BCS 312: Land and Environments of the Circumpolar North II

Module 3: Cold Climate Infrastructure Technology

Developed by
Sheri Praski
FEC, Saskatoon SK

Overview

In circumpolar regions large land areas contain what was once considered permanently frozen ground or permafrost. Permafrost is soil that has remained below water's freezing point for more than two years, but much of the soil has been permafrost for hundreds or possibly thousands of years. When frozen, permafrost is a strong foundation for infrastructure such as roads and buildings. Special design principals exist for construction on permafrost that assume permafrost will remain a permanent, strong foundation.

Although the word itself would lead us to believe it is permanent, permafrost can melt. Disturbing permafrost or the soil surrounding it, removing vegetation, building infrastructure that insulates or transfers heat, and warming climates are some actions causing the melting of permafrost. When permafrost melts, infrastructure that relied on its strength for foundations, embankments or containment may no longer be capable of supporting the infrastructure. Engineering design must utilize design practices that limit disturbance of permafrost and consider projected climate change to ensure infrastructure will last.

Environmental Impact Assessments (EIAs) are used to study environmental impacts of proposed projects and plan for or work to mitigate outcomes. EIAs are generally required for all projects that can impact the environment at and around planned construction sites.

Learning Objectives

Upon completion of this module, you should be able to:

1. Identify natural hazards associated with cold environments and permafrost.
2. Explain the challenges associated with construction of infrastructure in the North together with proposed cold-technology (engineering) solutions for transportation corridors, mineral exploration and extraction, water and sewage distribution systems, solid and liquid waste management, petroleum and natural gas extraction and distribution systems, hydropower and geothermal heat facilities,

and communications systems.

3. Explain the purpose of Environmental Impact Assessments (EIAs).

Required Readings (including web sites)

Read and study this course module.

Key Terms and Concepts

- Active Layer
- Geothermal
- Heat Transfer
- Hydropower
- Infrastucture
- Permafrost
- Permafrost Terrain
- Recycling
- Sequestered
- Solid waste
- Stabilize
- Subsidence
- Surface Water Hydrology
- Talik
- Thermokarst
- Thermosyphons

Learning Material

Introduction

Climates vary greatly in the circumpolar North, however, a large portion of this area is affected by cold climate and/or **permafrost** conditions. Not all cold climates or all of the circumpolar North are home to **permafrost terrain** as indicated in Figure 1. Permafrost zones occupy up to 24 percent of the exposed land area of the Northern Hemisphere. Infrastructure projects in cold environments and permafrost terrain require specialized construction and maintenance techniques compared with infrastructure in more temperate climates.

Standard methods of installing and constructing infrastructure are not feasible in permafrost terrain. Much infrastructure in northern communities relies on the properties of frozen materials for stability. Northern infrastructure is often designed to have its foundations firmly supported by the permafrost layer, which acts similarly to rock in that it was considered unmovable making an excellent foundation.

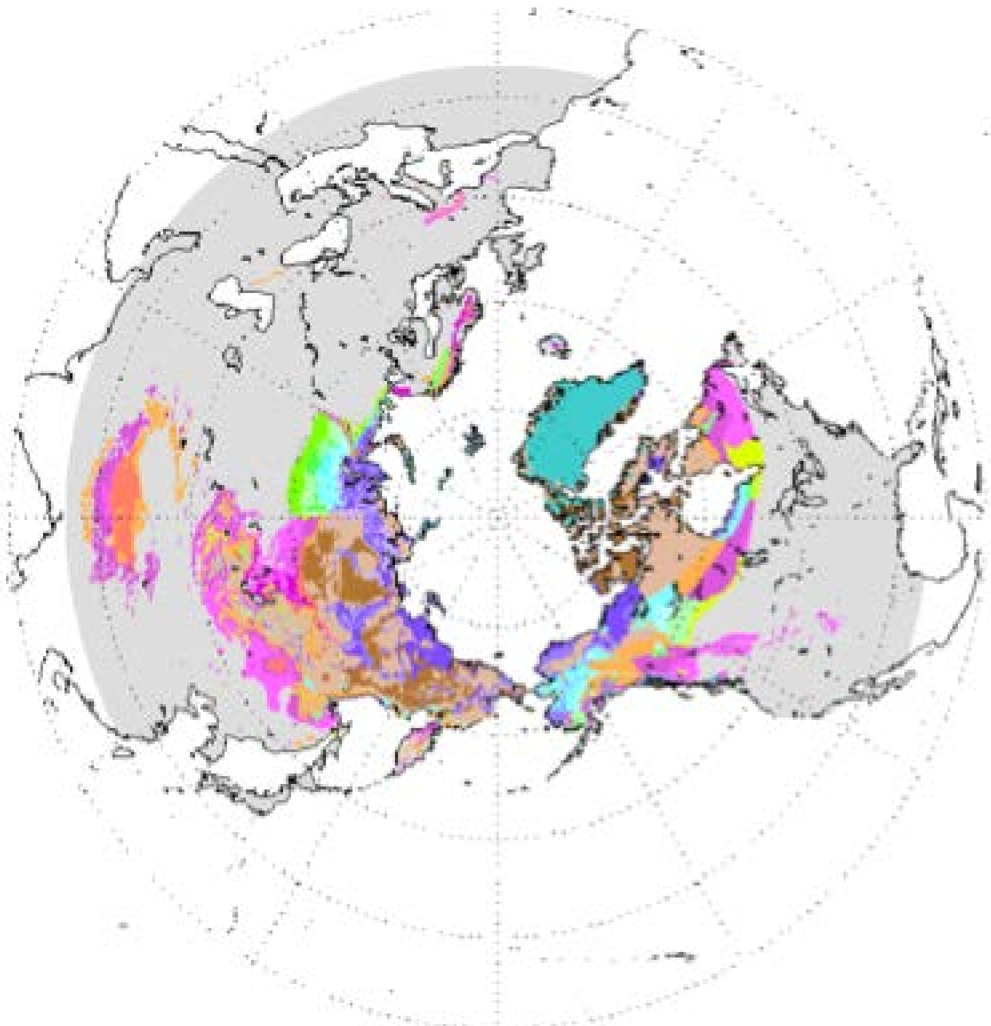


Figure 1. International Permafrost Association Circum-Arctic Map of Permafrost and Ground Ice Conditions, Scale 1:10,000,000. U.S. Geological Survey, J. Brown, O.J.J. Ferrians, J.A. Heginbottom and E.S. Melnikov (1997).

Spatial Coverage Map: 25°N - 90°N, 180°W-180°E.

Legend for EASE-Grid Permafrost and Ground Ice Map

Permafrost Extent (percent of area)	**Ground Ice Content** (visible ice in the upper 10-20 m of the ground; percent by volume				
	Lowlands, highlands, and intra-and intermontane depressions characterized by thick overburden cover (>5-10m)			Mountains, highlands, ridges, and plateaus characterized by thin overburden cover (<5-10 m) and exposed bedrock)	
	High (> 20%)	Medium (10-20%)	Low (0-10%)	High to medium (>10%)	Low (0-10%)
Continuous (90-100%)	Ch	Cm	Cl	Ch	Cl
Discontinuous (50-90%)	Dh	Dm	Dl	Dh	Dl
Sporadic (10-50%)	Sh	Sm	Sl	Sh	Sl
Isolated Patches (0-10%)	Ih	Im	Il	Ih	Il

Variations in the extent of permafrost are shown by the different colors; variations in the amount of ground ice are shown by the different intensities of color. Letter codes assist in determining to which basic permafrost and ground ice class any particular unit belongs. Letter codes are defined in the documentation that accompanies the data files.

Ice caps and glaciers

Permafrost has different layers:

1. The **active layer** is ground that freezes and thaws throughout the year, usually with the seasons, and serves to insulate the permafrost.
2. **Permafrost** is the layer, typically below the active layer, which is frozen year round.
3. **Talik** is unfrozen ground that lies between the active layer and the permafrost.Talik can also be found below or within the permafrost layer.

Learning Highlight 1

Permafrost is ground that remains frozen during all seasons. When frozen, permafrost can be a very strong foundation for buildings and roads.

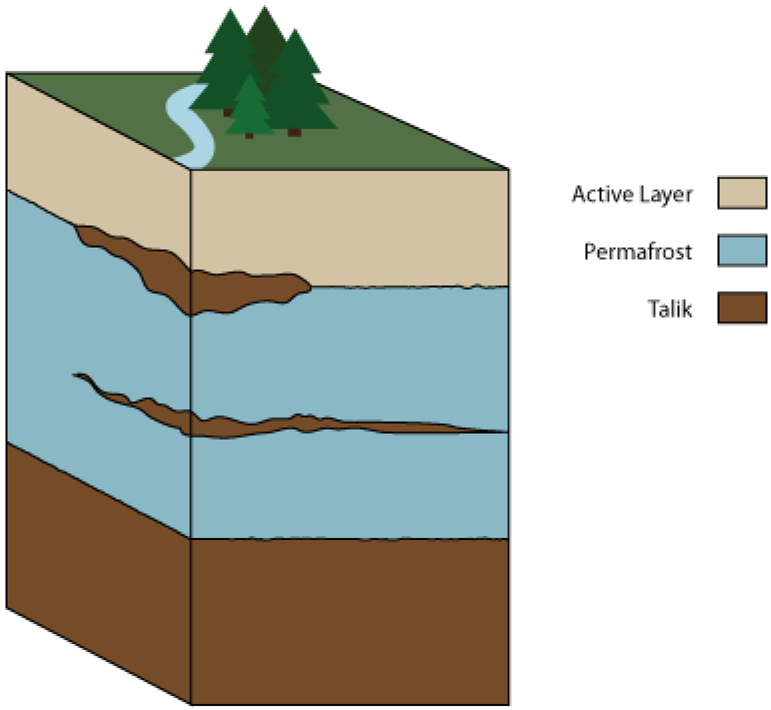
4. 

Figure 2. Idealized permafrost cross section. Source: Weather Underground. http://www.wunderground.com/climate/permafrost.asp

Permafrost affects construction and operations of all infrastructure built on or buried in it. Building on permafrost can incur significant costs because it requires structures to be **stabilized** or fixed in permanently frozen ground below the active layer and **heat transfer** to the ground is limited usually by elevating buildings on piles. If heat transfers to the permafrost layer, the permafrost can melt becoming unstable.

Natural hazards related to cold environments and permafrost terrain result from warming and melting of permafrost. Melting of permafrost can occur:

- **Directly by human activity** through removal or disturbance of overlying vegetation which acts as insulation to keep temperatures constant for the layers beneath. When the active layer is disturbed or removed, the permafrost begins to melt.
- **Indirectly by human activity** through changing climate or warming of ground over time due to heated infrastructure. Permafrost melts as the temperature of the ground increases.
- **By natural climatic cycles** which can increase the temperature of the ground causing permafrost to melt.

Learning Highlight 2

Permafrost that has been frozen for thousands of years is beginning to melt as the climate warms.

This module will look specifically at permafrost issues related to:

- transportation corridors,
- mineral exploration and extraction,
- water and sewage distribution systems,
- solid and liquid waste management,
- petroleum and natural gas extraction and distribution systems,
- hydropower and geothermal heat facilities, and
- communications systems.

As warming in northern climates occurs due to climate change, ground warming could degrade the performance of many existing and future structures such as roads, building foundations, utilities and embankments.

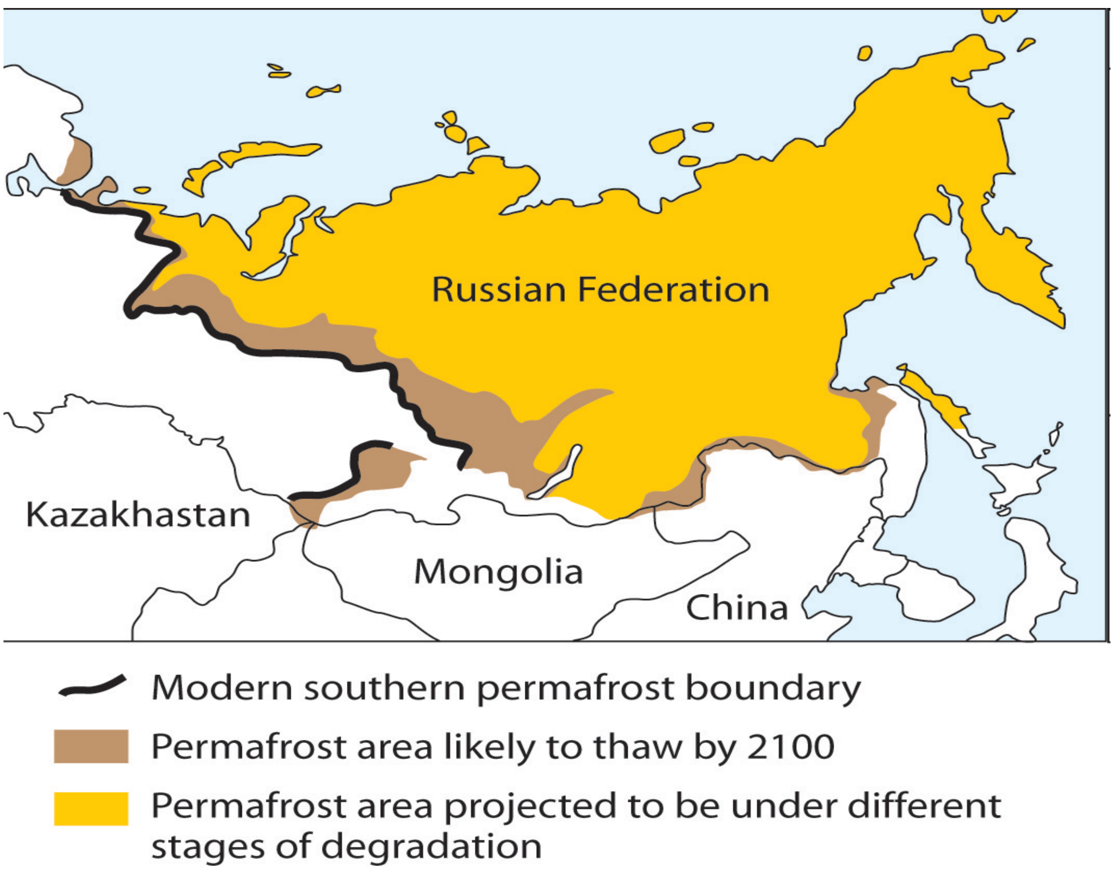


Figure 3. Feedback Loops: Example The Projected Shift of Permafrost Boundary in North Asia Due to Climate Change By 2100.

Source: IPCC 2007, Working Group 2, Figure 10.5, p 487.

3.1 Natural Hazards Associated with Cold Environments and Permafrost Terrain

Many natural hazards are associated with cold environments and permafrost terrain. Some hazards are related to melting permafrost and its impact on infrastructure. Other hazards are related to natural disasters that can occur as permafrost supporting or reinforcing natural terrain, i.e., glaciers, lakes or mountain melts. Examples include:

- Outbursts of glacial lakes causing floods;
- Weakening of frozen slopes resulting in landslides or avalanches;
- Effect of thaw settlement and frost heave on infrastructure causing cracking or collapse of roads, buildings and bridges; and
- Combinations or chain reactions of these processes.

Melting permafrost can create waterlogged ground causing it to become soft and collapse. Buildings and roads may slump or tilt resulting in permanent infrastructure damage and hazards to occupants or users.

Permafrost has played a significant role in the design, construction and maintenance of circumpolar infrastructure. Infrastructure relies on the solid foundation of permafrost, which becomes unstable as it melts. Thawing and melting change the permafrost and **surface water hydrology** having a significant affect on infrastructure designed and built assuming the strength and longevity of the permafrost. Changes in surface water hydrology or patterns can result in flooding, destabilization of foundations and creation of new lakes and rivers.

Many examples of changes observed due to permafrost thawing include:

- Increased coastal erosion and erosion along river banks has had serious impacts on infrastructure near oceans and rivers;
- Increased slope and soil instability, landslides and erosion affects infrastructure stability causing cracking and collapse;
- Safety concerns due to rock and mud slides caused by melting;
- Development of talik causing changes to the infrastructure foundation;
- Increased water table depth affects foundations and drainage leading to instability;
- Destruction of trees and loss of boreal forests affects infrastructure due to fallen trees and/or wind protection; and
- Expansion of thaw lakes, grasslands and wetlands causing infrastructure flooding, e.g., flooded buildings, blocked or impassable roads and displaced habitat.

Infrastructure plays an important role in the lives and livelihood of inhabitants who rely on northern resources. The ability to provide food, water, homes, waste disposal, power, transportation, education and health care to northern communities relies on infrastructure built on permafrost.

Where permafrost has high ice content thawing can induce uneven surface sinking called **thermokarst**. Changes in landforms caused by sinking or settling from thawing can seriously effect infrastructure and ecosystems destroying or completely altering them. In some cases what was once solid ground has become a bog. Where large-scale ground ice thawing has occurred, the landscape is transformed by mudslides, valley formations and melt ponds, and infrastructure slumping, sliding or collapse.

3.2 Challenges Associated With and Proposed Cold-technology (Engineering) Solutions for Infrastructure Construction in the North

Challenges associated with design and construction of northern infrastructure are generally related to four issues:

1. Thawing of ice-rich permafrost resulting in **subsidence** (settling or sinking) of the surface under unheated structures such as roads and airfields;
2. Subsidence under heated structures;
3. Frost action, which is generally worse if there is poor drainage caused by permafrost; and
4. Temperature of permafrost causes buried sewer, water and oil lines to freeze.

Access to exploration, construction and/or maintenance sites can be a challenge in permafrost areas. Seasonal melting of the active layer often makes land access to sites impossible making ice roads the only available form of ground transportation so construction timelines are limited by access and ability to bring in materials.

The impact of melting permafrost on the environment and infrastructure is dependent on the type and amount of ice present. Degradation of ice-rich permafrost causes terrain settling and development of thermokarsts. Thawing permafrost can change water flow paths impacting drainage patterns and infrastructure.

Thawing of permafrost can damage infrastructure leading to increased maintenance and mitigation costs. Thawing permafrost can release significant amounts of carbon **sequestered** in the permafrost. Sequestered carbon is carbon dioxide that has been stored in the earth over time as organic matter (trees, plants, animals). Carbon sequestration in bogs occurs when the rate of plant production exceeds the rate of plant decomposition.

Construction in permafrost regions requires different planning and techniques from construction practices in other areas. Choosing to undertake construction in winter or summer has significant impacts on how permafrost issues are managed. Construction timing and logistics must consider:

- **Planning** – ensuring adequate inventories of required supplies for a full project year can be challenging. Often helicopter is the only means of transport, which is often size and/or cost prohibitive.
- **Transportation** – many areas are only accessible by ice roads so equipment cannot be transported during summer months. Alternately, barges may be the only mode of transport making summer the only time to move equipment.
- **Site Staging and Site Development** – construction activity can cause damage to the environment. It is important to minimize the construction “footprint” and implement an environmental management plan to cover such issues as tundra sensitivity, air quality and noise, terrain and vegetation, wildlife, fisheries and aquatic resources, waste management and fuel and/or oil management.

- **Material (pit and quarry) Development** – where materials such as rock, sand or gravel are needed for roads, foundations or concrete production, timing and management of pits and production are important factors.
- Equipment use may be dependent on ground and temperature conditions.
- Maintenance of existing drainage patterns to preserve permafrost.

In permafrost regions, unforeseeable conditions are commonly encountered during construction. Recognition of these conditions and willingness to adapt designs during construction can avoid costly reconstruction in the future.

> Learning Highlight 3
>
> Infrastructure built on permafrost must mitigate the potential to damage or thaw permafrost through disturbance or heat transfer and must also be designed to protect the structure should the permafrost melt from non-construction related causes, e.g., global warming.

3.2.1 Transportation Corridors

Transportation corridors in the Arctic include roads, rail lines and air landing strips.

Challenges

Road construction in any climate is costly. Road networks generally are constructed based on population density. The type of road structure and surface is determined by the numbers of vehicles that will travel on the road, the density of the travel and potential vehicle weights using the road.

Communities constructed in cold climates have low populations and road building costs per person are high relative to communities with higher populations. Low population density combined with long road construction distances required to reach the 'next' community often means there is only one road to smaller communities and the road may only be passable in certain seasons. Historically, roads were designed with the assumption the permafrost layer would remain frozen. However, roadway construction normally produces a warming effect, which can result in thawing. If thawing occurs, difficulties may arise due to melting ice in the permafrost layer. When ice melts it produces wet soils and voids incapable of supporting the road, resulting in the road structure settling, becoming distorted and often unusable.

Providing and maintaining a reliable northern transportation system is key to maintaining and improving the quality of life in Arctic communities and imperative for development of natural resources.

Key Considerations

Key considerations related to transportation corridor construction include:

- Will the road be used in winter only or is an all season road required?
- What type of traffic will the road accommodate, i.e., passenger or heavy-haul vehicles?
- What regional materials are available for road construction?
- Road siting must take place during cold and warm seasons to identify permafrost and areas susceptible to thawing and/or flooding.
- What are future climatic conditions in the area? Will the permafrost melt as the climate warms? Will the area become flooded? Is the area potentially boggy?
- How accessible is the area? Is winter construction required?
- What risk is there that construction could cause permafrost degradation?
- What is the consequence of permafrost degradation in terms of severity and duration?

Recommendations provided by the Transportation Association of Canada's Developing and Managing Transportation Infrastructure in Permafrost Regions include:

- Maximizing use of existing road, rail, airport and marine infrastructure;
- Building the minimum necessary new infrastructure;
- Planning multi-user facilities by coordinating among all potential users;
- Using life-cycle costing analyses;
- Making the costs for government funded projects transparent; and
- Involving engineers with permafrost experience and expertise at all stages.

Engineering Solutions

Engineering solutions currently being implemented or studied include:

- Utilizing or replacing soil under roads with gravel so water drains better and there is less frost heave.
- Results of thawing on roads and runways can be reduced by constructing with gravel rather than paved surfaces as they can be more readily repaired after subsidence.
- **Thermosyphons** are self-powered refrigeration devices used to keep permafrost cool. Portions of Thompson Drive, Alaska and Chena Hot Springs Road, northeast of Fairbanks, Alaska used thermosyphons in the road bed and are studying the results.
- Recommendations have been made to paint roads white to reflect more heat, keeping roads cooler thereby preventing frozen ground from thawing underneath.
- Constructing ice roads on frozen marshes in wet areas too marshy for roads. Ice roads are also built on frozen lakes for winter travel. Ice roads melt and must be rebuilt each winter.

3.2.2 Mineral Exploration and Extraction

Mineral extraction removes naturally occurring minerals from the earth and can be divided into two common excavation types: surface mining and sub-surface or underground mining.

1. **Surface mining** is done by removing surface vegetation and material above mineral deposits to reach buried minerals.
2. **Sub-surface mining** consists of digging tunnels or shafts into the earth to reach buried mineral deposits.

Large equipment is required for all types of mining. Mineral extraction in cold weather causes extra strain on hydraulics and equipment. Permafrost affects all types of mineral resource extraction in the Arctic. When surface materials are removed or disturbed during mining processes, the risk of melting the permafrost is an environmental and a structural concern.

Challenges

Concerns associated with melting permafrost and its impact on mineral exploration and extraction include:

- Impacts on water quality as melting ice moves naturally occurring elements into new water systems;
- Containment structures that rely on permafrost for strength;
- Impact on migration of birds and animals important to northern communities; and
- Transportation of resources on local roads, i.e., seasonal road issues.

When soils near mine sites melt there is increased concern elements naturally present in the soil, such as mercury and arsenic, will leach into water systems. These elements can be detrimental to all life forms but effects are often more prevalent in fish which are consumed by other life forms including humans.

Containment structures intended to protect the environment from toxic mine tailings and other materials at mine sites often rely on the integrity of permafrost to prevent movement of toxic mine waste and industrial process waters. Frozen earth materials have stronger load-bearing capacity relative to non-frozen ground so site design has traditionally been based on preserving frozen conditions.

There are a number of concerns related to wildlife, water, vegetation and air quality at mine sites. Of particular concern is the impact of mining operations on the migration of birds and animals. Airstrips, machinery, housing for workers and monitoring equipment are area fixtures and can have a permanent effect on bird and animal migration. Many communities rely on animals such as caribou for their source of food. Melting permafrost caused by construction or operations affect water quality or vegetation animals rely on and potentially endanger this food source for local people who hunt these animals.

Key Considerations

Numerous permits and authorizations are required to develop and operate a mine site. Many of these issues can be addressed through careful planning and understanding of issues.

Information obtained through Globalization and Sustainability of the City of Yellowknife, Canada and Surrounding Environs: Mineral Extraction and Community Initiatives, December 2004 http://casestudies.lead.org/index.php?cscid=67 states “Traditional knowledge is officially recognized as an important factor in mining development practices and plans. The Canadian Northwest Territories Government (GNWT) and individual mining companies are bound by regional laws and individual agreements to consider local Aboriginal traditional knowledge and what it offers the development process. Traditional knowledge is defined by the GNWT as: "Knowledge and values which have been acquired through experience, observation, from the land or from spiritual teachings, and handed down from one generation to another." However, actually implementing traditional knowledge, such as creating structures to divert caribou migration around a mining site, is still being studied (WKSS, 1999).

Using the example of Bathurst Caribou, Aboriginal Elders were interviewed to learn about the patterns of migration and eating habits (described by examination of animals' stomach contents and memories of hunting experience), which were matched with geographical information survey data or historical documentation. The accuracy of traditional knowledge is proven over and over again, e.g., Dogrib Elders' descriptions of animal health during the 1940s and 1950s when uranium was mined in the region. The **Tłıchǫ** or **Tłįchǫ** First Nation formerly known as **Dogrib** are a Dene people living in the Canadian Northwest Territories. The animals were thin and unhealthy during these years and many Aboriginal people experienced hardship because of the temporary loss of this food source.

Engineering Solutions

Thermosyphons have been successfully used at mine sites to ensure dams remain frozen and stable year round. Pipes are filled with carbon dioxide (CO_2), which is maintained as a gas at temperatures near 0°C. In winter, gaseous CO_2 in the pipe embedded in the dam rises into the upper pipe, which is exposed to cold winter air. Cold is conducted through the metal pipe casing and cools the gas. The gas condenses and releases its internal heat by means of heat conduction through the pipe into the air. The condensed, cold and relatively heavy CO_2 descends down the pipe, is warmed by heat conducted or drawn from the ground and rises again to repeat the process. As a result, the ground is supercooled sufficiently to keep it frozen and stable throughout the summer. The thermosyphon shuts itself off in summer when air temperatures are warmer than the ground.

Figure 4. Thermosyphons at Lac de Gras, Northwest Territories.
Source: Permafrost Regional Studies, Natural Resources Canada.

Many other mine sites impacts cannot be avoided and careful study and planning are required to ensure the least disturbance to the environment. Decisions must be made determining if project benefits outweigh negative impacts. There is seldom agreement as different parties have differing values. Mine sites have short and long term and, most often, permanent changes to the land, environment and nearby communities.

3.2.3 Water and Sewage Distribution System

Water and sewage must be in a liquid state to be pumped through a pipeline. Therefore, water and sewage pipelines cannot be frozen to work properly. A properly operating pipeline (one which is above the freezing point for liquid) warms the material surrounding it, i.e., air, water, soil, permafrost and infrastructure.

Challenges

The consequences of a poorly designed or operating pipeline, e.g., one that freezes, is that the pipeline will not provide the service for which it is intended, i.e., water delivery or sewage removal and either can cause serious health concerns.

Key Considerations

Designing pipelines for use in permafrost and/or cold weather climates requires careful consideration of the climate and strata through which fluid must flow. Precautions must be taken to ensure pipes will not freeze or melt permafrost ground supporting other infrastructure.

Engineering Solutions

Water and sewer distribution systems enter and exit buildings so the structure's foundation must be considered. If the pipelines cause melting of permafrost under a structure, deformation or collapse can occur. Engineers avoid this problem by building protected above ground pipes supported by pillars. Above ground pipes are not protected therefore heat may be required through insulation and/or electric heat to prevent damage from freezing.

3.2.4 Solid and Liquid Waste Management

Solid waste consists of product residuals, including food and yard wastes, product packaging and other miscellaneous inorganic wastes from residential, commercial, institutional and industrial sources. Solid waste is placed in waste disposal facilities referred to as landfills or dumps. Waste disposal facilities refer to carefully engineered depressions in or on top of the ground in which waste is placed and buried. In any climate the aim is to avoid contact between waste and the surrounding environment, particularly groundwater.

Liquid waste is produced in two forms:

1. **Wastewater** refers to water adversely affected in quality by human impact. It comprises liquid waste discharged by domestic residences, commercial properties, industry and/or agriculture and can encompass a wide range of potential contaminants and concentrations.
2. **Sewage** is a category of wastewater contaminated with urine or feces but the term sewage is often used instead of wastewater.

Physical infrastructure for collection and treatment of liquid waste includes pipes, pumps, screens, channels, treatment buildings, lagoons and ponds.

Key Considerations

In any climate, solid and liquid waste disposal facilities (landfills and wastewater lagoons) can affect human health and the environment in a number of ways. They can:

- Alter the landscape;
- Impact possible human usage of nearby land;
- Affect animal habitat; and
- Affect the quality of nearby ground and surface water.

Therefore, waste disposal sites must be carefully chosen to minimize potential negative impacts on current and future infrastructure.

Unfortunately, in small communities landfills and wastewater lagoons are not always properly designed or maintained resulting in a high potential for ground and surface water and/or animals to come into contact with waste products. Waste products can be inert and harmless, e.g., food scraps, or toxic, e.g., leachate generated from chemicals, batteries or mine waste.

In cold climates environmental damage to permafrost due to solid and/or liquid waste results in:

- New or changed surface runoff due to thawing permafrost or
- Breaches in embankments, dams or liners due to thawing permafrost.

Both scenarios result in contamination of potential drinking water sources. Water-borne diseases can increase through pollution of water supplies caused by leaching of liquid or solid-waste sites. Compromised water quality can result in disease outbreaks in northern regions or introduce opportunities for new diseases.

Liquid waste environmental contamination follows the same pathways as solid waste by contaminating groundwater by leaching below settling channels or ponds, or by contaminating surface water by changing runoff patterns or breaches in dams or containment areas, e.g., broken pipes.

An issue gaining recognition is that solid waste generation is projected to increase as the climate warms and communities abandon and rebuild infrastructure that relied on permafrost.

Engineering Solutions

Solid Waste (landfills): Properly designed and maintained landfills address potential environmental harm from runoff or leaching by:

- Lining with impermeable material and using drainage layers and pumps to remove liquid and ensure proper disposal;
- Construct barriers to prevent surface water from entering or exiting the landfill;
- Construct leachate collection trenches in unlined areas of the landfill (older landfills may not have a liner and leachate may have seeped into surrounding soils and groundwater); and
- Cover waste to reduce the potential for animals and birds to come in contact with waste products and/or prevent it from being spread by wind.

Liquid Wastes (sewage lagoons, channels, etc.): Properly designed sewage treatment facilities mitigate potential environmental damage through:

- Constructing sewage transport and storage areas with an impermeable liner to ensure groundwater cannot be contaminated by leaching wastewater;
- Constructing barriers to prevent surface water from entering or exiting storage areas;
- Constructing containment areas under wastewater infrastructure that has the potential to be breached, e.g., buildings, tanks and pipelines.

As with other cold-climate infrastructure, often permafrost has been considered a permanent formation and used as a barrier, dam or liner and considered impermeable. As permafrost melts it will be important to have alternate systems in place to ensure the integrity of these sites.

3.2.5 Petroleum and Natural Gas Extraction Systems

Petroleum and natural gas extraction have a significant impact on the arctic tundra and permafrost. Oil occurs in certain geologic formations at varying depths in the earth's crust and much of the extracted product needs to be shipped to populated areas for use and sale, therefore extraction requires infrastructure including buildings, wells, pumps and pipelines.

There are many challenges related to extraction of oil and gas exist in cold climates and permafrost.

Challenges

Oil and gas operations are constrained by cold climate and permafrost through:

- Reduced access to roads for supplies during construction and operations;
- Reduced access to roads for transportation of the oil and gas to markets;
- Melting permafrost under or around pipelines; and
- Difficulty operating machinery and hydraulic equipment at low temperatures.

Seismic reflection and refraction are distorted by frozen ground so finding new deposits or assessing existing deposits is challenging in permafrost environments.

Drilling deep wells for oil and gas can thaw permafrost. If permafrost thaws, wells can collapse. Once the oil or gas is out of the ground companies need to transport it to markets. Hauling on roads can be costly and dangerous and is limited to winter when the roads are frozen and stronger or when ice roads can be constructed. Pipelines used to transport oil and gas experience many of the challenges discussed related to the thawing of permafrost under or around pipelines. There can be severe safety and environmental consequences when oil or gas pipelines leak, break or rupture.

Engineering Solutions

Transportation

Transportation of equipment and supplies for extraction of oil and gas is key to the selection of well sites. Many engineering solutions discussed in the “transportation corridors” section of this module would be considered or utilized for access roads. Transportation of extracted products to market must be considered. Transportation in and out of a site is constrained by deposit location and infrastructure design.

Well Construction

Some practices used to avoid collapse of wells include:

- Placing equipment on concrete pads built to prevent thawing of permafrost underneath the pads;
- Installing concrete well liners to prevent wells from collapsing; and
- Use of drilling liquids that freeze more slowly than water to lubricate drill bits.

Pipeline

Some practices used to avoid thawing permafrost around pipelines include:

- Constructing pipelines on piles above ground, sometimes utilizing thermosyphons; and
- Insulating pipelines.

The Alaska pipeline, built between 1974 and 1977, moves oil 1,299 Kms (800 miles) through Alaska to the Port of Valdez. The Alaska pipeline poses many challenges. Oil in the pipeline must be kept above 60°C (140°F) so it flows easily, therefore the oil is warm enough to thaw permafrost causing the pipeline to sink and break. The pipeline was built above ground in many places and approximately half the pipeline was built on threrrmosyphon piles to keep the ground frozen below.

The pipeline created concerns about effects on habitat and potential pipeline breaks and repair costs, which due to melting permafrost could become more significant in the future.

3.2.6 Hydropower and Geothermal Heat Facilities

Geothermal energy is power derived from the earth's internal heat. This thermal energy is contained in rock and fluids beneath earth's crust. Geothermal energy has been found in shallow ground and as deep as several miles below the surface. This underground steam and hot water can be used to generate electricity or to heat and cool buildings.

Hydropower is electrical energy derived from falling or running water. Pressure from water is used to turn the blades of a turbine connected to a generator that converts energy into electricity.

Hydropower and geothermal heat facilities require infrastructure including buildings, pipelines and transportation systems that are affected by cold weather and permafrost.

Key Considerations

Geothermal

Geothermal concerns include:

- Site considerations including construction of buildings, pipelines and transportation systems in permafrost which may heat due to soil disturbance and/or heat transfer;
- Disposal of some geothermal fluids that may contain low levels of toxic materials;
- Dams, embankments or containment structures built in permafrost must be protected from warming caused by infrastructure and warming climate; and
- Geothermal sites may cool after many years of heat extraction.

Hydropower

There are two basic types of hydropower plants: those that store water behind a dam and those that divert water into a channel parallel to a river, often called "run-of-river" hydropower plants.

Hydropower challenges include:

- Creation of large reservoirs which flood land and may kill vegetation, producing greenhouse gas emissions from decaying vegetation;
- Silt deposits can shorten the operational lifespan of hydroelectric reservoirs;
- Fish migration can be a concern and conservation measures, i.e., fish guidance, habitat compensation, need to be implemented; and
- In cold climates, the infrastructure and reservoirs can cause permafrost thawing and impact the site and surrounding infrastructure.

Challenges

Challenges related to construction and maintenance of geothermal and hydropower facilities in permafrost environments include:

- Construction issues related to climatic conditions;
- Maintenance issues related to access roads;
- Construction and maintenance related to surface water hydrology specifically when constructing and operating dams and channels (hydropower);
- Issues related to transmission lines constructed in permafrost;
- Displacement of wildlife habitat for facility and/or ancillary infrastructure, e.g., buildings, housing, roads;
- Melting of permafrost from construction and maintenance activities and associated settling and frost action; and
- Landslides and flooding from changes in surface water hydrology due to melting permafrost.

Engineering Solutions

In order to mitigate some challenges related to construction of geothermal or hydropower facilities it is important to:

- Plan and identify optimal sites and understand permafrost in the area;
- Not rely on permafrost as a permanent foundation for infrastructure and ensure foundations can withstand freeze and thaw cycles; and
- Understand environmental impacts and minimize their impact.

3.2.7 Communication Systems

Communication systems require towers or communication lines under or above ground for radio or transmission. Constructing and maintaining towers or lines in permafrost require special considerations. Tower foundations must be immovable and cannot settle, tilt or be uplifted.

Challenges

Permafrost affects the stability of the ground where communication towers are situated and/or where communication lines are trenched. Thawing and freezing of the active layer can create conditions of settlement and/or lifting so towers begin to tilt. Some key challenges affecting the strength of the tower and integrity of the lines include:

- Weakening of frozen slopes resulting in landslides or avalanches that bring down towers and break underground lines;
- Thaw settlement and frost heave which can cause collapse of towers or breakage of lines;
- Instability of infrastructure due to flooding and thawing of permafrost; and
- Combinations or chain reactions of these processes.

Towers must withstand unique and unpredictable conditions including settlement and frost heave during the same year. Often anchors are used to stabilize towers. Anchors must be checked regularly as they will move with settlement or frost heave. Anchors and towers can be exposed to forces that are difficult to predict.

Key Considerations

Challenges of building on permafrost are similar to other infrastructure:

- Care must be taken not to melt the permafrost when it is required for stability;
- Cold weather must be considered when selecting construction timelines including transport of equipment and supplies;
- Issues related to melting permafrost such as flooding and decreased strength must be considered for existing and future installations; and
- Migration of birds and animal must be considered so as to create minimal disruption.

Engineering Solutions

Many engineering techniques exist for building towers. When permafrost is available as a foundation, it is often relied on for its strength.

Towers and poles for communication lines can cause melting of permafrost under a structure due to disturbance of soils or heat created by the lines. Practices used to avoid collapse of towers or lines include:

- Placing equipment on special concrete pads built to prevent thawing of permafrost beneath the pads;
- Installation of anchors to support the structure, such as pile, gravity, grouted rod, helical screw, belled and plate anchors;
- Ensuring foundations go below the potential permafrost thawing zone.

3.3 Purpose of Environmental Impact Assessment (EIA)

An **environmental impact assessment** is an assessment of positive or negative impacts a proposed project may have on the environment. An EIA considers factors that a land development or construction project may have on the environment, including how it will impact:

- Geology,
- Hydrology,

- Traffic,
- Schools,
- Permafrost,
- Infrastructure requirements,
- Fire protection,
- Animals and birds (including migration patterns),
- Endangered species,
- Archeological artifacts, and
- Aesthetics.

The purpose of the assessment is to ensure decision makers consider environmental impacts of a project prior to deciding whether to proceed and to ensure projects do not create significant, long-term adverse effects on the environment. When impacts are identified through an EIA there is opportunity to determine mitigation measures or change the scope to avoid detrimental outcomes.

An EIA requires:

- Detailed description of the project;
- Baseline study to identify past, present and future conditions that will be utilized to assess the impacts of the project;
- Identification and evaluation of potential project outcomes;
- Development of strategies to manage these outcomes;
- Technical review of all information related to the project; and
- Public review of information generated including ways to consider and integrate public input.

This process results in a decision as to whether the project will proceed and under what conditions. Through the EIA process, developers and affected parties can better understand a project and create plans to mitigate or avoid problems.

Conclusion

Many techniques have been successfully used to design and construct infrastructure on permafrost. Much of the infrastructure in cold climates relies on permafrost for its foundation.

Prior to development of any infrastructure in northern climates, developers must complete an Environmental Impact Assessment (EIA). EIAs are a tool used to mitigate potential impacts of new infrastructure on the environment and can help prevent costly construction and/or operational problems.

Climate change is warming the climate for much of the permafrost zones. Melting permafrost will affect infrastructure built on permafrost. Strategic planning, research and adaptation will be required to protect existing infrastructure as the climate in the circumpolar region continues to warm.

Key factors that must be addressed to ensure the integrity of infrastructure as the climate warms include:

- Careful site selection can help reduce vulnerability by avoiding permafrost with high ice content and favouring permafrost with high gravel content;
- Effects of permafrost thawing on building and infrastructure can be reduced;
- Understanding the geology will help determine which measures are most appropriate depending on site characteristics, project type and intended lifetime;
- Local thawing can be reduced by minimizing surface disturbance;
- Piles used to support structures can be sunk deeper in the permafrost or refrigerated to maintain their strength as the permafrost warms;
- Thawing of the site can be induced prior to construction by stripping vegetation and surface soil away several years in advance;
- Consequences of thawing can be reduced by building roadways or foundations with gravel or other materials that drain easily rather than with materials that retain water and expand and contract with freeze/thaw cycles; and
- Infrastructure along coastlines can be protected with sea walls or other fortifications or relocated further inland.

It is important to understand the unique conditions related to permafrost construction, plan to address the issues during construction and plan for a future with less permafrost.

Discussion Questions

1. Is your region or the circumpolar region of your choice (Figure 1) affected by permafrost? If so, why?

2. What infrastructure in your community or the circumpolar region of your choice is designed with permafrost engineering principals? How will climate change affect infrastructure in your region? What existing facilities may be affected if the climate continues to warm?

3. What is the purpose of an Environmental Impact Assessment? How can EIAs positively impact infrastructure development in your community or the circumpolar North?

Study Questions and Answers

1. What are key considerations when constructing infrastructure on permafrost?

   A designer must be aware of the presence of permafrost and the type of construction least likely to melt the permafrost or design the infrastructure assuming the permafrost can and will melt. Key considerations include the depth of the active layer, the depth of the permafrost, and the potential for permafrost melting and its effect on infrastructure.

2. How can road construction be designed to lessen issues related to permafrost?

   Engineering solutions currently being implemented or studied include:

   - Utilizing or replacing soil under roads with gravel for better water drainage and less potential for frost heave.
   - The effects of thawing can be reduced for roads and runways by constructing with gravel rather than paved surfaces because they can be readily repaired after subsidence.
   - Use thermosyphons, which are self-powered refrigeration devices used to help keep permafrost cool.
   - Paint roads white to reflect heat and keep roads cooler to prevent frozen ground from thawing underneath.
   - Construct ice roads on top of frozen marshes.

3. How does melting permafrost affect infrastructure?

   As the temperature warms, permafrost melts causing infrastructure to become unstable and crack, fail or collapse.

4. What is the purpose of an Environmental Impact Assessment?

   An environmental impact assessment assesses the positive or negative impacts a proposed project may have on the environment. An EIA considers factors a development may have on the environment. When impacts are identified through an EIA there is opportunity to determine mitigation measures or change the scope to avoid detrimental outcomes.

Glossary of Terms

Active Layer: ground that freezes and thaws. The active layer is directly above the permafrost layer.

Geothermal Energy: power derived from the earth's internal heat. Geothermal energy is contained in the rock and fluids beneath the earth's crust and can be used to generate electricity or heat and cool buildings.

Heat Transfer: involves the exchange of heat or cold from one physical system to another. Heat transfer occurs because of a temperature difference and flows from high to low temperature regions.

Hydropower: electrical energy derived from falling or running water. The pressure from the water is used to turn the blades of a turbine connected to a generator that converts energy into electricity.

Infrastructure: technical structures that support a society, such as roads, water supply, sewers, electrical grids and/or telecommunications.

Permafrost: soil at or below the freezing point of water (0^{o} C) for more than two years.

Permafrost Terrain: permafrost in the soil can create a special type of terrain and topography. Water may not be able to seep into the soil where there is ice (permafrost) and shallow ponds or rivers can be created. Freezing and thawing of upper layers creates pressure and produces heaving creating unique landforms.

Recycling: processing used materials into new products.

Sequestered Carbon: carbon dioxide that has been stored in the earth over time as organic matter (trees, plants, animals). Carbon sequestration in bogs occurs when the rate of plant production exceeds the rate of plant decomposition.

Solid Waste: solid or semi-solid waste from households, construction and industrial sites containing materials that have not been separated or recycled.

Stabilize: to make firm so as to not have a structure overturn.

Subsidence: sinking or settling of the earth's crust.

Surface Water Hydrology: the existence and flow of water including oceans, lakes, streams, rivers, wetlands, marshes and ponds.

Talik: unfrozen ground between the active layer and the permafrost. Talik can also be found below or within the permafrost layer.

Thermokarst: a landscape formed due to melting of permafrost ground. Thermokarst can be caused by human activity or nature. Agriculture, deforestation, construction and natural erosion commonly lead to thermokarsts.

Thermosyphons: self-powered refrigeration devices used to keep permafrost cool.

References

Thawing and Melting. US National Assessment of the Potential Consequences of Climate Variability and Change Educational Resources Regional Paper: Alaska. US Global Change Research Program.
URL http://www.usgcrp.gov/usgcrp/nacc/education/alaska/ak-edu-3.htm

Permafrost. State of the Environment Report NWT. Environment and Natural Resources, Northwest Territories.
URL http://www.enr.gov.nt.ca/_live/pages/wpPages/soe_permafrost.aspx

Wagner, A.M. US Army Cold Regions Research and Engineering Laboratory, Ft. Wainwright, AK. J.P. Zarling, Dept Civil and Environmental Engineering, University Alaska, Fairbanks, Fairbanks, AK. E. Yarmak, E. and E.L. Long, Arctic Foundations Inc., Anchorage, AK. (2010) Unique Thermosyphon Roadway Test Site Spanning 11 Years. GEO 2010. URL http://pubs.aina.ucalgary.ca/cpc/CPC6-1770.pdf

Thermosyphons: Thermosyphons Keep the Permafrost Frozen. Dept. Mechanical Engineering, University of Alaska, Fairbanks. URL
http://www.alaska.edu/uaf/cem/me/news/thompson_drive_thermosyphons.xml

Primer on Developing and Managing Transportation Infrastructure in Permafrost Regions. Transportation Association of Canada (TAC), June 2010. URL http://www.tac-atc.ca/english/resourcecentre/readingroom/pdf/primers/permafrost.pdf

Supplementary Resources

Adaptation Options for Impacts from Thawing Permafrost and Melting Sea Ice. US National Assessment of the Potential Consequences of Climate Variability and Change Educational Resources Regional Paper: Alaska. US Global Change Research Program. URL http://www.usgcrp.gov/usgcrp/nacc/education/alaska/ak-edu-3.htm

All About Frozen Ground. National Snow and Ice Data Center NSIDC. University of Colorado, Boulder. URL http://nsidc.org/frozenground/people.html

Reimchen, D., Govt Yukon; G. Doré, Université Laval; D. Fortier, University Montreal; B. Stanley, Govt Yukon; and R. Walsh, Govt Yukon. Cost and Constructability of Permafrost Test Sections Along the Alaska Highway, Yukon. Paper presentation at the Soil Stabilization for Changing Environments Session, 2009 Annual Conference Transportation Association of Canada, Vancouver, British Columbia.
URL http://www.tac-atc.ca/english/resourcecentre/readingroom/conference/conf2009/pdf/Reimchen.pdf

Bond, J.D. and P.S. Lipovsky. 2011. Surficial geology, soils and permafrost of the northern Dawson Range. In*:* K.E. MacFarlane, L.H. Weston and C. Relf (eds.) Yukon Exploration and Geology. 2010. Yukon Geological Survey, pp19-32.

Robinson, S., R. Couture and M. Burgess. 2002. Permafrost: Climate Change, Permafrost, and Community Infrastructure: A Compilation of Background Material from a Pilot Study of Tuktoyaktuk, Northwest Territories. Geological Survey of Canada Open File No.3867.

Arctic Report Card Update for 2011. Permafrost. CAFF. Romanovsky, V., N. Oberman, D. Drozdov, G. Malkova, A. Kholodov, S. Marchenko. Geophysical Institute, University of Alaska, Fairbanks, Fairbanks, AK.
URL **http://www.arctic.noaa.gov/reportcard/permafrost.html**

Environmental impact assessment of irrigation and drainage projects. Chapter 3: EIA Process. 1995. FAO Irrigation and Drainage Papers. Natural Resources Managment and Environment Department. URL http://www.fao.org/docrep/V8350E/v8350e06.htm