

# DECISION MAKERS ATLAS: GEOSCIENCE INFORMATION FOR THE MACKENZIE DELTA AREA



Editors: M.J. Palmer and S.V. Kokelj

March 2015



Government of the Northwest Territories  
Department of Environment and Natural Resources  
Conservation Assessment and Monitoring  
Cumulative Impact Monitoring Program  
PO Box 1320  
Yellowknife, NT, X1A 3S8  
[nwtcimp@gov.nt.ca](mailto:nwtcimp@gov.nt.ca)

**Disclaimer:**

The Government of the Northwest Territories (GNWT) assumes no liability in connection with the information provided in this Atlas. While every effort is made to ensure the information contained is correct, the GNWT disclaims any liability in negligence or otherwise for any loss or damage which may occur as a result of reliance on any of this material. This Atlas is intended to provide general information. It is not meant as a replacement for site-specific geotechnical investigations by engineering and geoscience professionals.

**Acknowledgments:**

Many staff in the Government of the Northwest Territories (Centre for Geomatics, Dept. of Lands; Northwest Territories Geoscience Office, Department of Industry Tourism and Investment; Conservation, Assessment and Monitoring Division, Department of Environment and Natural Resources; Policy and Strategic Planning Division, Department of Environment and Natural Resources; Environment Division, Department of Environment and Natural Resources and Technical Services, Department of Transportation) and the Geological Survey of Canada (Natural Resources Canada) contributed to this project.

With federal support through Natural Resources Canada's Regional Adaptation Collaborative Program

**Suggested Citation:**

Department of Environment and Natural Resources. 2015. Decision Makers Atlas: Geoscience Information for the Mackenzie Delta Area. Palmer and Kokelj, (eds.). Government of the Northwest Territories. Cumulative Impact Monitoring Program, Yellowknife.

## TABLE OF CONTENTS

Introduction.....	3
Chapter 1: Ground temperatures in the Mackenzie Delta region .....	4
Chapter 2: Ice wedges and polygonal terrain .....	9
Chapter 3: Human development activity in the Mackenzie Delta area.....	15
Chapter 4: Permafrost Map for Northwestern Canada (Mackenzie Region)..	19

## **Introduction**

### **The Decision Makers Atlas series**

The Decision Makers Atlas series is a tool designed to bridge the gap between the generation of environmental data and decision making. The Atlas provides synthesized environmental information to decision makers for high priority areas in the Northwest Territories.

The Atlas concept is a plain language narrative with an interactive map file in Google Earth™ Kml format that contains site specific summary data and links to relevant reference material and raw data. This pilot version of the Atlas was developed for the Mackenzie Delta region: an area of development activity and where a significant amount of environmental research has taken place. Chapters of the Atlas are thematic and tell a story through plain language narrative and synthesized environmental information in the form of maps and summary figures. Users are linked to databases and other sources that contain raw environmental data through the interactive map file.

Decision makers require current and reliable environmental information to make sound environmental management decisions. This information often exists in peer-reviewed journal publications or technical reports that are inaccessible to many decision makers. The Atlas is a starting point for decision makers to learn about and visualize the results of pertinent environmental research being conducted in regions of interest.

### **The Mackenzie Delta Area Decision Makers Atlas**

The Mackenzie Delta region is a unique and dynamic environment in Canada's western Arctic. The region is characterized by Canada's largest delta and most of the landscape is underlain by ice-rich permafrost. Biophysical conditions in the region are diverse due to the presence of tree line, the proximity of the coast and the variation in regional morphology.

Several large infrastructure projects are being considered and constructed in the region including the Mackenzie Gas Project and an all-season road between Inuvik and Tuktoyaktuk. Sound planning, timely assessment and responsible management of projects is dependent on understanding environmental conditions and how they impact a project throughout its lifecycle. Therefore, decision makers, including planners, engineers, regulators and operators require an understanding of the current state of permafrost in the region.

## CHAPTER 1: GROUND TEMPERATURES IN THE MACKENZIE DELTA REGION

M. Palmer<sup>1</sup>, S.V. Kokelj<sup>1</sup>, C.R. Burn<sup>2</sup>, S.L. Smith<sup>3</sup>, C. W. Stevens<sup>3</sup>, and R.L. Jenkins<sup>4</sup>

<sup>1</sup> Conservation Assessment and Monitoring Division, Cumulative Impact Monitoring Program, Environment and Natural Resources, Government of the Northwest Territories, Yellowknife NT

<sup>2</sup> Department of Geography and Environmental Studies, Carleton University, Ottawa, ON

<sup>3</sup> Geological Survey of Canada, Natural Resources Canada, Ottawa, ON

<sup>4</sup> Water Resources Division, Environment and Natural Resources, Government of the Northwest Territories, Yellowknife NT

### INTRODUCTION

Permafrost is defined as ground that remains below 0°C for two or more years (ACGR, 1988). In northern environments this “frozen ground” often acts as a foundation for buildings, roads and other infrastructure projects. Therefore, the sound management of these projects requires an understanding of the state of permafrost in the region, the factors that control permafrost conditions and how these conditions may impact a project throughout its lifecycle.



**Figure 1** These photographs show the range of field conditions in the Delta region. The figure on the left is from the boreal forest near Inuvik, and the right is in upland tundra on Kendall Island, adjacent to the Beaufort Sea Coast. The sites are approximately 120 km apart.

## ABOUT THE DATA

Ground temperatures have been recorded at many different locations across the transition from the boreal forest near Inuvik to the tundra near the Beaufort Sea coast. To describe the **regional variation** in permafrost conditions, the Atlas compiles ground temperature information from several studies in the uplands and in the floodplain of the Mackenzie Delta. Instrumentation at stream valleys (hilltops, valley slopes and valley bottoms) offers insight into **local variation** in permafrost conditions across tree line. Thaw slumps, old drilling mud sumps and other disturbed locations have been instrumented in the region and help us to understand how ground temperatures respond to **natural and human caused disturbance**.

Additional information on the study design and methods for instrument installation are available in the individual publications listed in the references section, the NTGOMap database (<http://ntgomap.nwtgeoscience.ca>), or from the CIMP secretariat ([cimp@nwtcimp.ca](mailto:cimp@nwtcimp.ca)). This data has been reported in peer reviewed journal articles, GSC-NTGO Open File Reports and has been used in The Government of Canada Intervention on the Mackenzie Gas Project. See references at the end of the chapter for a complete list.

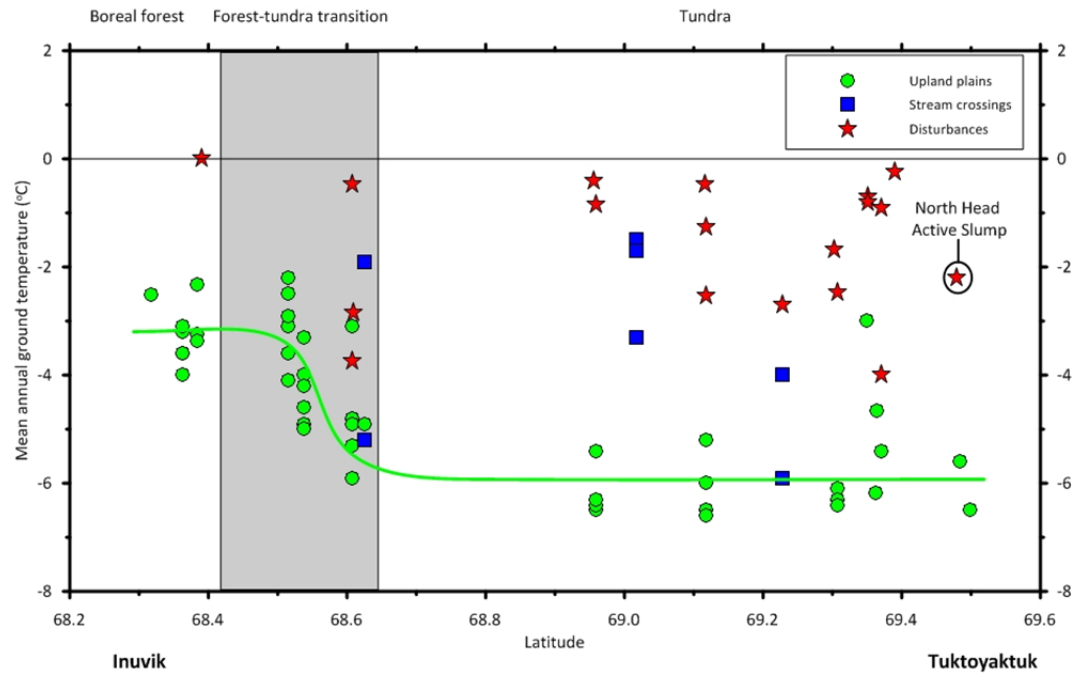
## THE STORY

The Mackenzie Delta region is characterized by a northward decrease in ground temperatures (Fig. 2). Permafrost in tundra uplands is typically lower than  $-5^{\circ}\text{C}$ , but permafrost in the boreal forests is typically above  $-2^{\circ}\text{C}$ . The gradient towards cooler temperatures at the coast is not linear, as most of the changes in ground temperature occur near the forest-tundra transition (Fig. 2). In the tundra uplands the most dramatic transition occurs just to the north of Inuvik.

It is important for infrastructure planners to recognize that permafrost temperatures can also vary across small distances or locally with slope, vegetation or moisture conditions. For example, the differences in ground temperatures across a stream valley could vary as much as across the entire region (Fig. 2). Temperatures on north facing slopes are generally similar to nearby upland plain locations, but in valley bottoms, where soil moisture is higher and snow tends to accumulate, ground temperatures can be  $1\text{-}3^{\circ}\text{C}$  warmer. The effect of disturbance on the ground thermal regime is also significant. Colonization of tall shrubs and enhanced snow accumulation at historical oil and gas leases can cause significant permafrost warming even at locations near the coast where undisturbed, or natural background conditions, may be as cold as  $-7^{\circ}\text{C}$  (Fig. 2).

Snow cover plays an important role in controlling the temperature of permafrost in the region. Ground temperatures are warmer in areas with a thick snow cover as the presence of snow insulates the ground during long winters. Regionally, snow cover is thicker in the forest than on the tundra, as strong winds on the tundra redistribute the snow cover to valley bottoms and areas with tall shrub cover. Locally, south facing slopes and valley bottoms, tend to gather more snow than surrounding landscapes, especially in areas where there is lots of redistribution of snow, such as in tundra environments. Disturbed areas in the region typically revegetate with tall shrubs. Following disturbances such as fire, thaw slumping or construction of drilling

mud sumps, destruction of an insulating surface organic cover in conjunction with shrub growth and snow capture can lead to dramatically warmer permafrost temperatures.



## RELEVANCE TO DECISION MAKERS

It is important for decision makers to consider both regional and local scale variation that exists in permafrost temperatures when designing, planning and assessing infrastructure projects in the region. While the undisturbed background conditions are well below 0°C in most areas, permafrost may thaw due to changes in vegetation, topography, soil moisture and organic layer thickness as a result of disturbance. This may have substantial effects on the integrity of the overlying infrastructure which typically relies on permafrost as a foundation. It is also important to consider the cumulative effects of both the project and of climate change on the long-term integrity of the permafrost. Proper consideration of these factors will ensure robust project design and facilitate responsible resource development.

## REFERENCES OF INTEREST AND RELEVANT LINKS

- ACGR. 1988. Glossary of permafrost and related ground-ice terms. Permafrost Subcommittee, Associate Committee on Geotechnical Research. National Research Council of Canada, Ottawa. 156 pp.
- Burgess, M.M. and Smith, S.L. 2000. Shallow ground temperatures. *In* The Physical Environment of the Mackenzie Valley, Northwest Territories: a Base Line for the Assessment of Environmental Change, *edited by* L.D. Dyke and G.R. Brooks. Geological Survey of Canada, Bulletin 547, p. 89-103.
- Burn, C.R. 1997. Cryostratigraphy, paleogeography, and climate change during the early Holocene warm interval, western Arctic coast, Canada. *Canadian Journal of Earth Sciences*, **34**: 912-925.
- Burn, C.R., Kokelj, S.V. The environment and permafrost of the Mackenzie Delta area. *Permafrost and Periglacial Processes*, **20**: 83-106.
- Lantz, T.C., Kokelj, S.V. 2008. Increasing rates of retrogressive thaw slump activity in the Mackenzie Delta region, N.W.T., Canada. *Geophysical Research Letters*, **35**:
- Mackay, J.R. 1963. The Mackenzie Delta area, NWT Geographical Branch, Department of Mines and Technical Surveys, Ottawa, Memoir 8.
- Mackay, J.R., Burn, C.R. 2009. The thermal regime of permafrost and its susceptibility to degradation in upland terrain near Inuvik, N.W.T. *Permafrost and Periglacial Processes*, **20**: 221-227.
- Mackay, J.R., and MacKay, D.K. 1974. Snow cover and ground temperatures, Garry Island, N.W.T. Arctic, **27**. pp 287-296.

Northwest Territories Geoscience Office. 2011. Northwest Territories Geoscience Office GOMap database. <http://ntgomap.nwtgeoscience.ca>.

Palmer, M.J., Burn, C.R., Kokelj, S.V. 2012. Factors controlling permafrost temperatures across tree line in the uplands east of the Mackenzie Delta area. Canadian Journal of Earth Sciences.

Stevens, C.W., Palmer, M.J., Wolfe, S.A., Kokelj, S.V., Kokelj, S.V. 2011. Permafrost and environmental conditions at stream crossing sites in the northern Mackenzie Corridor, Northwest Territories. Geological Survey of Canada Open File Report 6976.

## CHAPTER 2: ICE WEDGES AND POLYGONAL TERRAIN

S.V. Kokelj<sup>1</sup>, T.C. Lantz<sup>2</sup>, C.R. Burn<sup>3</sup>, S. Wolfe<sup>4</sup>, J. Kanigan<sup>5</sup>, and D. Irwin<sup>1</sup>

<sup>1</sup> NWT Geoscience Office, Department of Industry, Tourism and Investment, Government of the Northwest Territories, Yellowknife, NT

<sup>2</sup> School of Environmental Studies, University of Victoria, Victoria, BC

<sup>3</sup> Department of Geography and Environmental Studies, Carleton University, Ottawa, ON

<sup>4</sup> Geological Survey of Canada, Natural Resources Canada, Ottawa, ON

<sup>5</sup> Conservation Assessment and Monitoring Division, Cumulative Impact Monitoring Program, Environment and Natural Resources, Government of the Northwest Territories, Yellowknife NT

### INTRODUCTION

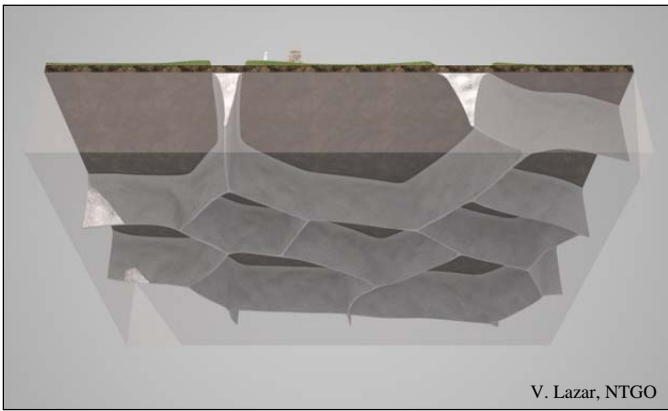
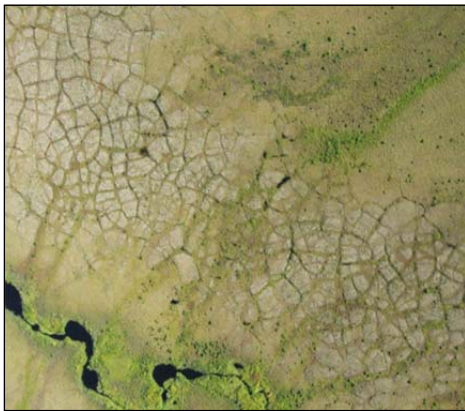
Permafrost is defined by temperature (see previous section), but the sensitivity of permafrost terrain is related to the amount and distribution of near-surface ground ice. Knowledge of the distribution and physical characteristics of near-surface permafrost is critical to anticipate the consequences of near-surface thawing and to appropriately plan the development and maintenance of infrastructure.

Ice wedges are one of the most common forms of near-surface ground ice in the Mackenzie Delta region. They are bodies of pure ice that develop due to contraction and cracking of the ground in winter (Figure 1). The infiltration and refreezing of snowmelt can form a vein of ice causing the ice wedge to grow. Repeated cracking over hundreds to thousands of years can lead to the development of large ice wedges (Figure 1) and extensive ice wedge networks (Figure 2A, B). Ice wedge networks form polygonal terrain, which is extremely sensitive to disturbance or climate change because wedge ice is typically encountered at the top of permafrost (Figure 2B). Thawing of near-surface permafrost in areas of polygonal terrain can lead to an irregular pattern of surface settlement.

In uplands surrounding the Mackenzie Delta, the northward transition from subarctic boreal forest to low-shrub tundra and variation in soil type leads to distinct differences in the ground temperatures and settings for the development and preservation of wedge ice. The degradation of ice wedges has caused significant challenges to the design and maintenance of linear infrastructure such as roads and pipelines. Degradation of polygonal terrain has also compromised buildings and waste disposal sites in areas of ice-rich permafrost. In this part of the atlas we report information on the distribution and density of polygonal terrain and on the size of wedge ice across treeline.



**Figure 1.** A large ice wedge exposed in headwall of a thaw slump on Niglintgak Island, outer Mackenzie Delta region. The wedge is more than 3 m wide and extends several meters into permafrost. Wedge ice is encountered immediately beneath the base of the active layer so near-surface thawing can result in subsidence and terrain modification.



**Figure 2.** (A) Tundra polygons in the Jimmy Lake area, Mackenzie Delta region, Canada. (B) A schematic view of the ice-wedge networks which polygonal terrain.

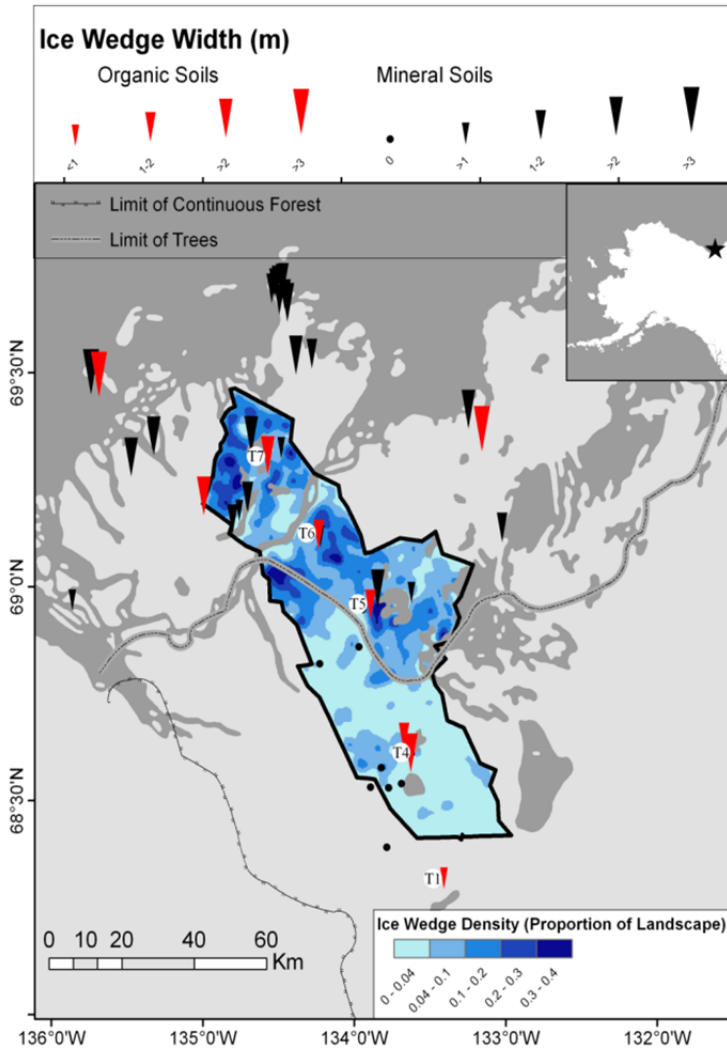
## ABOUT THE DATA

To examine the regional distribution of ice wedges, 1:30,000 scale aerial photographs were used to map all areas of polygonal terrain within a 3739 km<sup>2</sup> study corridor (Figure 2) [MVAP, 2004]. This data was summarized using ARC GIS to create a map showing the density of polygonal terrain.

To examine the size of ice wedges we summarized observations of individual wedges in the exposures of thaw slumps and quarries, and by shallow drilling in peatlands (Mackay, 2000; Kokelj et al., in preparation). The width of the ice wedge and the depth of the ice below the ground surface were recorded for each observation. This data along with information on wedge location, geomorphic setting, surficial materials and stratigraphy was compiled to support the database. Maximum ice wedge size observed in each exposure is shown on the map.

## THE STORY

The density and the size of ice wedges decreased southward across treeline with increasing ground temperatures. Large ice-wedges are widespread throughout the northern dwarf shrub tundra region. Polygonal terrain underlies up to 40% of the total landscape in the northern part of the study region. The largest ice wedges were up to 4 m in width and extended several meters below into the permafrost (Figure 3). The mapping and field observations reveal an abrupt decline in wedge ice occurrences and size through the tall shrub transition zone that is consistent with a southward increase in permafrost temperatures. In the tall shrub transition zone and subarctic boreal forest in the southern part of the study region, polygonal terrain is restricted to organic deposits such as peatlands. In the subarctic region ice wedges in the peatlands were at least 1 m below the ground surface and they were typically much less than 1 m in width.



**FIGURE 3.** Map showing density of polygonal terrain in the treeline transition study area and wedge ice characteristics in mineral and organic soils.

#### RELEVANCE TO DECISION MAKERS

This representation of data shows that terrain underlain by ice wedges can be effectively mapped at regional scales. Information in this Chapter also shows that ice wedges are both larger and more widespread in the northern shrub tundra regions than in the subarctic near Inuvik. Polygonal terrain in the shrub tundra contains significant amounts of ice because the wedges are very large. The density of polygonal terrain, the size of the ice wedges and their proximity to the ground surfaces can pose significant challenges to the construction and maintenance of infrastructure. This is evident in a regional assessment of infrastructure integrity which shows that degradation of ice wedges has had a notable, negative impact on

historical well sites and sumps in the northern part of the study region (Figure 4). The infrastructure impacts of ice wedge degradation decrease southward with the lower density and smaller size of ice wedges. Finally, in the subarctic boreal region, infrastructure planners should consider avoiding organic deposits which host wedge ice and when these materials are saturated they become highly susceptible to thermal degradation.



**Figure 4.** Examples of drilling-mud sumps and lease areas showing varying magnitudes of terrain subsidence caused by ice wedge degradation, Mackenzie Delta region, Canada. (1) Site 1 is in the tall shrub transition zone and shows no evidence of ice wedge subsidence; (2) Site 2 shows minor to moderate subsidence due to ice wedge degradation; and (3) Site 3, located in the dwarf shrub tundra is the most northerly site and has experienced major surface subsidence and ponding due to ice wedge degradation.

## REFERENCES OF INTEREST AND RELEVANT LINKS

- ACGR. 1988. Glossary of permafrost and related ground-ice terms. Permafrost Subcommittee, Associate Committee on Geotechnical Research. National Research Council of Canada, Ottawa. 156 pp.
- Kokelj, S.V., Pisaric, M.F.J. and Burn, C.R. 2007. Cessation of ice-wedge development during the 20th century in spruce forests of eastern Mackenzie Delta, Northwest Territories, Canada. *Canadian Journal of Earth Sciences* **44**: 1503–1515.
- Mackay, J.R. 1990. Some observations on the growth and deformation of epigenetic, syngenetic and anti-syngenetic ice wedges. *Permafrost and Periglacial Processes*, **1**: 15-29.
- Mackay, J.R. 2000. Thermally induced movements in ice-wedge polygons, western Arctic coast: a long-term study. *Géographie physique et Quaternaire*, **54**: 41-68.

## CHAPTER 3: HUMAN DEVELOPMENT ACTIVITY IN THE MACKENZIE DELTA AREA

M. Palmer<sup>1</sup>, S. Kokelj<sup>1</sup>, D. Panayi<sup>2</sup>, D. Irwin<sup>3</sup>, B. Sieben<sup>4</sup>,

<sup>1</sup>Conservation Assessment and Monitoring Division, Cumulative Impact Monitoring Program, Environment and Natural Resources, Government of the Northwest Territories, Yellowknife NT

<sup>2</sup>Golder Associates, Yellowknife, NT

<sup>3</sup>NWT Geoscience Office, Industry Tourism and Investment, Government of the Northwest Territories, Yellowknife, NT

<sup>4</sup>Environment Division, Climate Change Unit, Environment and Natural Resources, Government of the Northwest Territories, Yellowknife, NT

### INTRODUCTION

Information on the location and extent of past development and natural disturbance is required by regulators, industry, communities and other stakeholders to make effective decisions about future development in the Northwest Territories (NWT). An up-to-date inventory of natural and human induced changes on the landscape is a critical tool for monitoring and assessing these cumulative effects. This chapter of the atlas presents information on the location and extent of current and historic development in the Inuvialuit Settlement Region and the Gwich'in Settlement Area.

### ABOUT THE DATA

An inventory of current and historic development activity was compiled for the Inuvialuit Settlement Region and the Gwich'in Settlement Area using a variety of regulatory permitting records, resource management planning information and publically available geospatial base data. Human activity was defined as features on the landscape created by people, that may not only cause impacts while they are active (e.g. noise) but may continue to cause impacts after their operations are complete (ie. habitat fragmentation, contaminant sources). All of the information gathered was combined into a single file for each data type (ie. point data, line data and polygon data). Attributes about the data were streamlined between all sites and were populated with existing data where available. Examples of attribute information include the location of the disturbance, the type of operation, and the start/end date of operations. Complete details on how information was compiled can be found in the individual reports cited in the reference section at the end of this chapter available through the [NWT Discovery Portal \(www.nwtdiscoveryportal.enr.gov.nt.ca\)](http://www.nwtdiscoveryportal.enr.gov.nt.ca). The data from the inventory is available in shapefile format or KMZ format (Google Earth™).

### LIMITATIONS OF THE DATASET

The data as provided are subject to a variety of limitations. Central to these limitations is that coordinate locations for project activities gathered from permitting records are often imprecise. This leads to spatial inaccuracy when displaying this information in the visual tool. This suggests that the inventory is more appropriately used at the regional or landscape scale rather than at a local scale where spatial inaccuracies may significantly affect the results.

CIMP is leading a collaborative effort to develop a more detailed inventory of human activity on the landscape. Part of this initiative will be to visually reference human activity on the landscape at an appropriate scale and to include more detailed information on the timing and extent of operations in the inventory.

Finally, it is important to note that these data constitute an “inventory”, and do not provide an assessment of the impacts of disturbance on specific valued components. The determination of the impact of these cumulative disturbances on a particular valued component is left to the user to determine and demonstrate.

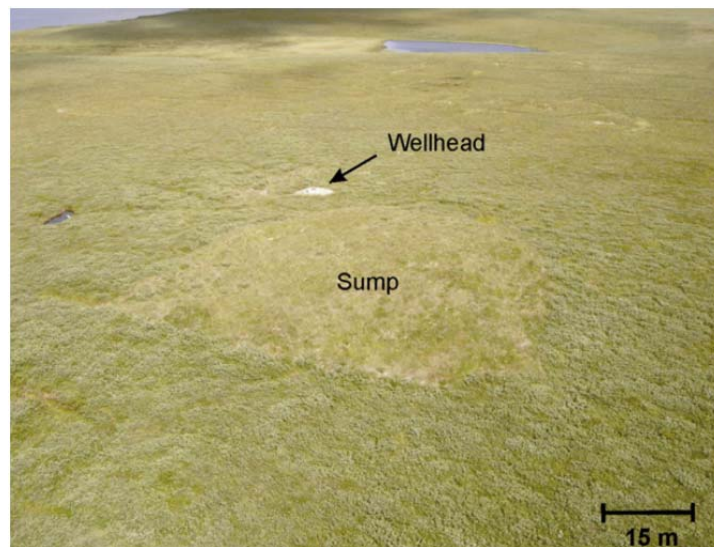


Figure 1. Drilling mud sump and wellhead Ivik N-17, northern Richards Island, Mackenzie Delta area



Figure 2. Seismic lines in the Mackenzie Delta. Photo D.Downing/ENR

## THE STORY

The Inuvialuit Settlement Region and the Gwich'in Settlement Area have been the focus of considerable resource exploration since the late 1960's. The majority of human disturbance features in the Inuvialuit Settlement Region are associated with these past resource exploration initiatives. Oil and gas exploration well-heads account for 63% of point features in the Inuvialuit Settlement Region and seismic lines are the predominant linear feature included in the inventory. The integrity of drilling mud sumps, which are often associated with oil and gas exploration wells in the region (Fig.1), is of concern to the Inuvialuit and the Gwich'in and several research and monitoring initiatives have been undertaken to survey sumps in the area and to determine the factors which control the integrity of these features (Jenkins et al. 2008; Kokelj et al. 2010). The atlas includes other human activities, including: airstrips, outfitter camps, contaminated sites, communications facilities, winter roads, pipelines and cutlines. A database of contaminated sites as classified by the Federal Contaminated Sites Bureau ([www.tbs-sct.gc.ca/fcsi-rscf/home-accueil-eng.aspx](http://www.tbs-sct.gc.ca/fcsi-rscf/home-accueil-eng.aspx)) is included in the inventory and represents Distant Early Warning (DEW) line sites, historic fuel containment areas, oil and gas staging areas and others.

## RELEVANCE TO DECISION MAKERS

Decision makers in the NWT are required to assess the cumulative effects of human activity as part of environmental assessment and land use planning. In order to undertake a robust cumulative effects assessment, decision makers require an accurate and detailed inventory of past and present human activity on the landscape for the area in question. It is currently the responsibility of the interested party (i.e. developer / land-use planning board) to compile information on developments and natural disturbances in the area of interest in order to be able to conduct a cumulative effects assessment. The lack of a comprehensive standardized disturbance dataset leads to inconsistencies in assessments, and subsequently leads to challenges in regulatory and land use planning processes. As a first step, CIMP has put together an inventory of human activity in the Inuvialuit Settlement Region and the Gwich'in Settlement Area using permitting records and other regulatory files.

## REFERENCES AND PUBLICATIONS OF INTEREST

Golder Associates Ltd. 2009. Observations and Recommendations for Human Development Data Collections in the Northwest Territories. Prepared for the Cumulative Impact Monitoring Program. March, 2009.

IMG-Golder Corp. 2010. Industrial Development and Human Activity Database for the Inuvialuit Settlement Region. Prepared for the Cumulative Impact Monitoring Program. March, 2010.

[http://sdw.enr.gov.nt.ca/nwtdp\\_upload/ISR\\_FOOTPRINT\\_DATABASE\\_FINAL\\_REPORT\\_DOC](http://sdw.enr.gov.nt.ca/nwtdp_upload/ISR_FOOTPRINT_DATABASE_FINAL_REPORT_DOC)

West Delta Golder Corporation. 2012. Human Development in the Gwich'in Settlement Area: A Spatial Database. Prepared for Department of Environment and Natural Resources, GNWT. May, 2012.

[http://sdw.enr.gov.nt.ca/nwtdp\\_upload/Draft\\_GSA\\_Development\\_Database\\_Report\\_16\\_August.pdf](http://sdw.enr.gov.nt.ca/nwtdp_upload/Draft_GSA_Development_Database_Report_16_August.pdf)

Jenkins, R.E.L., Kanigan, J.C.N., Kokelj, S.V., 2008. Factors contributing to the long-term integrity of drilling-mud sump caps in permafrost terrain, Mackenzie Delta region, Northwest Territories, Canada. In: Kane, D.L., Hinkel, K.M. (Eds.), Proceedings of the Ninth International Conference on Permafrost, 29 June to 3 July 2008, University of Alaska Fairbanks, vol. 1, pp. 833–838

Kokelj, S.V., Riseborough, D., Coutts, R., Kanigan, J.C. 2010. Permafrost and terrain conditions at northern drilling-mud sumps: Impacts of vegetation and climate change and the management implications. *Cold Regions Science and Technology*, **64**: 46-56.

Treasury Board of Canada Secretariat. Federal Contaminated Sites Inventory. <http://www.tbs-sct.gc.ca/fcsi-rscf/home-accueil-eng.aspx>. Last accessed February 7, 2013.

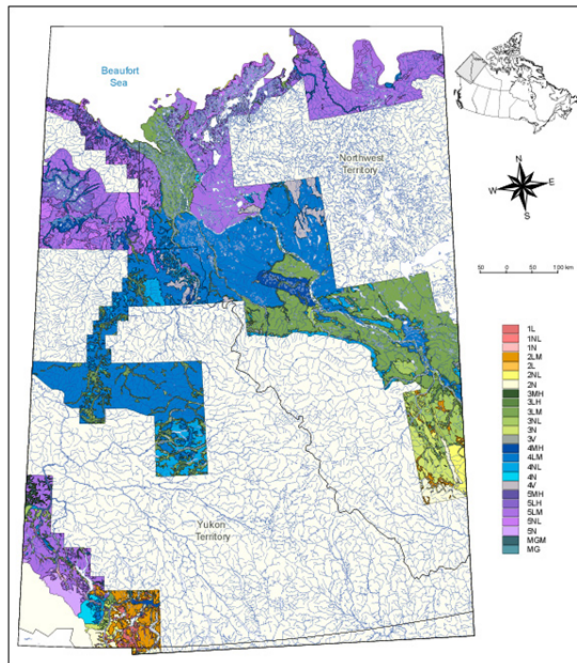
The National Energy Board of Canada. <http://www.neb-one.gc.ca/clf-nsi/index.html>ARD

## Chapter 4: Permafrost Map for Northwestern Canada (Mackenzie Region)

Data Author: Sharon Smith<sup>1</sup>

<sup>1</sup>Natural Resources Canada, Geological Survey of Canada, Ottawa

The Permafrost Map for Northwestern Canada (Mackenzie Region) is a digital version of the 1:1,000,000 map produced by Heginbottom and Radburn [Heginbottom, J.A. and Radburn, L.K. (compilers) 1992. Permafrost and ground ice conditions of northwestern Canada; Geological Survey of Canada, Map 1691A, scale 1:1 000 000.] The map provides information on permafrost distribution and ground ice conditions in the Mackenzie Region of northwestern Canada. The data set comprises three data layers: maps of permafrost zones, rivers, and lakes. The map themes (layers) are in the ESRI Shapefile spatial data format (ArcView files). The permafrost map codes continuous, discontinuous, intermediate, sporadic, and isolated permafrost, and glaciers. Data available at <http://nsidc.org/data/ggd630>



Heginbottom, J.A. and Radburn, L.K. (compilers) 1992. Permafrost and ground ice conditions of northwestern Canada; Geological Survey of Canada, Map 1691A, scale 1:1,000,000.

Digitized by S. Smith, Geological Survey of Canada. Boulder, CO: National Snow and Ice Data Center. Digital Media.