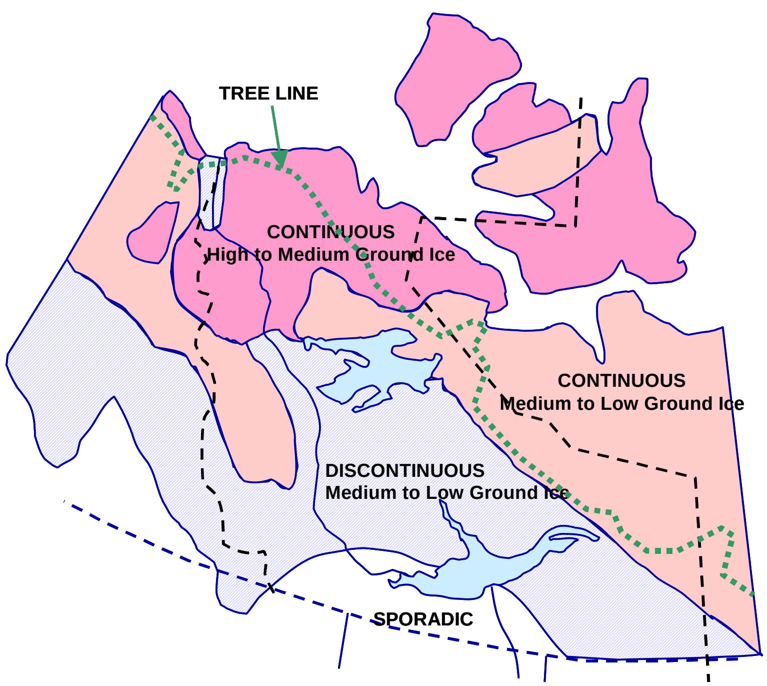
6.0 PERMAFROST, GROUND ICE AND SNOW COVER

6.1 INTRODUCTION

The Northwest Territories (NWT) has the third largest land area of the ten Provinces and three Territories in Canada; after Quebec and Nunavut. It has a total area of about 1,346,000 square kilometers; with about 13% of this area being fresh water. The uniqueness of NWT is that it is located within permafrost and is difficult to access most of its areas. A large part of NWT depends on winter roads and air transport for access and supplies. More than 50% of the permafrost is classified as sporadic and discontinuous that is readily disturbed by construction resulting in ground thawing and potential physical instability. Finally, NWT permafrost is warming 'rapidly' due to climate changes (Couture *et al* 2003).

Design and construction of projects in the NWT permafrost environment is considerably more difficult than in southern temperate parts of Canada. Challenges are created by the existence of frozen ground that may thaw due to construction disturbance and/or by warming due to climate change. Sensitive areas are located in high ground ice areas in both continuous and discontinuous permafrost and in all discontinuous and sporadic permafrost regions; these areas are highlighted in Figure 6.1-1.

FIGURE 6.1-1
SIMPLIFIED NRC CANADA PERMAFROST MAP MCR 4177



Source: (Heginbottom et al 1995).

Presence of permafrost and the magnitude of ground temperature that governs the properties and the sensitivity of permafrost to construction are dependent on many factors; some being: air temperature, vegetation, snow cover, orientation of the terrain and ice content. Since these factors vary across NWT, so does the condition of permafrost and its sensitivity to construction.

The impact of construction on frozen ground is different in discontinuous and continuous permafrost areas. In most southerly areas, permafrost has already thawed or is rapidly disappearing. A large part of NWT lies within discontinuous permafrost where ground warming may occur either due to removal of vegetation during construction or the slower process of air temperature rising. In continuous permafrost, the ground temperatures are colder and ground warming caused by vegetation disturbance is small. In these areas, ground warming is caused by climate change that alters the ground temperatures at a slower rate than is experienced by vegetation disturbance in discontinuous permafrost areas.

Warming that leads to thawing of the frozen ground may impact the physical stability of the natural terrain and structures built on permafrost. Thawing of the existing permafrost may result in: thaw settlement, ground instability, drainage course changes, high-suspended solid concentration in streams, and foundation settlement. Finally, the concept of encapsulation of wastes within permafrost may not work in the long-term period when climate warming is occurring.

Thawing of permafrost will impact areas in different years depending on present local permafrost ground temperatures and the rate of climate warming that varies with location. It is realistic to assume that significant warming will occur in about 30 to 100 years in NWT.

Physical development will increase with time and this will increase the footprint of human activity in NWT. An estimate of the present footprint of human activity in northern Canada is given 'Estimate Physical Footprint of Human Activity' study of the Slave Geological Province (Cizek 2003). Past human activities in the Slave Geological Province are summarized in Table 6.1-1.

TABLE 6.1-1
PHYSICAL FOOTPRINT OF HUMAN ACTIVITIES IN SLAVE GEOLOGICAL PROVINCE

Human Activity	Area, km^2	Percent of All Activities	
		Including Hydro	Without Hydro
Snare Hydro & Hydro Line Right of Way	135.5	46	
Past mine producers	39.2	13	24
Present mines; Ekati, Diavik & Snap Lake	32.0	11	20
Winter Roads, camps & borrow	8.6	3	5
Advanced exploration	73.5	25	46
Settlements	3.0	1	2
Others	4.4	1	3
Totals All Activities	**296.2**	**100**	**100**

Source: ***(Cizek 2003).***

The above estimate shows that, setting aside the Snare Hydro reservoirs, the largest human impact in the Slave Geological Province up to 2004 was produced by the mining industry. The past producing mines, largely abandoned orphaned mines, represent 24% of the total affected area, existing operating or under construction mines represent 20% and advanced exploration abut 46% of the human footprint. In comparison to the land area of the NWT, the disturbed areas cover less than 0.025% of the land mass.

NWT encompasses also a portion of the Slave Geological Province, Bear Province and the Interior Platform. The Slave Geological Province has more benign permafrost conditions then exist in the other two areas. The Interior Platform, which encompasses the Mackenzie River, has numerous settlements and the Norman Wells refinery with its associated pipeline. Also the areas adjacent to the Mackenzie River and its delta have seen large oil and gas explorations that may have disturbed the vegetation and thereby the permafrost equilibrium. Vegetation could have been disturbed by numerous seismic lines in areas below the tree-line and the construction of drill pads.

While the past producers encompass a slightly larger footprint than the present mine operations, they produced much smaller quantities of wastes (tailings and mine rock) than the present operations because they were mainly underground operations. Present mines, Ekati and Diavik, being open pit mines that employ large excavators and trucks, produce much greater quantities of mine wastes. Estimated total tonnage of mine rock and tailings reported during licensing of the mines is given in Table 6.1-2. Snap Lake mine waste tonnage will be considerably smaller because it will be an underground mine and will pump large volumes of the processed kimberlite into the mined-out underground workings.

TABLE 6.1-2
TONNAGE OF PROCESSED KIMBERLITE AND MINE ROCK OF NWT DIAMOND MINES (ESTIMATES BASED ON PRE-MINE LICENSE SUBMISSIONS)

Mine	Volume (in million tones)	
	Mine rock	Processed Kimberlite (tailings)
Diavik Diamond Mines	250	26
Ekati Diamond Mine	355	65
Snap Lake Diamond Project	1.4	12
Totals	606	103
Total mine rock and tailings		**709**

The Mackenzie Gas Project and the development of new mines from the advanced explorations will increase considerably the existing developed footprint. Mackenzie Gas Project's pipeline route is about 1220 km long and has three gas gathering areas, namely Niglintag, Taglu and Parsons Lake. It will likely develop additional gas gathering fields and extensive supporting infrastructures during its operation that will increase the footprint even more. Furthermore, the development of Beaufort Sea petroleum resources will require land based infrastructures.

6.2 ENVIRONMENTAL STRESSORS

6.2.1 Ground Temperature and Ground Ice

Permafrost is defined as a ground (soil or rock, including ice and organic material) that remains at or below 0ºC for at least two consecutive years (Everdingen 2002). This definition does not encompass vegetation cover, composition of the overburden (ice content) and the ground temperature. The latter two factors are important in assessing the effect of climate warming on permafrost conditions across the Canadian North. They indicate how the permafrost may react to construction and climate warming. High ice content within silt permafrost is illustrated in Figure 6.2-1. When this material thaws, its consolidation may disrupt the ground leading to erosion and sediment release.

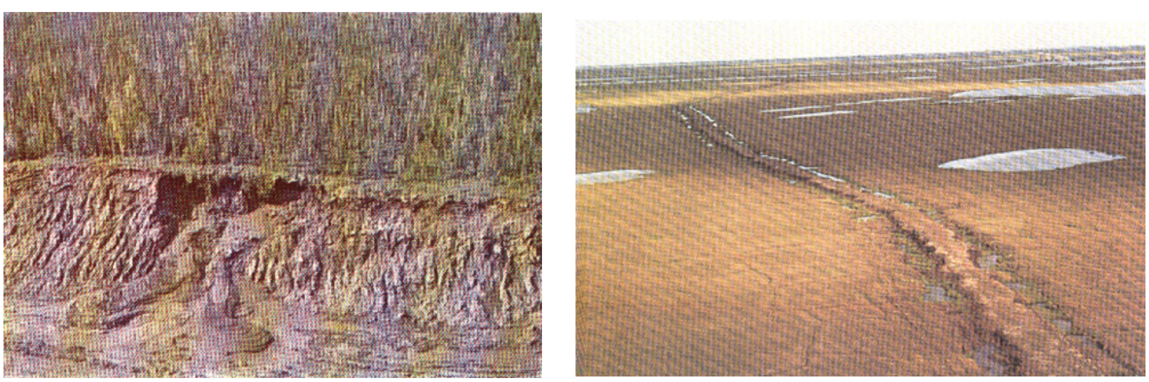
Areas with high ice content and in 'warm' ground temperature (range of 0 to minus 2ºC that is typical in discontinuous permafrost) are readily disturbed thermally by construction. This may lead to thaw settlement, slope instability and fine soil erosion.

Disturbance by construction is created by damaging the vegetation cover and excavating into frozen ground. In discontinuous permafrost areas, removal of vegetation cover (tree and bush cutting and removal of organic matting) generally leads to warming and thawing of the ground.

In continuous permafrost, the removal of vegetation cover causes the active layer to deepen and the new thawed zone may cause; settlement, ground instability and erosion. Damage to permafrost is illustrated in Figure 6.2-2.

FIGURE 6.2-1
HIGH GROUND ICE SHOWN BY ICE LENSES IN FINE-GRAINED SOIL

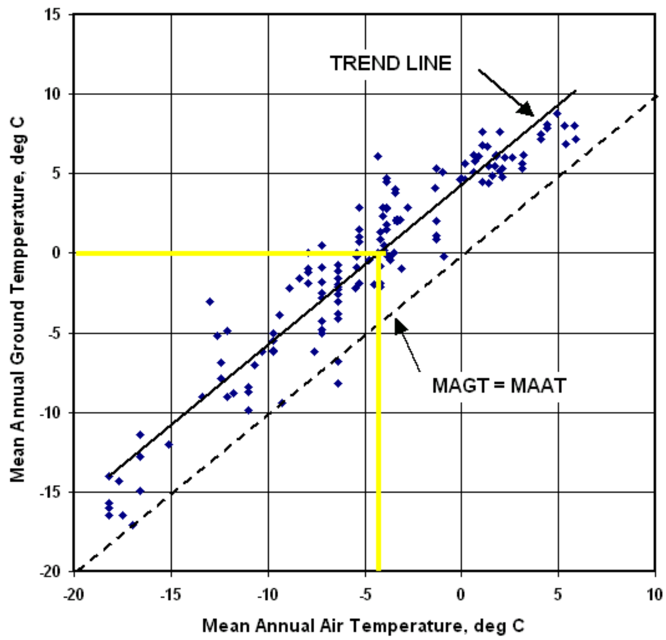
FIGURE 6.2-2
FLOW SLIDE ALONG DEMPSTER HIGHWAY CAUSED BY CUT INTO ICE RICH SOIL AND WATER ACCUMULATION AND SLUMPING ALONG A ROAD BUILT IN PRUDHOE BAY



Air temperature is a good indicator of the presence of permafrost and it provides a tool to estimate the ground temperature. It is not an exact indicator because other variables such as; vegetation, snow, and terrain have influencing roles. The permafrost group of the Geological

Survey of Canada (Smith & Burgess 2000) have developed a general relationship between the Mean Annual Air Temperature (MAAT) and Mean Annual Ground Temperature (MAGT) shown in Figure 6.2-3. The spread of points along the trend line show the influence of the other variables. For general estimation, it can be assumed that MAGT is about 4.5ºC warmer than the MAAT.

FIGURE 6.2-3
RELATIONSHIP BETWEEN AIR AND GROUND TEMPERATURES



Source: Smith & Burgess 2000.

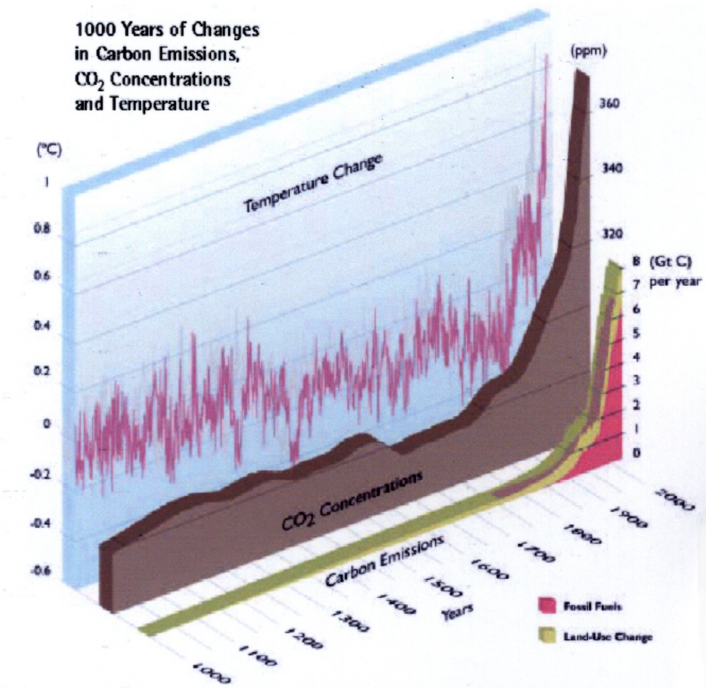
It needs to be noted that the temperature increment of 4.5ºC between MAAT and MAGT is an average. The increment at a specific location is dependent greatly on vegetation cover. At sites that are in trees and have a thick fibrous organic cover, permafrost may exist when MAAT is –1ºC. The incremental difference of 4.5ºC between MAAT and MAGT is representative of an area with no trees with thin organic mat or an area where the organic mat was either removed, compressed by construction equipment or fill as shown by the Lupin case history discussed below.

6.2.2 Climate Warming

During the last 10 years numerous studies have clearly demonstrated that climate warming is occurring and that the Arctic is warming at about twice the worldwide rate. The most recent authoritative study was commissioned by the Arctic Council, a high-level intergovernmental forum comprised of 5 northern nations and six Indigenous People; three of these being Canadian.

This study (Hassol 2004) concluded that human activities have increased the concentration of carbon dioxide, methane and other greenhouse gases that has led to climate warming. Furthermore, the Arctic is warming more rapidly than the world and much larger changes are projected. The rate of increase and the relationship between global carbon dioxide concentration and air temperature are shown in Figure 6.2-4.

FIGURE 6.2-4
RELATIONSHIP AND INCREASE OF CARBON DIOXIDE AND GLOBAL AIR TEMPERATURE



Source: Hassol 2004.

Highlights of the study are:

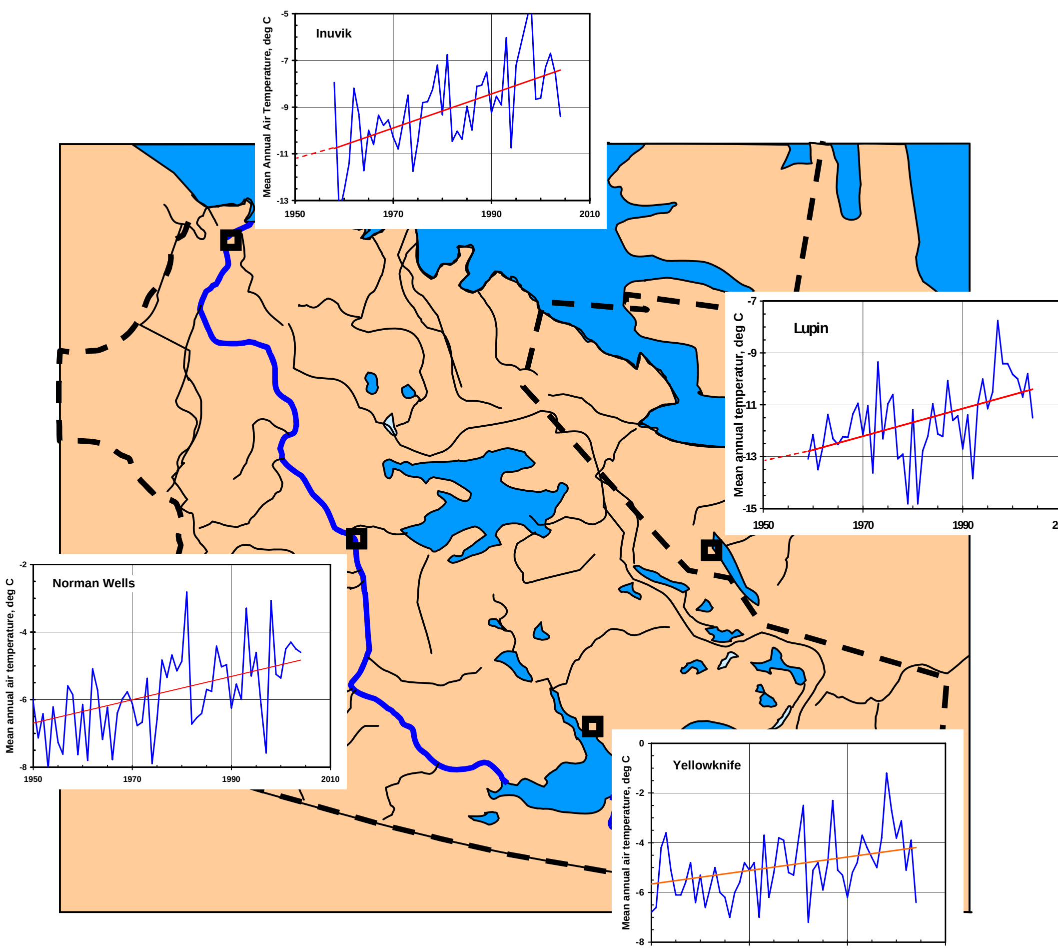
- Annual average Arctic temperatures have increased at twice the rate as that of the rest of the world over the past few decades.
- Increasing precipitation, shorter and warmer winters, and substantial decreases in snow cover and ice cover are among the projected changes that are very likely to persist for centuries.
- Projected temperature change from the 1990s to 2090s, based on the average change calculations by five ACIA climate models, indicate the mean annual air temperatures will be 3 to 5ºC warmer in the over land areas in the Arctic.
- Economic damage to infrastructure will result from permafrost thawing and coastal erosion and thawing will hinder land transport in winter.

Climate warming in northern permafrost areas has been reported in all countries in the northern hemisphere with major permafrost areas: in Alaska by Esch (1990) and Correl (2004); in Switzerland by Instanes (2003); and, in Canada by Etkin (1998), Byer (2004) and Burgess *et al.* (2004).

The rise of air temperatures across the NWT is evident from several Environment Canada meteorological stations that have records of about 50 years. These show that the air temperature has been rising in NWT for the last 50 years and the rate of rise has increased during the last 25 to 30 years. The increase is not evenly distributed across NWT.

MAAT at Yellowknife, Norman Wells, Inuvik and Lupin (in Nunavut but just northeast of the NWT-Nunavut border) are shown in Figure 6.2-5.

FIGURE 6.2-5
MEAN ANNUAL AIR TEMPERATURE RECORDS AT FOUR REPRESENTATIVE NWT LOCATIONS



Source: Environment Canada meteorological station records.

Data in Figure 6.2-5 show that the mean annual air temperature at any location fluctuates greatly on a yearly basis but there is a definite MAAT increase over the last 50 years. To show how the temperature increases across NWT and how this will impact the permafrost, the temperature data in Figure 6.2-5 was interpreted for the four locations as follows:

- rate of temperature increases were obtained from the linear trends;
- MAATs for 2000 were derived from the linear trends; and,
- number of years it will take for the ground temperature to reach 0ºC were estimated.

The results from this exercise are given in Table 6.2-1.

TABLE 6.2-1
MEAN ANNUAL AIR AND GROUND TEMPERATURES AT FOUR REPRESENTATIVE NWT LOCATIONS AND ESTIMATED NUMBER OF YEARS FOR GROUND TEMPERATURE TO REACH 0ºC

Locations	MAAT In 2000	MAGT In 2000	Avg. warming	Years to reach 0ºC
	ºC	ºC	ºC/100 yrs	MAGT
Yellowknife	-4.3	0.2	3.4	0
Normal Wells	-4.9	-0.4	3.2	14
Invuvik	-7.7	-3.2	7.0	48
Lupin	-10.6	-6.1	8.4	78

These results have the following implications:

- Permafrost along most of Mackenzie River valley may either disappear or be present in sporadic areas, found under thick vegetation covers, within about 50 years.
- Permafrost may disappear from within the continental part of NWT in less than 100 years.
- Project closure and reclamation design need to consider the disappearance of permafrost in less than 100 years.

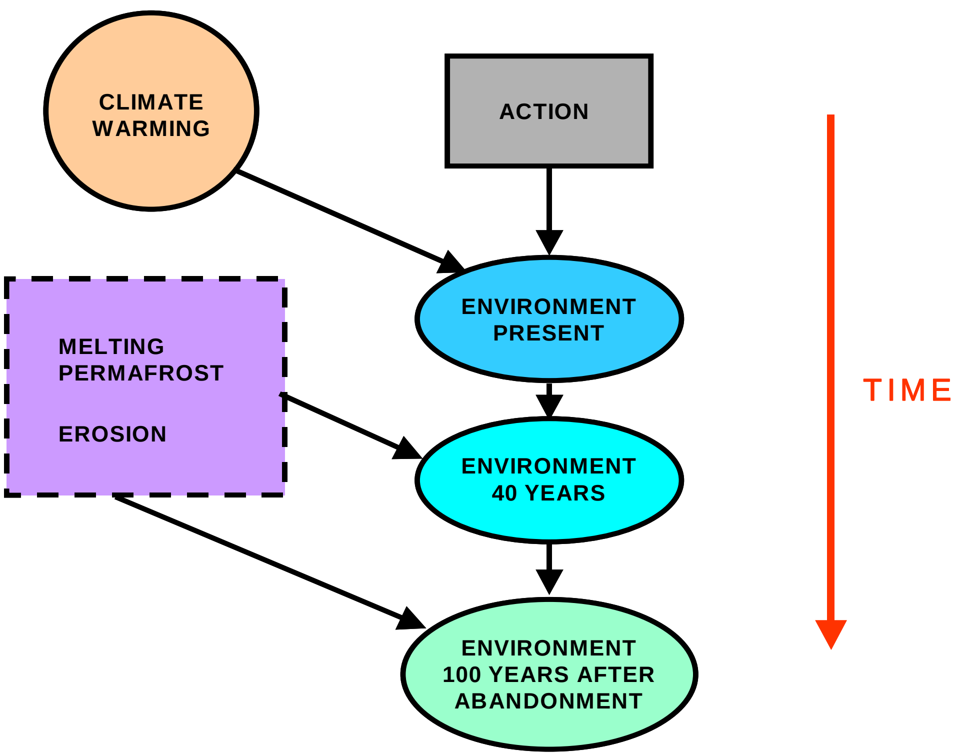
Potential environmental impacts of loss of permafrost include erosion of landforms along stream and riverbanks, lake and sea shorelines and slow sheet erosion of undulating land. Natural erosion will accelerate in permafrost regions as climate warms and thaws the permafrost. The thawing of the frozen ground that in turn will lead to ground softening, differential settlement and slope instabilities may create physical damage to terrain. These ground instabilities may occur even without any human alteration by projects or settlements. However, human activities, such as, construction of roads, pipelines, settlements, mine rock dumps or tailings storage facilities may increase even further the ground instabilities and environmental impacts. The hazards to infrastructure in Western Arctic and along the Mackenzie Valley due to climate warming was identified by Couture *et al* (2003).

At the present time serious physical damage due to climate warming is experienced in Switzerland's mountains where melting of glaciers and the underlying ground is producing numerous landslides (key note address at the 2003 Int'l permafrost conference in Switzerland). The importance of the climate change on permafrost and environmental impacts are demonstrated by the number of papers on these subjects (Chudinoa *et al* 2003, Dominnikova 2003, Gorshkov and Tishkova 2003, Hof *et al* 2003, Kershaw 2003, Khrustalev 2003, and Osterkamp 2003).

The NWT will experience some degradation of the terrain due to the thawing of permafrost caused by climate warming even without human activity contributions. However, alteration by Actions will further increase the instabilities of the ground as permafrost thaws and this in turn will lead to increased erosion and sediment loads.

Action is defined in the Cumulative Effects Assessment Practitioners Guide as any project or activity of human origin (CEAA 1999). The impacts by Actions that should be minimized are the ones caused by the construction of new projects. The impacts may occur several years after project abandonment. The relevance of climate and time to cumulative environmental impact monitoring is illustrated in Figure 6.2-6.

FIGURE 6.2-6
FACTORS RELEVANT TO CUMULATIVE ENVIRONMENTAL IMPACTS MONITORING



6.3 PERMAFROST, GROUND ICE AND SNOW INDICATORS

NWT differs from most of Canada, (as do Yukon, Nunavut and northern Quebec and Newfoundland and Labrador) in that much of the land mass is underlain by permafrost. The susceptibility of permafrost to change is dependent upon a number of factors including ground ice content, ground temperature, snow cover and vegetation cover. The deterioration of permafrost with time and the fact that different types of projects (e.g., roads, pipelines and mines (Actions)) produce different impacts, suggests that project type also needs to be considered in assessing the cumulative environmental impact of a project during construction, operation and for many years after project closure.

6.3.1 Permafrost Indicators

Permafrost by itself is not adequate to determine how it will behave under climate warming and human activities as determined by Actions. Two dominant parameters that determine the response of permafrost to an Action are the ground temperature and the volume of ground ice within the permafrost overburden. The ground temperature in turn is determined by several parameters that include: air temperature, vegetation cover, snow cover and ground slope. Air temperature is the most dominant parameter within this group of parameters. In summary, the key indicators of permafrost conditions are listed in Table 6.3-1.

TABLE 6.3-1
KEY INDICATORS OF PERMAFROST CONDITIONS

Valued Component (VC)	Indicators
Permafrost	Mean annual air temperature
	Mean annual ground temperature

6.3.1.1 Mean annual Air Temperature

The most important factor governing the presence of permafrost, its temperatures, properties and the ground temperature change due to climate warming is air temperature. Two air temperature measures that are used in the interpretation of permafrost are the cumulative daily and mean annual air temperatures. The cumulative daily air temperature controls the thawing and freezing of the active layer (layer of ground that is subject to annual thawing and freezing in areas underlain by permafrost). However, the depth of the active layer is also strongly dependent on thickness of the organic layer, volume of water within the layer and snow cover being some of the other controlling parameters. This limits the value of the daily temperatures of assessing permafrost.

The mean annual air temperature (MAAT) is a more useful indicator for the general condition and stability of permafrost. As mentioned earlier, there is a good relation between the MAAT and the mean annual ground temperature (MAGT).

(i) What is being measured?

The benefit of using the MAAT as an indicator is the presence of a number of meteorological stations in the NWT managed by Environment Canada. Stations that have air temperature records of about 50 years are most indicative in the assessment of climate warming. Climate norms and averages can be obtained from htt://www.climate.weatheroffice.ec.gc.ca/.

Other meteorological stations, managed by DIAND and larger mine operators, have monitored the air temperature over shorter periods and can be used to augment the former information.

(ii) What is happening and what does it mean?

The mean annual air temperature is rising across the NWT but its rate of rise is not uniform across the NWT. The greatest rate of air temperature rise is occurring in areas with cold MAAT. This means the length of time to thaw the permafrost in the colder northern regions will nearly be the same as in the southern areas. The variability of the rise of the MAAT was illustrated previously in Figure 6.2-5 and Table 6.2-1.

(iii) What are the information gaps?

There are sufficient meteorological stations to monitor the MAAT and predict permafrost warming along the Mackenzie River. There is a limited long-term MAAT northeast of Yellowknife where many of the mines are located. The only long-term meteorological station in this area with MAAT data is the Lupin station that is located just north of the NWT/Nunavut border. This station may not continue to operate since the Lupin mine, where the station is located, has terminated its operation and is in the process of closure and thereby shutting down this meteorological station.

The MAAT gap can be filled with the meteorological stations operated by the new diamond mines, Ekati and Diavik, and the under construction at Snap Lake. These mines operate meteorological stations and report data annually to the licensing authority. These data could be incorporated into a NWT climate database.

6.3.1.2 Mean annual ground temperature

MAGT provides a direct measure of, and confirms how, climate warming is impacting regional permafrost. Scientific monitoring in Alaska (Osterkmap 2003), Russia (Romanovsky *et al* 2004) and Canada (Smith *et al* 2004) show a direct relationship between the MAAT and MAGT changes.

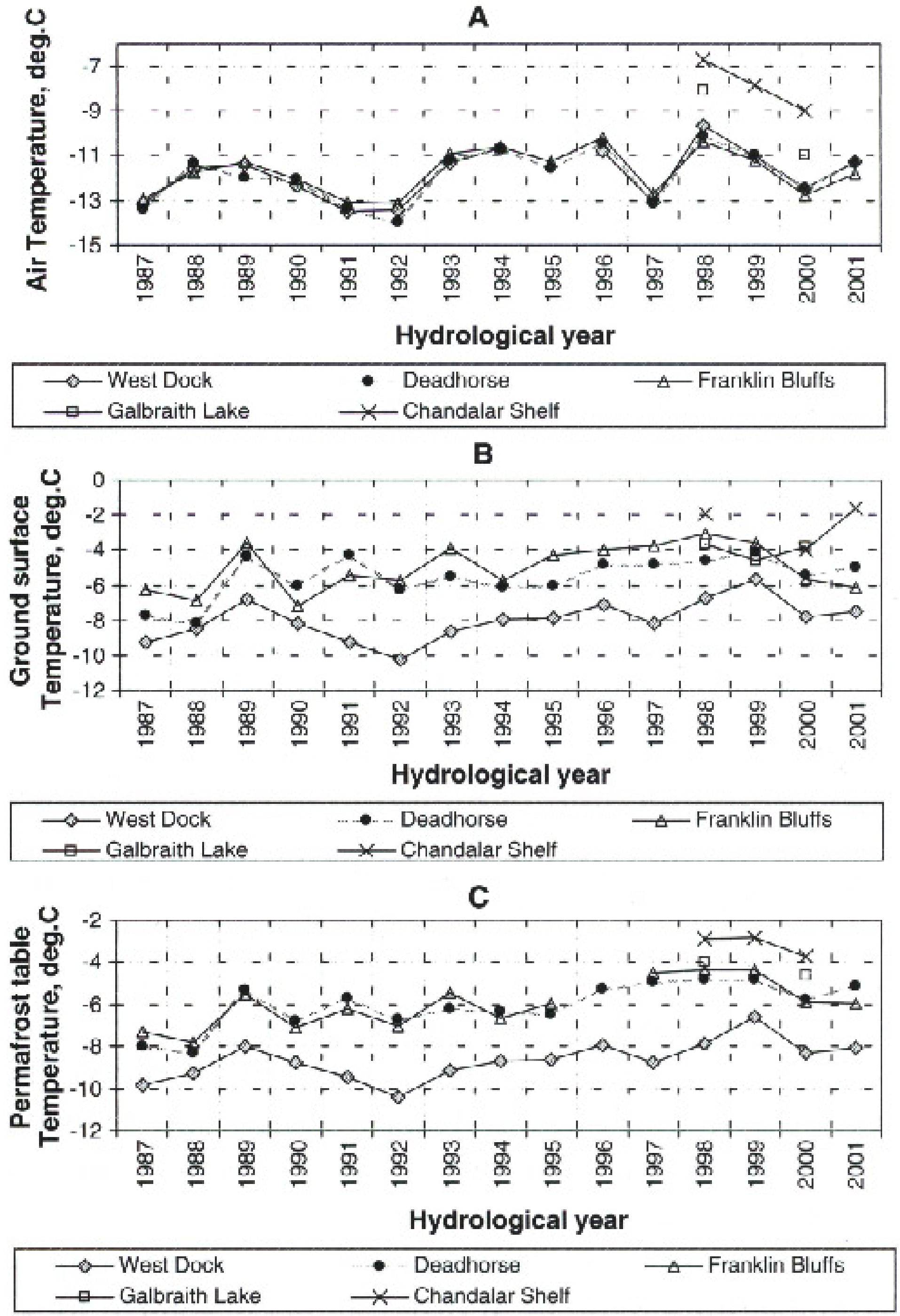
(i) What is being measured?

In Canada there is a lack of long-term MAGT monitoring. One site where such information is available for a period of 8 years is Lupin. The relationship between MAAT and MAGT obtained from this location can be seen in Figure 6.2-3 (presented previously).

(ii) What is happening?

Ground permafrost temperatures are rising across the whole northern hemisphere. This is illustrated by air and ground temperatures changes at 5 locations in Alaska shown on Figure 6.3-1 (Romanovsky *et al* 2004), measurements made near Norman Wells (Couture *et al* 2003) and most recently at Lupin (Holubec 2005).

FIGURE 6.3-1
AIR AND PERMAFROST GROUND TEMPERATURE CHANGES AT 5 ALASKA LOCATIONS

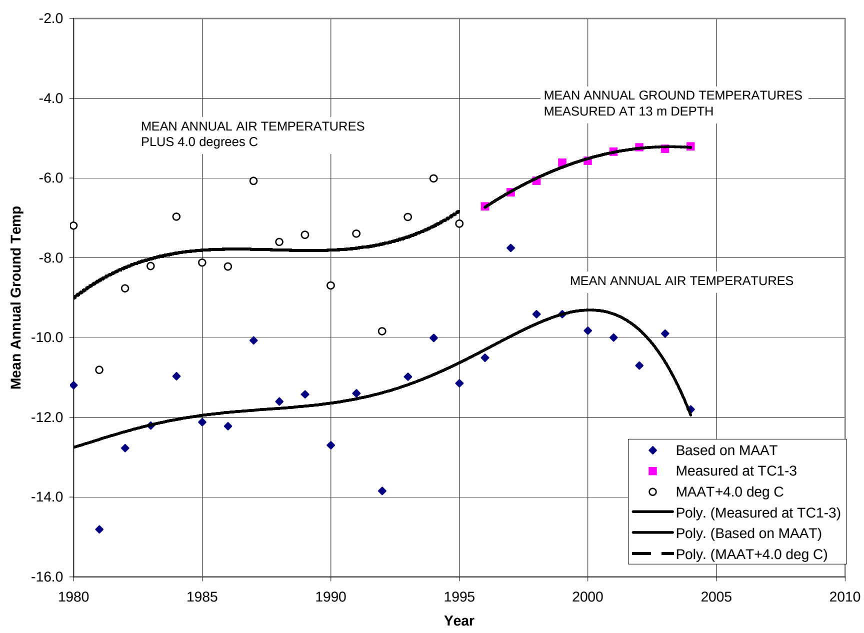


Source: Romanovsky et al 2003).

(iii) Why is it happening?

Figure 6.3-2 illustrates the ground warming and the relationship between MAAT and MAGT. This figure provides MAAT data from 1960 to 2004 and the measured MAGT from 1997 to 2004. To complete the MAGT information from 1960 to 1996 on Figure 6.3-2, the MAGT was derived from that year range using the 4ºC offset. This figure illustrates the warming of the permafrost is directly related to mean annual air temperature (MAAT).

FIGURE 6.3-2
MAAT AND MAGT MONITORED AT LUPIN



Source:Holubec 2005.

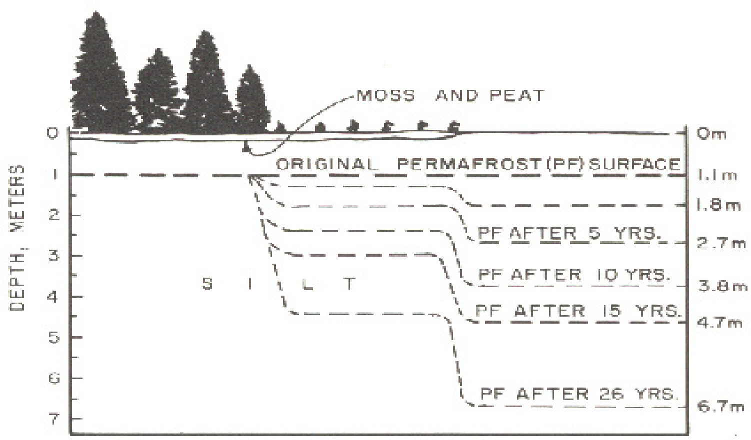
(iv) What does it mean?

International data that is confirmed by Canadian ground temperature monitoring in permafrost regions show that the permafrost ground temperature is rising in lock step with climate warming.

The rationale for monitoring the MAGT at selected sites is that permafrost warming may have a significant environmental impact in time on Actions that are founded on ice rich (high ground ice) permafrost and are not designed for climate warming. The rise in the ground temperature has different immediate impact below the tree-line, Area a), above the tree-line, Area b), and in the Arctic Islands, Area c), as stated below:

Area a) - has a MAGT in the range between 0 to –3ºC and therefore it is very sensitive to ground cover disturbance and permafrost thaw. Ground cover disturbance by clearing trees and removing the organic mat resulting in permafrost thawing is illustrated in Figure 6.3-3. Furthermore, even if the permafrost is preserved during construction, a large part of permafrost in this region will thaw within 10 to 50 years if the present climate warming continues at the present rate.

FIGURE 6.3-3
EFFECT OF VEGETATION REMOVAL ON PERMAFROST



Source: (Linner, 1973).

The warming of permafrost is, or will be, impacting both undisturbed areas and areas affected by Actions in the discontinuous permafrost regions that is represented by much of NWT. This was noted as early as 1990 by Etkin (1990) and more recently by Couture *et al* (2003) and Smith *et al* (2004).

Area b) - the MAGT in the area above the treeline ranges between –3 to –8ºC and is underlain by continuous permafrost. This area is not as readily affected by construction unless there is appreciable organic cover disturbance or major cuts are made in high ground ice conditions. However, permafrost may disappear in about 50 to 150 years. This would negate any dependence on permafrost for physical stability of dams, earth/rock embankments or the concept of permafrost encapsulation of waste materials.

Area c) - has colder MAGT than Area b) where prediction of the effect of climate warming on permafrost is more difficult. It is likely that even here the permafrost may disappear with time, but at a much later date, if the climate warming continues.

(v) What is being done about it?

General ground temperature information is provided in the Canadian Permafrost Map NCR 4177F prepared by Heginbottom et al. (1995). This information needs to be considered as general information since the ground temperature measurements were measured in different years between about 1980 and 1995 and these temperatures were not adjusted to one common year.

Considerable ground temperature measurements have been obtained along the Mackenzie River by the Permafrost group of the GSC Terrain Sciences Division (Smith *et al* 2004). It is likely that the Mackenzie Gas Project has installed similar sensors in the same area.

The ground temperatures information in the northeastern part of NWT where past and most recent mines are located is limited. The best long-term information is available from the Lupin Mine (located just north of the NWT/Nunavut border, Holubec 2005). Ground temperature information is reported to the Mackenzie Valley Water Board by the Ekati and Diavik but this is for relatively short time frame and it is not been analyzed for climate warming.

(vi) What are the information gaps?

There is limited information in regard to the present ground temperature within northeastern NWT and how it is responding to climate warming.

(vii) Overall Assessment and Recommendations

Air temperature - is the most significant parameter in determining the ground temperature and therefore the presence and the state of permafrost. It is recommended that:

- Air temperature data gaps in northeastern NWT be filled with the data from existing operating mines.
- Air temperature data for the NWT be collected and maintained in one central database. This would include data from Environment Canada and DIAND meteorological stations and stations operated by the mines.

Ground temperature – can be used for predicting the time when permafrost may thaw. A consistent ground temperature program should be developed that will provide an overall picture of the permafrost temperature in NWT and how it is changing. To accomplish this it is recommended that:

- A representative ground monitoring program be instituted that will monitor the ground temperatures at about a dozen NWT locations.
- Suitable locations are the existing meteorological stations along the Mackenzie River region and additional meteorological stations and ground temperature locations should be installed in the northeast NWT region.
- Specifications for the temperature sensor should be developed so that there is a consistency in information. The installation should be such, that malfunctioning cables can be replaced in existing tubes without the need for new drilling.
- One group should be responsible for design specification, collecting and analyzing the data and its distribution.

6.3.2 Snow Cover Indicators

Snow cover affects ground temperature because of its insulating properties and reflection of radiation. Snow is one of several parameters that determine the depth of the active layer and the magnitude of the ground temperatures.

(i) What is being measured?

Snow information in the NWT is monitored, assessed and compiled by Environment Canada and DIAND. This information includes snow cover area, depth, properties and duration that are used by water resource groups for hydrological reasons. Snow information collected by the Meteorological Services is available through Canada National Snow Information System for Water (http://www.socc.ca/nsisw/).

(ii) What is happening?

There are numerous scientific discussions on the effects of snow on the permafrost ground temperatures (Holube/GSC 2005). While there is agreement that snow insulates permafrost thereby resulting in warmer ground temperatures, it is also been observed that warmer ground temperatures are associated with snow cover melting earlier in the year due to climate warming.

(iii) What does it mean?

Snow cover is one of the parameters that determine the presence and the temperature of permafrost. However, it is not a dominant parameter and there is a lack of agreement on how it could be used to interpret permafrost ground temperatures.

(iv) Overall Assessment and Recommendation

Measurement of snow cover depth has not been shown to be particularly useful indicator of permafrost conditions.

6.3.3 Ground Ice Indicators

Ice is commonly present in frozen unconsolidated deposits (Johnston 1981); including gravels and bedrock (Mackay and Black 1973). Its volume and distribution within overburden varies greatly.

Ice is an important engineering design parameter if its volume is greater than what is required to fill the voids within a soil matrix or is present in rock fractures. In ice rich soil the ice may affect creep strength that governs slope stability of frozen ground. If the ground ice melts, thawing may produce uneven ground settlement and ground instability in soil and major seepage through fractures in bedrock when located beneath dams.

(i) What is being measured?

Areas with excess ground ice are established by visual identifications and measurement of ice lenses and the determination of ice volumes by melting of fine grained soils.

(ii) What is happening?

Ground ice information has been compiled by the GSC and presented in Canada Permafrost Map, MCR 4177F (Heginbottom 1995). This provides a general picture where ground ice (ice rich soils) is common and should be anticipated. However, presence of excess ground ice at a particular structure location, such as a road, pipeline, building foundation or dam, has to be investigated on a site specific basis.

(iii) What does it mean?

There is sufficient general information to indicate where ground ice may be found. However, for the design and construction of projects, this parameter has to be determined on site specific basis that requires detailed field studies for each structure.

(iv) Overall Assessment and Recommendation

Ground ice is a technical parameter that needs to be determined on site specific basis.

6.3.4 Human Activity/Action Indicators

The impact of human activities on the environment depends largely on the types of activities/actions and their design. The impact may vary from destroying habitat for animals to increasing ground instability or introducing metals in water. Ground instability may lead to erosion that in turn may release large quantities of suspended solids into streams, rivers and lakes.

The Yukon State of the Environment Report (1999) discusses the impacts of actions under different types of human activities. A similar approach was taken in the Updated State of Knowledge Report of the West Kitikmeot and Slave Geological Province (2001) in which the activities are discussed under stress effects due to human activities. In the Deh Cho Cumulative Effects Study, Phase I: Management Indicators and Thresholds (2004), actions are associated with Land and Resource use indicators.

Actions may be classified by type, e.g.: settlements, airstrips, plants, roads & pipelines and mines. This was done by Cizek (2003) for the assessment of human activities of the proposed Bathurst inlet port and road and used by Couture *et al.* (2003) in their paper on the hazards to infrastructure in the North associated with thawing of permafrost. Potential environmental impacts identified by these actions are shown in Table 6.3-2.

TABLE 6.3-2
ACTIONS AND THEIR POTENTIAL IMPACTS ON THE ENVIRONMENT

Action	Impacts and Comments
Settlements, Airstrips & Plants	• Compact area • Settlements & airstrips – likely long life • Settlements & plants – air and water quality • Reclamation requires removal of all physical structures • Likely low impact due to climate warming
Roads & Pipelines	• Linear geometry • May impact watersheds drainage • Impacts during construction and operation • Pipelines; likely operating for 50 years in NWT • Can be reclaimed relatively readily • Climate warming during operation if located in discontinuous permafrost
Mines	• Early mines were mostly small and underground • Most new mines are open pit that produce large quantities of waster rock and tailings • Waste rock may have large visual and migration impact if not designed properly • Major environmental impacts may not start until tens of years after closure if the site is not properly remediated • Tailings may lead to long-term sediment impacts caused by tailings cover and containment structure erosion and physical stability due to permafrost thawing • Potential large long-term environment impact if rock/tailings are acid generating and climate warming and erosion take effect

Actions may have common and specific indicators; for instance, size of land area being impacted and the depletion of esker material may be used by all actions. Actions specific indicators would be applicable to:

a) Settlements and plants that may impact on water quality;
b) Roads and pipelines that have long corridors where vegetation is cleared and that frequently impact a large number of watersheds and streams/rivers, and
c) Waste deposits from mines that may impact terrain and water quality when sulphides are present in the mine wastes.

Sample indicators that may be appropriate for actions include: land area and geometry; ground cover disturbance by construction; granular borrow needs (esker material); drainage impact (roads & pipelines); watershed crossed by unit length of (km^2/km); permafrost and physical stability over life of project and after closure; and, presence and quantities of sulphides in tailings or mine rock and long-term stability of closed storage design.

(i) What is being measured?

Quantifying the impact of actions on the environment in the NWT is in the preliminary stages and has done by several jurisdictions. Two examples where impacts were quantified are: estimation of the physical footprint of human activities in the Bathurst Inlet Port and Road Study Area of the Slave Geological Province (Cizek 2003), and the assessments of potentially acid generating mine wastes provided by abandoned and operating mines that are submitted to the MVLWB by licensed mines (Ekati, Diavik and Snap Lake mines)

(ii) What is happening and what does it mean?

NWT is experiencing much larger development than it has ever experienced in its history. The new operating diamonds mines are creating much larger terrain changes and are producing more mine waste materials than all the 36 closed, and in most instances orphaned, mines combined. Some of the mine wastes have a potential for leaching metals and the resulting seepage from these deposits may impact the quality of adjacent water. Large mine rock and tailings deposits may affect animal habitat and their migration routes. Finally, the stability of these waste structures may deteriorate if permafrost thaws with time.

The development of gas and petroleum resources along the Mackenzie River and Delta and the infrastructures that will be needed for the development of Beaufort Sea may impact the environment as much as the mining industry. The proposed Mackenzie Gas project will have a 1,200 km pipeline route with associated infrastructures and three gas gathering facilities near the Mackenzie Delta. It is likely that new actions with equally large areas and mine waste deposits will follow these actions.

(iii) What are the information gaps?

There is limited cumulative information in one organization to quantify impact of the abandoned, operating and planned projects. The collection of following information would be an asset in assessing the present and long-term effects of actions:

- Footprints of actions within NWT.

- Inventory of esker materials and their exploitation.
- Inventory of potentially metal leaching deposits.
- Measure of development within intermediate watersheds.

(iv) Overall Assessment and Recommendations

Industrial and residential developments and other human activity can have an impact on the physical environment, including permafrost conditions. Accordingly, it is recommended that:

- Actions should be defined for cumulative environmental monitoring and existing and future actions be grouped by type.
- Actions may be grouped as used by regulations and guidelines.

6.4 OTHER CONSIDERATIONS

Time is an important consideration in NWT because of climate warming. Climate warming and the eventual thawing of permafrost may lead to increased erosion. It is likely that when this occurs, access to abandoned sites will be difficult or impossible by winter/ice roads and the airstrips may not be available.

The Canadian Environmental Assessment Agency Guide (1998) indicates that monitoring environmental cumulative impact should consider past, present and future conditions. Variations of permafrost ground temperatures across the NWT and climate warming will lead to thawing of the permafrost and therefore the design of facilities (e.g., roads, dams, etc.) should to be evaluated at different time stages.

For instance, the greatest potential environmental impacts in the short time frame may occur during the construction and operation phases of facilities in areas with low ground temperature; such as is the case of the Mackenzie Gas Project. Routing of the pipeline through vegetated areas underlain by ground susceptible to thaw settlement may lead to problems during the construction period. Additionally, problems could be experienced during the operation phase since large section of the pipeline route is in discontinuous permafrost that may thaw during the operation phase of some 40 years.

Construction and operation of projects in the NWT are governed by federal and territorial legislation and regulation and land agreements with applicable aboriginal and First Nation’s people. Some of the regulatory regimes include the Territorial Lands Act, Northwest Territorial Waters Act, Arctic Water Pollutions Prevention Act, Mackenzie Valley Resource Management Act, Environmental Protection Act, Fisheries Act and Canada Mining Regulations.

Guidelines provide objectives, principles and design criteria for planning, operation and final remediation of projects. Most of the guidelines prepared for the NWT were prepared by DIAND between 1987 and 1994. Other contributors have been NWT Water Board, Government of NWT and technical associations. A list of Guidelines prepared for the NWT and the agencies that have prepared these guidelines are given in Table 6.4-1.

Guidelines are complimented by technical publications, such as texts, technical reports, conference proceedings and journal papers. Texts and technical reports describe the properties and behaviour of materials, analyses methods, suggest design procedures and provide selected case histories. Conference proceedings and journal papers concentrate more on recent research and case histories. These do not provide the information that guidelines should provide.

Two of the most relevant textbooks on dams (temperature, climate) and permafrost were written in 1963 and 1981. These books are based on extensive experience and deal with both design and construction. These have been complimented by Environmental Geochemistry of Minesite Drainage (Morin and Hutt 1997) and extensive coverage of acid mine drainage by the MEND program. The most up to date technical information is presented in engineering journals, symposia and conferences.

Guidelines were prepared when climate warming and the concern about cost of remediation of orphaned mines were not identified. Present NWT guidelines do not sufficiently address NWT permafrost conditions nor do they consider the impact of climate warming on Actions. Hence, DIAND has initiated the preparation of new Guidelines for Mine Reclamation for NWT and Nunavut to be completed in late 2005 or early 2006.

Projects contemplated for development in the NWT need to:

- Reflect the complexity of permafrost,
- Address effect of climate warming; and,
- Consider cumulative environmental impact in the longer time span.

Closure planning needs to consider the fact that it is costly to access and remediate problems at remote sites once the infrastructure has been removed.

TABLE 6.4-1
PARTIAL LIST OF GUIDELINES AND TECHNICAL PUBLICATIONS RELEVANT TO NWT
DETAILED REFERENCE INFORMATION ON ABOVE GIVEN IN SECTION 8.2 REFERENCES

Guidelines - DIAND		
Reclamation Guidelines for Northern Canada	1987	DIAND
Guidelines for Tailings Impoundment in the NWT	1987	DIAND
Environmental Operating Guidelines: Access Roads & Trails	1990	DIAND
Guidelines for Acid Rock Drainage Prediction in the North	1992	DIAND
Mine Reclamation in Northwest Territories and Yukon	1992	DIAND
Land Use Guidelines: Access Roads and Trails	1984	DIAND
Environmental Operating Guidelines: Hydrocarbon Well-Sites in Northern Canada	1986	DIAND
Environmental Operating Guidelines: Access Roads & Trails	1990	DIAND
Guidelines for ARD Prediction in the North	1992	DIAND
Mine Reclamation in Northwest Territories and Yukon	1992	DIAND
Land Use Guidelines: Mineral Exploration, DRAFT	2000	DIAND
Mine Site Reclamation Policy for the Northwest Territories	2002	DIAND
Guidelines NWT		
Guidelines for Tailings Impoundments in the Northwest Territories	1992	NWT Water Board
Guidelines for Abandonment and Restoration Planning for Mines in NWT	1990	NWT Water Board
Env. Guidelines for Construction, Maintenance & Closure of Winter Roads in NWT	1993	GNWT
Guidelines - Others		
Canadian Water Quality Guidelines. Freshwater Aquatic Life.	1991	Environment Canada
Pipeline Abandonment; A Discussion Paper on Technical and Environmental Issues	1996	Pipeline Abandonment Steering Committee
A Guide to the Management of Tailings Facilities	1998	Mining Association of Canada
Watercourse Crossings	1999	Cdn Pipeline Environmental Committee
Dam Safety Guidelines	1999	Canadian Dam Association
Classical Textbooks and MEND Reports		
Water Crossing Handbook	1999	Cdn Pipeline Water Crossing Committee
Earth-Rock Dams, Engineering Problems of Design and Construction	1963	Sherard *et al.*
Permafrost, Engineering Design and Construction	1981	Edited by G.H. Johnston.
Environmental Geochemistry of Minesite Drainage	1997	K.A. Morin and N.M. Hutt
MEND Manual, Vol. 1 - Summary	2002	MEND Rpt 5.4.2 SENES Consultants Limited
MEND Manual Vol. 6 - Monitoring	2000	MEND Rpt 5.4.2f SENES Consultants Limited
Covers for Reactive Tailings Located in Permafrost Regions Review	2004	MEND Rpt; 1.61.4. I. Holubec

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DIAND, 2000. *Draft: Toward a Mine Site Reclamation Policy for the Northwest Territories.* Discussion paper. p 18.

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Hardy Associates (1978) Ltd. 1984. *Land Use Guidelines; Access Roads and Trails.* For Land Resources, Northern Affairs Program, DIAND p 49.

Hardy BBT Limited 1987. *Reclamation Guidelines for Northern Canada.* For Land Resources, Northern Affairs Program, DIAND. P 40.

Hardy BBT Limited 1990. *Environmental Operating Guidelines: Access Roads and Trails.* For Land Resources, Northern Affairs Program, DIAND. P 49.

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Johnston, G.H. 1981. *Permafrost, Engineering Design and Construction.* National Research Council of Canada, John Wiley & Sons, 1981. 483 p.

Kent, R & Technical Advisory Committee 1990. *Guidelines for Abandonment and Restoration Planning for Mines in the Northwest Territories.* NWT Water Board. P 12.

Mining Association of Canada team 1998. *A Guide to the Management of Tailings Facilities.* Prepared as part of Environmental Management Framework. p 48.

Morin, K.A. and Hutt, N.M. 1997. *Environmental Geochemistry of Mine-Site Drainage: Practical Theory and Case Studies.* MDAG Publishing, Vancouver, BC. P 333.

National Energy Board 1996. *Pipeline Abandonment: A Discussion Paper on Technical and Environmental Issues*. For Pipeline Abandonment Steering Committee. P 41.

SENES Consultants Limited (SENES) 2002. *MEND Manual, Volume 1- Summary. MEND 5.4.2a.* Tremblay G.A. and Hogan, C.M. editors. P 109

SENES Consultants Limited (SENES) 2000. *MEND Manual, Vol 6- Monitoring, MEND 5.4.2f. MEND Program.* Tremblay G.A. and Hogan, C.M. editors. P 113,

Spencer Environmental Mgt Services Ltd. *Environmental Operating Guidelines: Hydrocarbon Well-Sites in Northern Canada.* For Land Resources, Northern Affairs Program, DIAND. P 38.

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