth materials which thaw and refreeze on an annual basis. Changes to the annual maximum thickness of the active layer may provide an indication of climate warming or cooling trends. From approximately 1990 to 1998, there was a general increase in active layer depth throughout the Mackenzie Valley of about 15 cm. In 1998, the temperature in the Mackenzie region was 3.9 degrees higher than normal, the warmest year since the beginning of records for the entire Mackenzie region in 1948. Since 1999, the active layer in the Mackenzie Valley has thinned on average more than 10 cm in response to a number of cooler seasons. The mean active layer depth in 2003 was only 1 cm thicker than the active layer a decade ago. However, it is important to note that where permafrost is ice-rich, thawing of permafrost may only yield a slight deepening of the active layer in conjunction with landscape scale subsidence.

✻ Winter snow depths play an important role in insulating the ground, retarding heat loss, affecting the ground thermal regime. For example, there is a northward decrease in snow depths and vegetation height across treeline in the western Arctic. The variation in snow depths can explain a large proportion of the differences in permafrost temperatures observed across this gradient.

✻ During the last century, permafrost beneath peat plateaus in the northern prairie provinces and southernmost Northwest Territories has been disappearing, indicating that the southern edge of permafrost has retreated northward roughly 100 km, probably as a result of land use, as well as global warming.

Ground Ice

✻ Ground ice content of permafrost exhibits a high degree of spatial variability, occurring most commonly, but not exclusively in fine-grained sediments. Soil that contains greater than 15% visible ice is considered ice-rich. The volume of ground ice in permafrost generally decreases with depth. If ice-rich permafrost thaws, the ground may subside proportional to the ice content. Major types of ground ice include: a) pore ice which bonds enclosing sediments; b) wedge ice which forms due to thermal contraction cracking of the ground in winter and infilling of the cracks by snowmelt; c) near-surface segregated ice lenses only a few mm to cm thickness which develop immediately beneath the base of the active layer; and d) large bodies of segregated or buried glacier ice that may be up to several meters thickness. Most ground stability problems arise as a result of terrain disturbance in areas of ice-rich permafrost.

✻The thawing of ice-rich permafrost can result in the collapse of peat plateau and in rolling terrain along coast and lakeshores, landslides and thermokarst slumps may develop. The aerial extent and growth rates of thermokarst slumps in the western Arctic of NWT have increased significantly since 1973 in concert with accelerated climate warming. Degradation of permafrost results in ionic enrichment of soils and surface runoff and lake water, thus permafrost disturbance will likely magnify the direct effects of warming on terrestrial and aquatic ecosystems.

RECENT AND CURRENT MONITORING

Ongoing monitoring programs with respect to snow, permafrost and ground ice in the NWT are found below.

✓ Northwest Territories snow survey network (Indian and Northern Affairs Canada since 1965)

- The survey started in the Talston basin in the 1960's, and was expanded to include the Snare basin in the 1970's and sites near main communities. There are 50 monitoring sites in the Northwest Territories. Snow depth and snow water equivalent data are collected at representative sites and snow density is calculated.

✓ Snow accumulation/runoff in high latitude permafrost basins (P. Marsh, National Hydrology Research Institute, Saskatoon, since 1992)

✓ Snowfall measurements at weather stations (Environment Canada since the 1940s/50s)

✓ Snow water equivalent modeling using passive microwave imagery (Anne Walker, Environment Canada)

✓ Mackenzie Valley and Delta shallow ground temperature and active layer monitoring network (M. Nixon, Geological Survey of Canada since 1991)

- Approximately 60 sites are located between Fort Simpson and Tuktoyaktuk, with ground temperature cables at about 20 sites. Annual thaw penetration and maximum ground surface heave and subsidence are measured allowing calculation of active layer. Many of these sites are also instrumented to record air and ground surface temperatures throughout the year. Three snow depth monitoring stations have been added to temperature cable sites near Inuvik and between Fort Simpson and Wrigley.
  There are also several sites where snow and active layer depths are monitored over 100 m^2 grids (Circumpolar Active Layer Monitoring sites - CALM).
  Enhancement of the monitoring network is ongoing through funding from the Northern Energy MC.

✓ Mackenzie Delta region deep ground temperature monitoring (Indian and Northern Affairs Canada)

- Deep temperature cables originally placed in 1960s and 1970s were reinstalled in 2003. Comparison of data may indicate effect of climate change on permafrost temperatures in the region.

✓ Permafrost conditions across treeline, western Arctic Canada (S.V. Kokelj, Indian and Northern Affairs Canada, C.R. Burn, Carleton University)

- Relations between snow, vegetation and ground-temperatures have been investigated across treeline in the Mackenzie Delta region. Deep thermistor cables have been installed in collaboration with NRCan.

✓ Norman Wells pipeline corridor permafrost and terrain monitoring network and pipe-soil interaction studies (M. Burgess and S. Smith, Natural Resources Canada since 1985)

- Both short- and long-term changes in the active layer, permafrost and terrain stability are monitored along the pipeline right-of-way. More than 20 monitoring sites have been established. This program monitors the impact of pipeline construction and operation on the physical environment in Mackenzie valley from Northern Alberta to Norman Wells, Northwest Territories. In addition, the response of terrain to natural climate change and variability is studied. Parameters measured include ground temperature, thaw depth, surface settlement, pipe temperature, air temperature and pipe movement (heave/settlement).

✓ Investigating the viability of permafrost as a waste containment medium (S.V. Kokelj, Indian and Northern Affairs Canada)

- In the Mackenzie Delta region, permafrost is used to encapsulate drilling wastes. Evaluation of the thermal evolution of drilling mud sumps under varying snow and climate conditions was evaluated in a modeling exercise. Modeling results were validated with field data collection.

✓ Long-term investigations of permafrost growth. The most thoroughly documented site is Illisarvik, the drained lake on the north end of Richards Island (J.R. Mackay, UBC, C.R. Burn, Carleton U.).

✓ Soil temperature monitoring along the Norman Wells pipeline (Enbridge (IPL) since 1985)

✓ Deformation of ice-rich permafrost slopes as a result of creep (Geological Survey of Canada since 1990)

✓ Geomorphological and permafrost investigations in the alpine tundra of the western Mackenzie Mountains (G.P. Kershaw, University of Alberta since 1974)

- The program was established to investigate regional post-disturbance recovery associated with Canol corridor development, and to monitor climate change impacts on permafrost landforms such as palsas and peat plateaus in the Macmillan Pass area of the Mackenzie Mountains. The permafrost landform research area is located within the Northwest Territories to approximately 40 km west of the Yukon border. A continuous record from permafrost and microclimate monitoring stations exists from 1990.

✓ Deformation of ice-rich permafrost slopes as a result of creep (L. Dyke, Geological Survey of Canada since 1990)

- This work has been carried out near Tuktoyaktuk (Inuvialuit Settlement Region) and is presently being expanded to other sites in the Northwest Territories (Wrigley) and Yukon.

✓ Soil climate study – sites from tundra north of Inuvik to southern NWT (C. Tarnocai, Agriculture Canada since 1983)

✓ Predicted permafrost distribution modeling for the NWT is currently being conducted by the Geological Survey of Canada (F. Wright, Geological Survey of Canada).

✓ Tibbitt Lake post-fire study (Indian and Northern Affairs Canada)

- Since 1998, post-fire microclimates have been monitored, including ground temperature, soil moisture and snow water equivalents in adjacent areas of burned and unburned vegetation.

GAPS AND RECOMMENDATIONS FOR MONITORING

A list of monitoring gaps and recommendations for future monitoring under the NWT Cumulative Impact Monitoring Program is found below.

Gaps

➙ Snow survey network is sparse and is focused on basins with hydroelectric developments and major communities. No snow data collected in the Mackenzie Mountains and very little in three key development areas: Liard Valley, Coppermine River basin and along the east bank of the Mackenzie River.

➙ Snow data are generally collected only once per year at the end of winter. Timing of snowfall affects heat extraction from the active layer. Inter-annual variability in field measurements should be calibrated against Meteorological Station data.

➙ Testing effects of pipeline construction on permafrost

➙ The extent to which changes in albedo as a result of development (e.g., dust, vegetation clearing) impact permafrost and snow cover is not well known.

➙ Given that slope stability in permafrost areas is tied to ground temperature and ground ice volume, a better understanding of how these variables control slope movement is required.

➙ Active layer and ground temperature data are sparse between Norman Wells and the Mackenzie Delta, and virtually non-existent elsewhere.

➙ Detailed prediction of ground ice is limited to alluvial materials in the Mackenzie Delta, but many other regions are extremely ice-rich and thaw sensitive (although this may be very difficult to achieve).

➙ The impact of the release of nutrients from the thaw of snow and permafrost has not been adequately addressed.

➙ Lack of knowledge on the requirements for acceptable disposal of industrial wastes in permafrost.

➙ Require a better understanding of the role of forest fire in altering permafrost distribution, slope stability and hydrology.

➙ Require a better understanding of the hydrologic cycle and the roles of snow and permafrost in areas of current and future development (Liard Valley – Mackenzie Mountains; Coppermine River basin – Canadian Shield; East bank of Mackenzie River – Franklin Mountains, Taiga Plains north of Norman Wells).

➙ Linkages need to be better understood between various indicators (e.g., air temperature, precipitation, water quantity, permafrost, vegetation) in order to assess cumulative effects of development on the environment.

Recommendations

➙ A closer coordination between agencies with monitoring programs could result in a broader coverage of environments and an improved understanding of the sensitivity of snow, ground ice and permafrost to development pressures and climate.

➙ Identify representative sites from existing locations and set up complimentary monitoring systems (e.g., at a CALM site, set up air temperature and precipitation gauges).

➙ Tie study locations to areas where development is anticipated or at initial stages. Establish program of intensive monitoring locations in order to examine effects of development. Apply information gained to other sites.

➙ Ensure that existing monitoring networks (i.e., shallow ground temperature, active layer depth and snow survey) are maintained so that long-term records are established.

➙ Establish new monitoring sites (snow surveys, CALM grids, air temperature, precipitation, etc.) in Liard Valley, Mackenzie Mountains, Coppermine River basin and east bank of Mackenzie River where large gaps exist.

➙ Increase the frequency of data collection at selected snow monitoring sites.

➙ Analysis of existing pipeline right-of-way data (i.e., ground temperature, subsidence) would help to determine the impact of new pipeline construction.

➙ Assess the role that forest fire plays in altering permafrost distribution, destabilizing the ground and modifying hydrology.

➙ Investigate the causes of sump collapse and determine the environmental effects.

➙ Continue efforts to predict permafrost distribution considering various disturbance scenarios.

REFERENCES

Relevant monitoring reports, past monitoring programs, research documents, and scientific publications are found below. This list is a small sample of what is available.

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http://sts.gsc.nrcan.gc.ca/permafrost/index.html

Snow survey data from Indian and Northern Affairs Canada, NWT:
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Bibliography listing scientific contributions from Illisarvik, NWT, northern Canada's longest-running field experiment, conceived by Dr. J. Ross Mackay in the 1960s as a research program on the behaviour of aggrading permafrost:
http://www.nwtresearch.com/illisarvik/authors.asp