

“Change and Challenge”

Climate Change Adaptation Plan for the GNWT Department of Transportation

August 2013

Prepared for:

Department of Transportation

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Abstract

WHAT IS CLIMATE CHANGE?

The Intergovernmental Panel on Climate Change (IPCC) defines Climate Change as follows:

Climate change in IPCC usage refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), where climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time period.

The U.S. EPA describes these variations in climate as “any significant change in the measures of climate lasting for an extended period of time, and includes major changes in temperature, precipitation, or wind patterns, among others, that occur over several decades or longer”.

(<http://www.epa.gov/climatechange/glossary.html>)

WHAT DOES CLIMATE CHANGE MEAN FOR THE DOT?

The Government of the Northwest Territories Department of Transportation (DOT) has a responsibility to actively plan for and operate a safe and reliable transportation network. Preparing for the impacts of climate change is required to fulfill that mandate.

Impacts from climate change are already being felt in the NWT and are expected to be exacerbated in the coming years. Key climate impacts are: temperature increases, changes in precipitation amounts, and changes in the variety and intensity of storms. These climate alterations have (and will) result in: changes in sea level, changes in the extent of arctic sea ice, changes to permafrost stability, and changes in runoff and drainage conditions. These impacts translate into problems with permafrost stability, drainage, landslides, icing and visibility, and even the friction an airplane requires to use a runway safely.

WHAT IS CLIMATE CHANGE ADAPTATION?

Climate change adaptation involves making changes to a design, process, or infrastructure asset so it can continue to function safely and reliably in a changing environment.

WHAT ARE THE CHALLENGES OF CLIMATE CHANGE?

Transportation infrastructure, maintenance, operations and safety have always been affected by weather conditions at any given time. However, statistical analysis and overwhelming anecdotal and reported information indicates that the conditions have changed and that our past practices may not be suitable in the future. Maintaining the status quo is not an option.

Looking forward, the long term trends and forecasts indicate that our past assumptions – about the weather, about soil and ground conditions, about water levels etc. – may no longer be valid.

Engineering design has traditionally developed safe, efficient design by relying on historical climate conditions. In the future we will have to design to meet conditions that will change. Engineering design and infrastructure operation will have to be re-assessed based on “What will happen” rather than “What has happened”.

IS IT CRITICAL THAT WE ACT ON CLIMATE CHANGE IMPACTS FOR NWT’S TRANSPORTATION INFRASTRUCTURE?

It is critical and essential, as the economy and way of life in Northern Canada relies heavily on the transportation network. A reliable, multi-modal transportation infrastructure system reduces the cost of living in NWT, supports inter-community and social mobility, bolsters economic diversification, fosters effective resource development and reinforces Canadian sovereignty and security for northern regions.

As climate change intensifies in the NWT, the impacts and risks to critical transportation infrastructure will grow, and reliance on passive observation or purely reactive coping measures to these impacts will not be enough.

HOW WILL THE DOT ADAPT TO CLIMATE CHANGE?

The DOT has been adapting to the impacts of climate change for many years. To date this has generally been through expanded effort for maintenance and use of materials (sanding, plowing, repair). Some physical asset changes have been made (permanent winter road bridges, runway grooving). In some areas service disruptions have occurred (road closures and travel bans, flight delays). In the future the DOT must increase its adaptation measures. Routine maintenance may not be sufficient, more physical asset may be required, and service disruptions may become unacceptable.

Substantial changes in funding programs, industrial and government partnerships, research, collaboration and application of knowledge are required in order to develop a new understanding of how the NWT is changing, how these changes degrade critical transportation infrastructure, and how engineering designs and operational planning can adapt to NWT’s rapidly changing operating environment for transportation networks.

ABOUT THIS REPORT

This report identifies areas where infrastructure and services are at risk, where new and robust data monitoring programs must be initiated to respond effectively as climate change impacts worsen with time, and to develop a better understanding of how emerging climate trends and impacts will force us to adapt NWT transportation networks for ongoing reliability, public confidence and safety.

Summary Report

This summary report is the distillation of the information in the Government of the Northwest Territories Department of Transportation (DOT) climate change adaptation plan. It sets out the key messages from the plan and interprets them for the reader. It is intended to be read as a summary of the report but can also be used as a stand-alone document. The structure parallels the chapters of the main report.

S1: INTRODUCTION

DOT is developing a proactive strategy to address climate change impacts to its transportation infrastructure. The development of a Climate Change Adaptation Plan (CCAP) is a step to respond to transportation infrastructure vulnerabilities resulting from the impacts of climate change. Deton' Cho Stantec (DCS) has prepared this report to support DOT in its strategy.

DOT: MISSION AND RESPONSIBILITIES

The Department of Transportation's mission is “to provide for the safe, secure, accessible and reliable movement of people and goods to serve the social and economic needs and aspirations of the people of the Northwest Territories”. The Department of Transportation (DOT) is responsible for multiple sectors of the NWT transportation system including:

- Highway System including winter roads
- Airport System with paved and gravel runways
- Ferries and ice crossings.

The NWT Transport Network at a Glance

Highways:	2,200 kilometers of all-weather road – 45 % paved or chip sealed and 27 %gravel 1,425 kilometers of publicly constructed winter road Over 300 bridges, and thousands of culverts Privately constructed winter roads including the 570-kilometer Tibbitt to Contwoyto winter road
Airports:	27 airports: Gateway hub (Yellowknife), two regional hubs (Norman Wells and Inuvik) and 24 community airports
Ferry crossings:	Four ferry crossings (Highways 1, 2 and 8) Ferry operations from May/June through to October/December.
River Transportation:	Privately operated supply barges serving industry, residents, and delivering fuel for the GNWT electricity generation.
Arctic Marine and Community Re-supply:	Privately operated supply barges to communities, Federal installations exploration camps and arctic communities.

DOT has an interest in the services of the river barge transport and arctic marine transportation systems.

CLIMATE CHANGE ADAPTATION PLAN (CCAP) OBJECTIVES

The objectives of this Climate Change Adaptation Plan document are to:

- Inform on the nature and severity of climate change impacts in each mode of transportation under DOT's jurisdiction and responsibility.
- Identify significant risks to the transportation system infrastructure assets and operations as a result of anticipated climate change impacts.
- Examine adaptation options, including cost considerations, to reduce impacts of these changes and rate the ability of DOT to maintain or restore transportation assets, operations and services.
- Define research and monitoring needs to allow tracking, analysis and ongoing assessment of severity of climate change impacts.

This report identifies areas where infrastructure and services are at risk, where new and robust data and monitoring programs must be initiated to respond effectively, and indicates where developing a better understanding of how emerging climate trends and impacts will trigger responses that require adaptation for ongoing reliability and safety of NWT's critical transportation network.

SCOPE OF REPORT AND PLAN DEVELOPMENT

The scope of this document includes assessment of transportation infrastructure assets and related operations of DOT. The assessment was led by DCS, supported by specialist experts in river dynamics, ice dynamics, permafrost, as well as northern climate engineering, construction and operations. Consultations in personal interviews, public stakeholder forums and technical risk assessment workshops were conducted involving marine and aviation operators, winter and all-weather road operations/maintenance personnel, ferry crossing staff and managers, representatives from several GNWT departments, DOT managers and staff, climate support personnel and northern community residents.

A literature review was conducted on DOT available holdings, and supplemented by DCS-sourced materials regarding climate change, transportation networks, and infrastructure responses as applied to the Canadian arctic.

S2: CONTEXT

IMPORTANCE OF CLIMATE CHANGE IN NWT

Climate change is a growing challenge that has impacts for NWT transportation infrastructure. Several GNWT and DOT documents have identified that climate change will be an important issue for the NWT.

Climate changes are inducing expensive damage and reducing the service life of existing infrastructure designs already, and new approaches must be implemented in order to offer residents and investors in the NWT region the reliable and safe transportation links that is critical to a successful future for the territory.

The economy and way of life in Northern Canada relies heavily on the transportation network. A reliable multi-modal infrastructure system reduces the cost of living, supports inter-community and social mobility, bolsters economic diversification, fosters effective resource development and reinforces Canadian sovereignty and security for northern regions.

In the NWT, transportation routes connecting sparsely distributed populations are limited compared to regions in the south. In the event of a service disruption, there are typically no alternative routes. This makes the efficient operation of the components of the transportation network critical to the economy and people of the NWT.

CLIMATE CHANGES IN THE NWT

Climate change expresses itself in many ways, including increases in temperature, precipitation, sea level and storm surges. Each of these changes has impacts on transportation infrastructure. Each of these will affect the design, planning and operations related to NWT's transportation sector.

Interpretation of results from international modeling centers developed for the Intergovernmental Panel on Climate Change (IPCC) suggest significant changes in Arctic surface temperatures, drastic reductions in sea-ice, and increases in precipitation. The most dramatic changes have been to the stability of permafrost – as warmer temperatures have resulted in the degradation of permafrost

For northern regions such as the Northwest Territories, this is of concern for two reasons:

- Climate change impacts such as permafrost, ice melting and extreme weather events are occurring in Northern Canada at rates faster than climate model projections have predicted. (Auld, 2011)
- Transportation systems will be strongly affected by climate change. In the NWT, climate change impacts affect the critical links that connect remote communities, provide life-lines to essential supplies, and enable economic and social sustainability. Without these critical links, the sustainability of communities and economic development in NWT is highly unlikely.
- Permafrost serves as the foundation that much of the NWT transportation infrastructure is built on. When it degrades the infrastructure built on it will be subject to additional stresses and possible failure.

Northern residents and traditional knowledge have contributed to observations that the northern climate is changing. These sources are supported by a number of atmospheric measurements over recent decades.

In general the expectations are that climate change will bring:

- A trend of increasing average temperatures, especially in winter
- Increased variability of climate parameters.
- Increased occurrence of ‘extreme weather events,’ that is, activities that were formerly rare will become more common.
- Occurrence of weather conditions never experienced before in some areas.

As a representative prediction, forecasted average temperatures for selected NWT locations are shown in Figure S-1. This example highlights that (i) climate change can be expected to be felt throughout the territory’s northern and southern regions, and (ii) that there is likely to be a gradient from south to north in climate changes. As a result, impacts that occur in the south may not be experienced in the north, or will be at a later date.

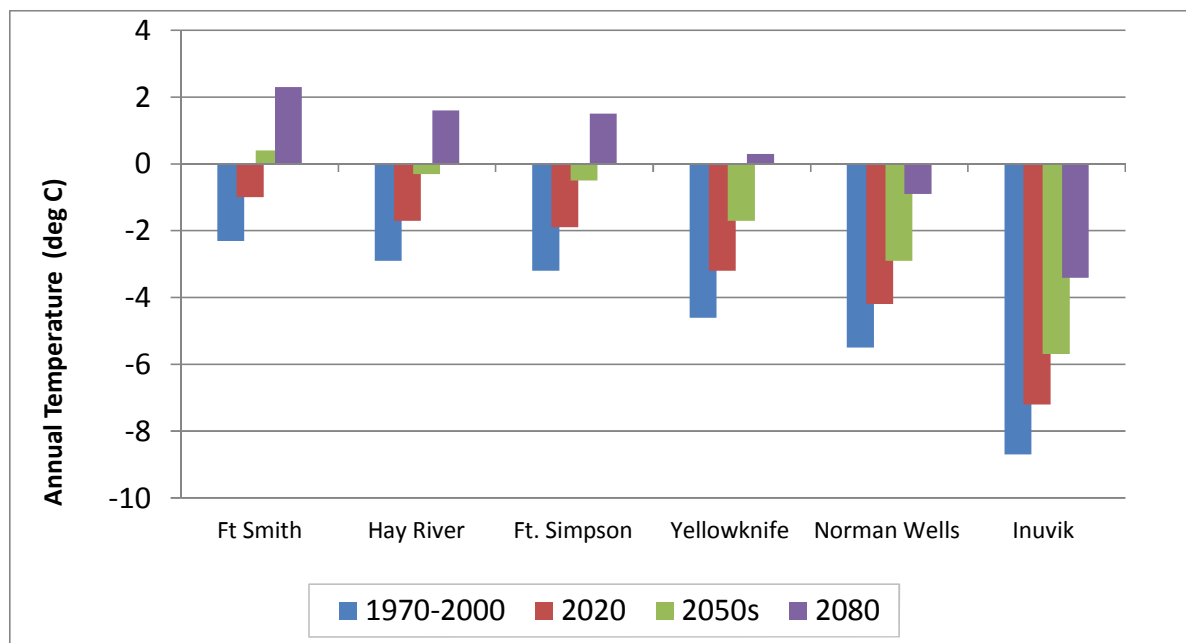


Figure S-1 Predicted Average Annual Temperatures for Selected NWT Locations

Future precipitation is more difficult to project than temperature values. Future precipitation projections indicate substantial precipitation increases for Canada's Arctic, including the NWT. These projections compare the historical averages (or 'climate normal') to forecasts over the next several decades. For the annual total, and each of the seasonal estimates precipitation is expected to increase.

Increases in precipitation of this magnitude may not seem to be of great concern. Forecasts are not able to define how that precipitation will occur – either as an increase in existing storm types, or by an increase in more severe precipitation events. In addition to these factors, the seasonality (timing) of the precipitation will also pose potential impacts. Trends in other locations and anecdotal evidence in the NWT indicate that at least some of this precipitation will occur through more extreme storm events.

An important consideration is that the planet is already “locked in” to a substantial amount of climate change – regardless of the success of international efforts to reduce emissions. It is well understood in the scientific research that even if global emissions were to decrease by a meaningful magnitude immediately, climate change impacts from past and existing GHG emissions will cause ongoing progression of climate change for several decades or more. Adaptation to intensifying climate change impacts will be necessary.

APPROACH TO ASSESSING CLIMATE CHANGE RISKS

This assessment reviewed each major public mode of transportation under the jurisdiction of DOT.

The assessment investigated how climate change could affect current practices in areas including design, construction and operations of transportation infrastructure in the NWT. The key question driving the assessment was to identify the most vulnerable transportation sector services and components on a transportation mode-specific basis.

The assessment rated transportation components in terms of their Adaptive Capacity and Engineering Resilience. In the context of this report:

- Adaptive capacity is the ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences. ***It relates to the extent of available adaptation options a given system can offer.*** For the discussion of this report we have developed a qualitative statement of the relative adaptive capacity of infrastructure ranging from “Low” (where limited effective adaptation is possible) to “High” (where readily available and rapidly implementable adaptations are possible).
- Engineering resilience is the speed of return to the steady state following an alteration to a system. ***It relates to the time and effort required to restore acceptable operability.*** For the ratings assigned within this report we have developed a qualitative statement regarding the relative resiliency of infrastructure ranging from “Low”, (involving loss of an asset and requiring reconstruction) to “High”, (involving return of asset to intended operability after a short-term delay).

Action priorities were then reviewed and grouped in order of urgency for each DOT transport sector using information and operational experience obtained from multiple rounds of technical workshops.

CLIMATE CHANGE IMPACTS ON NWT TRANSPORTATION SYSTEMS

Climate change impacts on NWT Transportation systems were reviewed and assessed on a mode-specific basis, in the following categories:

- All-Weather Roads (AWR)
- Winter Roads
- Airports
- Ferries and Crossings
- River Transportation and Barge Traffic
- Arctic Marine and Coastal Resupply

Impacts are summarized here in sections S3 to S8, based on chapters 3 to 8 in the plan.

S3: ALL WEATHER ROADS

All Weather Roads: The DOT's all-weather road (AWR) network is already under significant stress without considering the added burden of climate change impacts. These pre-existing stresses result in a low-resiliency foundation of this infrastructure. In other words, the all-weather road system is already subject to significant degradation in its stability and service quality due to the following factors:

- Increased traffic trips and cargo loads are being transported along the AWR network. Most significantly, transport truck industrial cargo is increasing as interest in resource extraction activity grows within the NWT. Many of the AWR routes were not originally designed for this burden of industrial traffic.
- Many AWR routes are degraded and aging, with road sections that are nearing the end of their service life.

Adding to the stresses on AWR listed above, climate change impacts are affecting DOT AWR network. Each individual impact has potential to cause significant damage to a section of road, rendering it impassable or reducing capacity due to partial lane closures, reduction in speed limits or road bans. The climate change related impacts can occur to a given AWR section individually or cumulatively. These impacts are:

- **Drainage:** Higher snow volumes and increases in precipitation causing increased runoff challenges. In some cases, existing culvert capacity to carry larger spring runoff and stormwater volumes is no longer sufficient.

- **Saturation of fine grain soils:** Higher than normal precipitation and runoff in road sections established in zones of fine grained soils. These soils lose traction and stability under wet conditions, which can result in extensive damages to affected sections.
- **Permafrost degradation:** leading to ground settlement and subsidence of the road embankments, failure for highway sideslopes, increased sloughing and shoulder sinking and cracking. For the road surface itself, longitudinal and transverse depressions can readily form.
- **Increased icy conditions:** more freezing rain and “rain on snow” events requiring increased demand for sand, gravel and salt materials and more maintenance.
- **Earlier spring runoff:** Washouts are occurring on AWR sections more frequently as spring melt events take place within a shorter time period, leading to faster onset of spring runoff. As well runoff from spring melt is occurring earlier in the year, prior to ditches and culverts being clear of ice and snow.
- **Increased vegetation growth:** The additional vegetation increases snow entrapment, resulting in more runoff, more instances of wet road conditions, and in permafrost areas, can result in net annual warming of ground temperatures that induce thaw settlement.

All the impacts above also contribute to accelerated “wear and tear” degradation of road surfaces, and this leads ultimately to a reduced public perception of safety along these routes.

S4: WINTER ROADS AND ICE CROSSINGS

Winter Roads and Ice Crossings: The DOT’s Winter Road (WR) network is facing changes resulting in abbreviated operating seasons, additional effort and difficulty in establishing sufficient ice growth to support construction equipment, and loss of bearing capacity in the subgrade along winter road routes. Climate change impacts to the DOT’s WR network include:

- **Incomplete Re-Supply:** If a winter road is not open long enough to allow full re-supply due to late opening or early closure, the alternative could be a very expensive airlift. This situation almost occurred in Deline in 2010, and did occur with the users of the Tibbit to Contwoyto winter road (also known as the JV Road, a non-DOT road) in 2006, resulting in tens of millions of dollars of extra shipping costs.
- **Drainage Issues:** Temperature increases are also causing increased drainage issues along WRs. Areas along the Mackenzie Valley Winter Road (MVWR) have experienced flooded road sections and created challenges in establishing land crossings. Along the Tlicho Winter Road (TWR), DOT has shut down road sections due to flooding in three of the past five years.
- **Late Freeze up:** Warmer temperatures have meant that consistently colder ambient air temperatures are not occurring until later into the winter season delaying ice formation on lakes and rivers

- **Snowfall changes:** Greater amounts of snowfall are occurring early in the WR season in some areas and this additional snow acts as a layer of insulation that prevents efficient ice formation. This is particularly an issue for lakes on the TWR. Alternatively, land based portions of the winter roads require a minimum amount of snow to form the base and protect the frozen ground. Lack of snow has delayed the opening of the MVWR in recent years
- **Earlier spring thaw:** Conditions causing winter road melt are occurring earlier in the spring in some recent years, and generally occurs on the land-based portions, particularly south-facing slopes.
- **Localized extreme weather events:** high intensity storms and winds are causing impacts to the quality of lake ice resulting in problems in ice structure and thickness.
- **Variable conditions:** Increase in variability of conditions at shallow locations such as near shore at portage (land) sections complicate and adds to the effort required in road construction and can delay opening the road.
- **Structural stability:** Warmer temperatures are leading to changing soil conditions related to permafrost degradation and changes in runoff regimes. These impact temporary bridge crossings, culverts and related infrastructure.

S5: AIRPORTS

Airports: DOT is responsible for the maintenance and serviceability of the runways, aprons, landing approaches, parking areas for 27 airports. DOT's key focus areas for airports are operations, maintenance and rehabilitation of existing infrastructure. Climate change impacts to the DOT's airport network include:

- **Structural degradation due to freeze/thaw cycles:** Melt water can access subsurface below paved runways resulting in pavement surface damage and melt water-induced degradation of permafrost.
- **Drainage issues:** Increased rain and snowfall events are causing drainage problems with localized flooding of runways and taxiways.
- **Permafrost degradation** has led to settlement of runway areas and in some cases, sinkhole formation and runway buckling. This is relatively easy to repair on gravel runways but requires substantial effort on paved runways.
- **Weather pattern changes:** are resulting in higher incidence of freezing rain events and frost build-up on runway surfaces, thereby reducing the necessary friction for safe operations, particularly at Inuvik and Norman Wells. More frequent extreme-event travel delays are also occurring due to fog-induced airport closures during conditions of limited visibility.

- **Increased use of friction materials:** to counter low friction conditions. DOT has indicated a substantial increase in maintenance effort and materials to satisfy sanding requirements to maintain adequate runway friction. Sanding requirements are reported to have escalated from 15 tonnes per year prior to 2000 to over 150 tonnes per year in 2012.
- **Increased need for de-icing:** Increased demand and use of de-icing materials (Glycol) and management of glycol runoff.

S6: FERRIES AND FERRY CROSSINGS

Ferries and Ferry Crossings: DOT is responsible for the operation and maintenance of four ferry crossing sites in NWT. DOT Ferry Captains and support staff have reported climate change related impacts to their operations related to river bank stability, fluctuations in river water levels and flows, river ice dynamics, ferry load capacity reductions and ferry crossing site drainage.

Climate change impacts to the DOT's Ferry System network include:

- **River bank stability:** Riverbank sloughing and reduced bank stability due to fluctuations in river levels, increased precipitation, and warmer temperature-induced permafrost degradation. A stable riverbank is a necessity for safe loading and offloading the ferry vessels.
- **Reduced ferry carrying capacities:** Lower water levels have resulted in reduced ferry carrying capacities.
- **Damage to landings:** Severe water level fluctuations are also impacting ferry landing sites and ramps. Ferry ramps are built from gravel, and are subject to scour but are also easily adjusted to current water levels as required.
- **Drainage at landings:** Under wet conditions caused by intense rainfall events, the landings and approaches for some ferry crossings can be subject to extreme softness and slippery conditions, resulting in service disruptions.
- **Increase in large debris:** Runoff-induced increases in large debris within river flows are occurring. Large debris such as trees cause temporary disruption of ferry service.
- **Increased operating seasons:** Due to longer ice-free periods late in the ferry operating season, closing dates in the ferry season have extended by 1-2 weeks over the past 20 years, resulting in added cost and labour to extend the ferry operations each year.

S7: RIVER TRANSPORTATION AND BARGE TRAFFIC

River Transportation and Barge Traffic: DOT has an interest in a system comprised of privately operated supply barges serving industry, residents, and delivering fuel for GNWT electricity generation. During the ice-free season, shipments departing from the hub in Hay River ship cargo up the Mackenzie River. The Mackenzie serves as a major cargo transport route through the NWT. An operator in Fort Nelson also barges down the Liard River to service communities on the Mackenzie River.

This system is experiencing impacts due to climate change, including water level fluctuations, but operators appear to be adapting, and it is not seen as being at risk in the foreseeable future.

S8: ARCTIC MARINE AND COMMUNITY RESUPPLY

Arctic Marine and Coastal Resupply: The GNWT manages community resupply to three NWT arctic coastal communities: Paulatuk, Sachs Harbour and Ulukhaktok. The GNWT ensures fuel resupply through the Petroleum Products Division (PPD), along with other essential supplies including building materials, food products, and other staples.

The arctic marine environment is characterized already by variable and swiftly changing conditions that create challenges for transportation in these waters. Arctic storms are increasing in both frequency and intensity – with no mechanism to predict substantially in advance when or where these extreme events will occur. These storms expose arctic marine vessels to more hazardous weather conditions.

Impacts associated with climate change in the arctic marine environment pose problems to coastal resupply:

- difficulties in navigation, maneuverability and access to coastal community ports, compounded by lack of adequate charting of harbours and shipping routes lead to vessel damage
- increased frequency of higher wind conditions and intense and difficult to forecast arctic marine storms
- threats to vessels resulting from changes in the distribution of multi-year ice and icebergs / ice islands
- reductions in land fast ice leave coastal harbours more vulnerable to erosion from waves and storm surges
- coastal permafrost erosion threatens the integrity of harbours

S9: ADAPTATION ACTIONS

INFORMATION GAPS AND RESEARCH NEEDS

Information gaps and research needs have been identified for the different transportation modes, along with data management infrastructure.

- Enhanced Monitoring and Condition Tracking

- More formalized infrastructure assessment records
- Compilation of operational data related to incident tracking (deployment, response required to restore, issue, etc.) is required.
- Application of newer technologies for gathering geo-referenced data and condition reports (GPS tracking, data tablets with DOT-specific data entry forms for remote entry etc.)
- Updating of infrastructure inventories and baseline assessment of current conditions, ongoing updates of conditions to track changes with time
- Enhanced inspection practices
- Testing of construction technologies and materials
- Formalized GIS-based asset management system is essential for managing data capture in actions listed above
- Requirement for securing region-specific future climate projections for temperature and precipitation. Assemble climate projections by dividing NWT into potential zones of similar micro-climate. Obtain data through climate modeling agencies such as Ouranos or via Canadian Climate Change Scenario Network (CCCSN).
- Where available, obtain atmospheric data that may be analyzed and correlated to operational parameters.
- Apply appropriate remote sensing technologies

ALL WEATHER ROADS

To respond to the impacts to All Weather Roads described above, a number of priority actions are recommended to DOT.

Drainage Issues: a dominant, widespread mechanism for undermining AWRs, especially in zones where fine grained soils are prevalent. Drainage issues impacting serviceability of AWRs include summer rainfall washouts, localized road section flooding, and road section erosion. Priority actions include:

- Increased maintenance and surveillance of road infrastructure
- Consideration of new practices and road bed technologies when conducting repairs and replacement of drainage systems.
- Culvert replacement upon evidence of exceedance of runoff capacity. Application of better design storm data (reflecting changing precipitation and runoff regimes).

Permafrost Degradation: results in slumping of landforms, differential settlement and damage to road surfaces. Priority actions include:

- Updated road route condition assessments. Regular and ongoing road condition assessments, including tracking of road and embankment elevations to analyze and monitor differential settlements

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- Selective thermistor temperature monitoring networks for road segments with high permafrost degradation.
- Roadbed stabilization programs (i.e. measures to lower ground temperatures in order to maintain cooler subgrade, different embankment configurations and fill materials) for road segments identified to be highly sensitive and problematic, such as
 - Highway 3 Behchoko to Yellowknife
 - Liard Highway
 - Dempster Highway
- Data collection and information collection, engineering analysis and costing evaluations and assessment/implementation of mitigation techniques shown to be successful in stabilizing heat transfer and permafrost degradation for road routes experiencing increasing damage due to permafrost degradation.
- Alternative routing assessment prior to reconstruction of roads under high extent of permafrost degradation. Current roads were mostly built in flat areas to minimize cut and fill. In the north, flat areas commonly contain sedimentary basins filled with ice-rich permafrost sediments.
- Strategic snow clearing and management for vulnerable permafrost road sections.
- Replacement of culverts experiencing accelerated degradation due to climate change.

Increased Demands on DOT Staff, Equipment Needs and Budgets: all measures required to respond to climate change impacts on AWRs will require additional resources and optimization of potential resource gains. Priority actions include:

- Defining service baselines for AWRs. Identifying minimum needs for road performance and once defined, communicating acceptable conditions to road users.
- Increasing equipment fleet, enhancing capabilities of equipment and optimizing deployment of equipment. Evaluation of expansion of DOT fleet and contracting fleets on a seasonal basis.
- Seek, secure and allocate additional funding to meet demand for more labor hours, higher demand for AWR maintenance consumables and increased maintenance equipment needs.

Changing window for construction and maintenance of roads: Budget allotments and scheduling will need to factor in longer work windows in order to keep up with DOT maintenance requirements. Some equipment already operates 24 hours/day, but methods of performing maintenance over longer periods of the year are required. Priority actions include:

- Consideration and, where possible, conducting construction and excavation of roads in colder periods to minimize thermal disruption (Alaska DOT is implementing now).
- Gradually expanding the maintenance activity season through periods of the year that DOT has not traditionally conducted maintenance.

Road surface degradation: soft conditions and damages due to high volumes of heavy commercial loads, vegetation encroachment and changing drainage and runoff dynamics. Priority actions include:

- Enhanced monitoring and reporting of road site stabilities, vegetation growth and encroachment upon road embankments, and erosion conditions.
- Partnerships with industrial road users. Evaluation of current support funding framework and assessment of user-fees for high load cargo and other high frequency industrial traffic. All user fees would be fed into ongoing maintenance of these routes.
- Review of road construction and design criteria such that climate change-induced trends of increasing temperature and runoff are factored into designs. Evaluation of option to import fill instead of using local silt-laden materials. Apply snow modeling and embankment geometry to identify zones of potential problematic snow accumulations along new road routes (e.g. Inuvik to Tuktoyaktuk Highway).
- Evaluate new construction practices, with emphasis on techniques in other arctic regions that may be applicable to NWT routes. (e.g., geotextile reinforced soils).

Communication of Travel Delays: DOT currently updates its website in this regard on a regular basis; however newer technologies that push data out to users will grow in their implementation, particularly as smart phones become more widespread. Development of DOT twitter feeds for travel delays or smartphone “App” should be considered.

Information gaps and research needs:

- Insist upon design criteria enhancement for new road construction that incorporates climate change considerations, instead of codes based upon purely historical climate data.
- Initiate research into mechanisms of culvert failure, including enhanced understanding of thermal regimes around highway culverts, changing freeze-thaw cycles on culvert longevity, and impacts of permafrost degradation on culvert performance.
- Apply remote sensing technologies to road condition monitoring, landform changes near road routes, and for route planning and design efforts.
- Implement monitoring programs for intensive monitoring of specific road sections, particularly those related to new remediation or construction techniques.
- Study is required to better understand the impact of groundwater flow on the thermal regime of road subgrades.

WINTER ROADS

To respond to the impacts to Winter Roads described in Section 9 above, a number of priority actions are recommended to DOT.

Changes to Winter Road Season and Operations: changing conditions affect the construction and operating season duration for winter roads. Priority actions to respond to this challenge include:



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- New operations and strategies such as:
 - Pre-emptive snow removal to enhance ice formation
 - Advanced ice profiling equipment for condition assessments
 - Establishing snow caches at troublesome land crossing locations
 - Equipment caching to allow for swifter deployment and construction
 - Enhanced route reviews to allow for optimized construction planning
- Increased manpower and equipment to allow compressed construction in the event of delayed onset of winter road construction conditions.
- Hybrid winter roads where shallow embankments are built at portage sites along the winter road route.
- Vegetation management to reduce amounts of snow cover required to establish portage sections.
- Expanded information sharing and collaboration with DOT and between external jurisdictions (AK, Manitoba, USACE, etc.)
- Proactive and aggressive reduction of overflow occurring on road beds through higher intensity tracking and intervention.
- Construction of embankments on south sides of winter road portages to reduce solar heat applied to roadbeds at sensitive portages.
- Where winter road sections are increasingly difficult to keep in reliable service, develop and assess alternative routing for these roads.

Problems with Ice Crossings on Winter Roads: Ice crossings across streams, rivers and lakes will reduce in stability as temperatures increase in the north. Priority actions to respond include:

- Establish more permanent crossings along the MVWR.
- Review crossing design in terms of reducing overflows, avoiding scour, and structural stability
- Convert more temporary culvert crossings to permanent culverts, including stacked culvert systems for handling higher flows.
- Re-assign ice bridge equipment formerly deployed at Fort Providence ice crossing to be used on MVWR crossings now that Deh Cho Bridge is in service.

Information gaps and research needs:

- Apply remote sensing technologies to ice condition monitoring, and for route planning and design efforts.
- Conduct a winter road service level review, defining key objectives and determining practical user expectations for each route (i.e. a resupply route, an industrial access route, a community access route, to what degree and what priority to each?).

AIRPORTS

To respond to the impacts to Airports described in Section 9 above, a number of priority actions are recommended to DOT.

Runway buckling due to changing runoff, soil and permafrost conditions: changing subsurface conditions results in runway surface buckling or slumping. Priority actions include:

- Apply the DOT-developed airport climate risk assessment protocol to selected airports. The first candidates are Yellowknife, Inuvik, Norman Wells, and Ft. Simpson.
- Conduct strategic snow clearing on runway aprons and shoulder areas to preserve permafrost integrity.
- For paved runways with chronic problems, rebuild runways as determined from results obtained through the DOT airport risk assessment protocol.
- For gravel airstrips, periodically re-grade to maintain safe runway running surface.

Runway and Taxiway Flooding: settlement of runways creates depressions allowing pooling of melt water and precipitation to accumulate on runways. Priority actions include:

- Drainage assessments of airstrips with recurring drainage issues.
- Using drainage assessment findings, upgrade drainage infrastructure on a priority basis.

Runway Loss of Friction: water, ice accumulation or frosting results in reduction of friction on runways, with potential to impact or abort takeoff and landing operations. Where this occurs (primarily Inuvik) priority actions include:

- Increased supply and application of sanding and de-icing fluids
- Assessment of runway grooving techniques
- Extending runways to allow more runway length in cases of reduced friction conditions.

Increase Maintenance Burden: application of additional materials to sustain safe airport operations. Priority actions include:

- Increasing resources to apply more traction-enhancing materials.
- Increased use and supply of glycol and ground de-icing agents.
- Enhanced glycol management and containment facilities at airports.

Travel delays due to extreme weather and fire: includes extreme events with potential to disrupt air travel, such as intense storms, freezing rain, and visibility-limiting fog or smoke. Priority actions include:

- DOT review and enhancement of passenger notification systems.
- Installation of instrument landing systems at more airstrips.

Information gaps and research needs:

- Apply remote sensing technologies to airport runway condition monitoring, and settlement changes near airport facilities.
- Enhanced investigation and confirmation of degree of permafrost degradation in airports located in zones of expected advanced permafrost loss.

FERRIES AND FERRY CROSSINGS

To respond to the impacts to Ferries and Ferry Crossings described in Section 9 above, a number of priority actions are recommended to DOT.

Changes to ferry landing site riverbank stability: Changing water levels, sloughing action, erosion and ice dynamics can damage riverbanks and impair riverbank stability. Priority actions include:

- Ongoing monitoring for bank instability. Where identified, ongoing tracking of stability should be considered.

Changes to ferry operating season duration: warmer temperatures will delay establishment of ice crossings and require extended ferry service operations. Priority actions include:

- Prepare budget and resource allocations to allow for longer duration ferry service on an annual basis.

Information gaps and research needs:

- Where available, obtain atmospheric data that may be analyzed and correlated to operational parameters. Water levels and ice dynamics should be priority data.
- Apply remote sensing technologies to ice condition monitoring and spring ice breakup passage. A priority should be placed on ice forecasting systems for river reaches upstream of ferry crossing sites, allowing advance warning of problematic ice and debris formations occurring upstream of crossing sites, and protective action to avoid damage to ferry equipment.

RIVER TRANSPORTATION AND BARGE TRAFFIC

To respond to the impacts to River Transportation and Barge Traffic described in Section 9 above, a number of priority actions are recommended to DOT.

Damage or loss of shore facilities: Damage to piers and boat and barge mooring structures:

- Reconstruction or rehabilitation of facilities.
- Dredging of channels at Hay River and near wharfs at Norman Wells.
- Relocation of navigational aids or mooring anchor points in response to shoreline erosion and slumping along the Mackenzie River.

Water levels and riverbank slumping along Mackenzie River:

- Regular monitoring of Mackenzie River bank alignments and locations of riverbank slumping.
- Regular monitoring and reporting of river levels at problematic reaches of the river, with real-time reporting to barge operators.

Information gaps and research needs:

- Implementation of a system of water level tracking and reporting along problematic reaches of the Mackenzie River to allow barge operators to anticipate low-water levels along reaches of the river.

ARCTIC MARINE AND COASTAL COMMUNITY RESUPPLY

To respond to the impacts to Arctic Marine and Coastal Community Resupply described in Section 9 above, a number of priority actions are recommended to DOT.

Damage to Marine Vessel Propellers and Rudders: vessel damage due to lack of up to date marine charts, changing and unpredictable ice conditions, and movement of formerly non-mobile ice. Priority actions include:

- Stricter regulation regarding maintaining operational prudence and skill.
- Use of larger cargo vessels, and offloading these vessels using smaller lighterage vessels based in each coastal community.

Challenges to Vessel Maneuverability, Docking and Mooring: the operating environment for arctic marine vessel operation includes shallow, poorly charted waters, unpredictable ice dynamics and in some cases, highly confined harbor landings with limited space for vessel maneuverability. Priority actions include:

- Accentuate charts and weather/ice information to inform vessel traffic active in the region.
- Deployment of different vessels to conduct resupply (see lighterage option mentioned above)
- Upgraded shore facilities, for example, establishment of a permanent landing ramp at Paulatuk.

Disruption to Resupply Campaigns: All activities in the high arctic are weather dependent. Variable and extreme weather events will increase in frequency and intensity, creating high potential for recurring delays in offloading of cargo shipments. Priority actions include:

- Scheduling cargo shipments to allow buffers in resupply.
- Establishing higher capacity and reserves in critical resupply commodities such as fuels.
- Ongoing review and revision of contingency plans to respond to incomplete or critical delay in coastal community resupply.

Information gaps and research needs

- Correcting the current status of inadequate marine charting in the resupply operating area.
- Ongoing monitoring and reporting of ice dynamics.
- Detailed assessment of lighterage option for coastal community resupply.
- Assessment and feasibility study for establishing Tuktoyaktuk as a bulk reserve storage hub for essential arctic coastal communities.

S10: IMPLEMENTATION

A number of “key themes” emerged from the actions compilation. These themes reflect the general nature of each activity. They have been given informal titles of: learn, cope, plan, and build.

- **“Learn”:** There is a need for more data and research into the physical processes affecting the infrastructure:
 - Infrastructure and asset management data.
 - Applied research through pilot testing of new designs.
 - Engineering studies and evaluation methods.
 - Climate and hydrological data.
- **“Cope”:** The DOT operations groups (and other transportation players) have been addressing the evolving needs of the system in an incremental fashion by maximizing existing systems, increasing existing effort, and making some changes to current practices. In the short term (1-5 years) these activities are appropriate adaptation strategies (not all impacts require a dramatic adaptation measure).
- **“Plan”:** There are a number of initiatives that the DOT must prepare for. During the next 5 (perhaps 10 years) some major decisions, and accompanying investments will have to be made.
- **“Build”:** In the future other infrastructure changes or repairs have been and will be required. Some of these may be smaller in scale (e.g. a culvert replacement program, etc.) while others could be massive (e.g., Liard Highway reconstruction).

PRIORITIES

DCS has applied a risk assessment methodology to an immense range of information from a variety of sources, and identified high, medium and low areas of impact for the DOT. For each of these impact areas a number of response actions are proposed. While the identified high risk impacts do highlight issues that should be “at the top of DOT’s list” to focus on for adaptation, there must be an understanding that all of the actions identified are important, and are likely to increase in importance.

Due to the large number of unknowns, many actions are focused on data collection and research. This emphasis will allow development of key datasets, GIS and infrastructure management analysis tools and confirmed understanding of mechanisms that DOT will be required to understand and respond to in longer-term operational and capital planning. These data and research findings will assist to confirm the urgency of additional funding and investment in establishing, maintaining and operating transportation networks that are critical to the sustainability of communities and industrial development in the NWT.

DCS commends DOT for its efforts to date to effectively maintain its infrastructure using limited resources, but the system as a whole is increasingly stressed. In the longer term it is our assessment that current funding and resources will not be sufficient to address the combined effects of climate change, renewal of existing infrastructure, and development of new infrastructure in the long term.

RESOURCES

Substantial changes in funding programs, industrial and government partnerships, research, collaboration and application of knowledge are required in order to develop a new understanding of how to build and operate the transportation network in the future. These changes will require resources to understand the problems and implement the required changes.

IMPLEMENTATION RESOURCE REQUIREMENTS

This section defines the staff and resource requirements expected for implementation.

- Existing staff budgets: A subset of the actions defined within this report can be implemented by existing staff and budgets. However experience suggests that freeing up staff time is unlikely to occur.
- New Staff: It is proposed that at least one new Full Time Equivalent (FTE) transportation planner position be created within the department.
- Existing Operating budgets (disbursements): Material and supply costs – gravel, glycol, etc. - are expected to increase going forward. This will require continued, incremental increases in operation budgets. As well, it is possible that increased operations staff may be required.
- Small Capital Program: Small capital budgets (projects < 400k\$) are allocated to the department based on need, and the department has the opportunity to establish priorities. Overall it should be expected that small capital budgets are going to have to start increasing in the next several years.
- Large Capital and “Partner Capital” Projects: Large capital projects (up to \$50 million) and partner capital projects (typically >\$50 million) are special projects, requiring many years to develop and fund. It is clear that climate change considerations will need to be included in these projects – which could result in additional costs. Heightened interest and access by industry as climate change “opens up” the north will add pressure for some major projects.

SOURCES OF FUNDING

Funding for the actions will arise from a number of sources including:

- Base staff allotment
- Operations funding: Includes staff overtime, increased contractor effort, more consumables.
- Research funding
- DOT small capital budgeting as described above
- Large Capital funding as described above.

ROLES AND RESPONSIBILITIES

DOT is expected to be the lead agent in addressing these issues for the roads, airports, and ferry crossings. “Ownership” of the plan will be by DOT, with cooperation from other GNWT departments.

For river transport and arctic marine operation DOT has a lesser role. These actions fall primarily to other players to implement. The expectation of the plan is that DOT would take a role to actively encourage those parties to implement actions, and to actively support these actions through in-kind resources.

COMMUNICATION AND ENGAGEMENT

Any changes to departmental objectives, mandate, or service levels should be communicated to staff and stakeholders as early as possible in the planning stages. Communications plans will need to be put in place for several audiences including:

- Public: General public consultation will be required if any changes are made in transport policy that is perceived by the public to reduce or restrict levels of service.
- Stakeholders: Actions that affect road pricing, or cost for service, or changes in current activity will need to be reviewed with stakeholder groups.
- Internal communication: There may be a need for DOT to communicate internally and with other GNWT staff about any actions being taken. As well, communication to management about the urgent need to commence some of these actions is important.

REPORTING AND REVIEW

Reporting and periodic review is essential. It ensures that actions are being implemented, new knowledge is incorporated, and that DOT can be proactive rather than reactive in their activities.

Reporting would include:

- Documentation of activities performed under the plan

- Incremental expenditures (actual or estimated)
- Compilation of monitoring metrics

Review would include:

- Annual review of the plan prior to budget setting to define priorities and actions for the next annual budget.
- A more comprehensive review every 5 years to readjust the plan, and to incorporate new conditions.

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“Change and Challenge”

Climate Change Adaptation Plan for the GNWT Department of Transportation

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Acronyms and Abbreviations

AWR	All weather road
CC	Climate Change
CCG	Canadian Coast Guard
CO ₂	Carbon dioxide
CO ₂ e	Carbon dioxide equivalent
DCS	Deton Cho Stantec
DFO	Department of Fisheries and Oceans
DOT	Department of Transportation
ENR	Environment and Natural Resources (of the GNWT)
GHG	Greenhouse Gas
GSL	Great Slave Lake
GNWT	Government of the NWT
ITH	Inuvik to Tuktoyaktuk Highway
IPCC	Intergovernmental Panel on Climate Change
JV	Joint Venture – referring to the Tibbitt to Contwoyto winter road
MACA	Department of Municipal and Community Affairs (of the GNWT)
MVH	Mackenzie Valley Highway
MVWR	Mackenzie Valley Winter Road
NWT	North West Territories (the place)
PPD	Petroleum Products Division (of the GNWT)
TWR	Tlicho Winter Road

1 INTRODUCTION

In October 2011 the Government of the Northwest Territories Department of Transportation (DOT) retained DCS to develop a DOT Climate Change Adaptation Plan.

1.1 Climate Change Impacts and Challenges for Canada’s north

Climate change, as defined by the IPCC, refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity. The U.S. EPA describes climate variability as major changes in temperature, precipitation, or wind patterns, among others, that occur over several decades or longer.

Climate change is different from weather changes, in that weather consists of short-term (minutes to months long) fluctuations in the atmosphere, while climate and climate change refer to long term changes measured over decades.

Scientific data and regional observations indicate that climate change has induced and will continue to induce impacts to Canada’s North. The Intergovernmental Panel on Climate Change (IPCC) indicated a global average surface temperature increase of 0.6 C during the period from 1861 to 2000. In the Arctic regions, warming trends indicate a 20th century warming trend in air temperature of up to 5 C has occurred. Multiple global climate projection models indicate global temperatures could increase 1.4 to 5.8 C by 2100, and it is widely recognized that the impacts of climate change are evident now. Polar and northern areas will experience more pronounced changes than are expected in the mid-latitudes.

Canada’s north is on the ‘frontline’ in the global climate change challenge. Nowhere else in our country, are the early effects of climate change so evident. Nowhere else in Canada are communities and traditional ways of life so clearly at risk due to climate change¹.

While climate change impacts will vary within the vast geographic range of Canada’s Northwest Territories, the significance of these impacts will have effects on the sustainability of northern communities and the management, development and conservation of natural resources. Natural features such as river hydrology, soil stability, plant species distribution, wildlife habitats and migration patterns are all subject to alteration in response to climate change. Infrastructure will be particularly impacted where it is built on permafrost (roads, and runways), or under seasonal conditions which may be changing (winter roads), or is subject to the variability of climatic events (e.g. navigation and aviation).

¹ Canada’s National Round Table on the Environment and the Economy report “True North: Adapting Infrastructure to Climate Change in Northern Canada” 2009,

1.2 Transportation and Climate

Changes in climate for the NWT, as with all of Canada's north, will result in a number of impacts, including but not limited to:

- Warmer winter temperatures
- Shorter winter road seasons
- Less predictable ice conditions
- Thawing of permafrost
- Extreme weather events
- Changes in hydrology.

Each of these impacts has potential to create issues and challenges for transportation infrastructure and systems in the NWT. In many regions of the north, transportation routes rely on soils depending upon frozen ground conditions for stability. The establishment and maintenance of winter roads (ice roads) is highly dependent on prevailing temperatures. The presence of warmer winters and earlier spring melts in the north creates huge challenges to communities and industries reliant on these road networks for transport of people and goods. Airport aprons and runways are impacted by melting permafrost, causing damage to airport infrastructure that is critical for the sustainability of isolated NWT communities who rely heavily on air transport for connections to the rest of the world. Warmer temperatures also impact marine transportation, as reductions in sea ice and land fast ice result in both increased shipping access through the Northwest Passage and increased coastal erosion near landings and ports.

The combined effects of climate change are expected to result in changes to the transportation sector's operating environment in the form of increased ground subsidence, increased instances of slope failures, and changes to the surface water and groundwater regimes. Each of these operating environment changes creates serious impacts and potential risks that will require additional and comprehensive monitoring and management by DOT to deliver safe and efficient transportation networks to its communities.

1.3 Department of Transportation and Climate Change Adaptation Planning

DOT recognizes that the economy and way of life in Northern Canada is directly reliant on the transportation network. A reliable multi-modal infrastructure system reduces the cost of living, supports inter-community and social mobility, bolsters economic diversification, fosters effective resource development and reinforces Canadian sovereignty and security for northern regions.

DOT faces unique challenges to the operation of a safe and effective transportation system due to its inherently harsh climate, large distances between communities and markets, abbreviated construction season, sensitive and relatively undeveloped environmental setting, and a developing economy. Under the best conditions, establishing and operating transportation infrastructure in this environment for a

small, distributed population is a highly challenging task. The NWT transportation system faces challenges in the need to upgrade substandard existing infrastructure, as well as to rehabilitate and replace aging infrastructure with limited financial resources. A significant portion of NWT’s transportation infrastructure was built to minimum standards of the day and now requires extensive investments to maintain operability and reliability. Industries such as resource extraction bring economic activity but also much larger cargo loads than were anticipated when this existing infrastructure was first constructed. Many of these infrastructure elements, such as major culverts, bridge structures and maintenance buildings are reaching the end of their lifecycles.

In addition to the basic challenges of providing vital transportation infrastructure to NWT’s remote and distributed communities, much of this vital infrastructure is susceptible to impacts resulting from climate change. Over the past 20 years, warmer than normal temperature trends have resulted in impacts expanding DOT’s burden in managing, operating and maintaining vital infrastructure. DOT has already been experiencing and developing measures to attempt to cope with impacts such as delayed openings of ice bridges at river crossings, increased O&M costs, increased consumable materials costs, a reduced functional window of the winter road system, increasing airport closures due to weather events – all factors leading to increased variability and unreliability within the transportation system.

As DOT gains more knowledge and observations regarding the nature and extent of various climate change impacts to its transportation system, it develops methods to reactively respond to these challenges. DOT’s capacity to respond reactively to a growing set of climate change-induced impacts is not unlimited. In order to prioritize remedial actions and develop adaptation strategies that allow for longer term planning horizons, DOT has decided that it must transform from a reactive to proactive strategy to address climate change impacts. The development of a Climate Change Adaptation Plan (CCAP) is the first step to respond proactively to transportation infrastructure vulnerabilities resulting from climate change.

1.4 Objectives

In October 2011 the Government of the Northwest Territories Department of Transportation (DOT) retained Deton’ Cho Stantec to develop a DOT Climate Change Adaptation Plan.

Specific objectives of this Climate Change Adaptation Plan are to:

- Provide guidance to DOT about the nature and severity of impacts to be expected from climate change 5, 20 and 40 years from today.
- Inform DOT decision-making processes
- Identify significant risks to the transportation system posed by climate change.
- Identify best practices for adapting to climate change
- Define adaptation actions that can be taken to reduce the impacts of these changes, as well as budgeting implications

- Define data gaps and research and monitoring needs that will be required to track current and identify future impacts of climate change and additional adaptation actions.
- Develop an implementation plan for the department, which may also include actions to partner with, or recommend to other agencies and stakeholders

This plan is intended to function as both a policy guide – directing planning activities, as well as to provide direction for current and future actions. It will inform decision making, provide courses of action, define data gaps, and identify and establish directions for research needs.

1.5 Methodology

1.5.1 Activities

In developing the CCAP, DCS carried out a number of activities, which are reported on separately.

- Report on community-specific climate forecasts for the NWT
- Review of relevant northern literature and past studies on climate change. This includes identification of 62 documents of which 29 were reviewed using a formal template.
- Conducting a risk assessment workshop for impacts of climate change on NWT Ferry and Marine Transportation January 25 & 26, 2012 with 15 stakeholders. The report includes summary of discussion, presentations made and results.
- Engaging with stakeholders through community visits and interviews. This included five community visits, interviews with 13 stakeholders and users from road, winter road, air and marine modes, and input from three experts with northern climate change expertise
- Compiling a consolidated risk assessment and identification of adaptation actions. This included results from an October 2010 risk assessment workshop for impacts of climate change on NWT Roads and Airports carried out under a separate contract, conclusions of other studies previously completed, and discussions with DOT staff.
- Conducting a workshop with 14 DOT staff and selected staff from other GNWT departments to review preliminary risk assessment results and adaptation actions

These activities all informed the development of the CCAP. In addition the DCS team reviewed substantial additional literature, conducted additional interviews with stakeholders and experts within and outside DOT, and incorporated additional expert review of the final document.

1.5.2 Assumptions

A number of assumptions were applied in this assessment. These include:

- The NWT continues to rely upon road, air, barge and marine vessel for social and economic sustainability of its communities.

- DOT continues to serve its role to GNWT and continues responsibilities as defined in this report for transportation sectors related to road systems, airports, barge and coastal vessel resupply campaigns.
- No introduction of rail into DOT roles and responsibilities is considered in this assessment
- Funding to study, research, design and implement adaptation measures (in new designs, retrofits and operations) must and will be identified, but mechanisms of this funding are not defined.



2 CONTEXT

2.1 The DOT Mandate

The Department of Transportation (DOT), Government of the Northwest Territories (GNWT), is responsible for the planning, design, construction and maintenance of a safe and reliable transportation system across the Northwest Territories (NWT)². As part of this mandate, the Department administers facilities, which support activities in three transportation modes: land, marine and air.

2.2 DOT General Description and Responsibilities

The DOT structure includes six headquarter divisions:

- Directorate
- Corporate Services
- Policy, Planning & Environment
- Airports
- Highways & Marine; and
- Road Licensing and Safety.

² DOT 2013/14 Business Plan

Regional offices are located in Inuvik, Fort Simpson, Hay River, and Yellowknife. Over 300 DOT staff are responsible for providing the services necessary to operate, maintain, repair and construct NWT transportation infrastructure, which includes the following infrastructure categories under DOT's jurisdiction:

- 2,200 km of all-weather highways
- 1,425 km of seasonal winter roads
- 93 bridges
- 244 major culverts
- over 3,000 small culverts
- 27 airports
- Five (5) ferry vessels, at four (4) active ferry crossings.

2.2.1 DOT Vision

DOT is guided by a stated vision to provide NWT citizens with:³

- Safe secure, affordable, reliable and accessible personal mobility
- A higher standard of living for the territory and its communities through the more efficient and lower cost of freight.
- Sustained economic growth and prosperity through better development access to the territory's renewable and non-renewable resources.

2.3 DOT Missions and Goals

2.3.1 Mission

Created in 1989, the NWT Department of Transportation's mission is to provide for the safe, secure, accessible and reliable movement of people and goods to serve the social and economic needs and aspirations of the people of the Northwest Territories.

2.3.2 Goals

DOT's stated goals for the department are:

- The NWT transportation system continues to improve

³ GNWT DOT “On Track” 2011

- The NWT has an ongoing high level of Northern business and employment opportunities in the public and private transportation sectors
- The NWT has a safe and secure transportation system in all modes
- The Department has a high performance workplace that is adaptable, effective, efficient and innovative in delivering programs and services
- Continue to ensure that the high quality of the NWT environment is maintained
- The Department supports local transportation infrastructure.

2.4 Previous Relevant Studies and Reports

DOT has been involved in the preparation of several reports dealing with transportation system operations and management within a historically challenging arctic environment as well as the emerging impacts and resulting challenges arising from climate change. Each document provides evaluation of specific transportation system impacts and recommendations for potential adaptation measures and acquisition of critical data that is essential for planning against climate change induced vulnerabilities.

2.4.1 NWT Climate Change Impacts and Adaptation Report

The GNWT's Department of Environment and Natural Resources (ENR) developed the report “NWT Climate Change Impacts and Adaptation Report” in 2008. For this document, GNWT departments provided background information to ENR, who considered this data and developed a summary of impacts of climate change on GNWT activities and the actions that departments are taking to adapt to these impacts. This report includes discussion regarding immediate risks and longer-term vulnerabilities stemming from changes to permafrost regimes, ice conditions, hydrologic cycles, vegetation and wildlife, culture and heritage, and human health. A qualitative discussion of types of impacts that GNWT departments are forced to adapt to is included in activities such as construction on permafrost, winter road development, and hydrological cycle changes and impacts on infrastructure.

The information in the *NWT Climate Change Impacts and Adaptation Report* represents a first synthesis of the overall impacts of climate change on GNWT activities and the actions taken to respond and adapt to these impacts. The report concludes that the climate is expected to continue warming for decades, and presents immediate considerations, longer-term vulnerabilities and potential challenges for future adaptation planning in the NWT.

2.4.2 Green Light: Signaling The Department of Transportation’s Commitment To The Environment

DOT’s “Green Light” report highlights existing environmental practices and to further foster a corporate culture of environmental excellence at DOT and through the northern transportation industry⁴.

Green Light was intended to focus DOT staff on progressive approaches to address environmental challenges, while continuing to maintain high service standards. It was also intended to spark action by individuals in each operational region of the NWT and across the DOT organization. “Green Light” provides a blueprint for priority actions in the short-term (0-2 year horizon) and medium term (2-5 year horizon).

Short-term actions in the Green Light report focus on:

- Determining appropriate roles and responsibilities to address priority environmental challenges
- Collecting important baseline information
- Developing clear and practical environmental policies for DOT.

Medium-term actions focus on implementing the required policies and plans under a new departmental Environmental Management System (EMS). Policies, guidelines and initiatives resulting from Green Light were intended to complement and enhance existing GNWT programs and initiatives, including the department’s Climate Change Adaptation Strategy.

2.4.3 Climate Change and Transportation in the NWT – Dillon (2007)

When the Arctic Climate Impacts Assessment (ACIA) was released in 2004, it concluded that the Arctic climate is warming at a faster rate than any other part of the world, with projected temperature increases between 4-7 C over the next century. The ACIA also indicated that winter temperatures would rise more rapidly than summer temperatures. Projected increases in precipitation, particularly for rainfall, along with projected decreases in snow and ice cover were all considered to have significant impacts on transportation in the north. DOT was already reported to experience changes in their operating conditions resulting from localized instability of road and airport infrastructure, changes to water and groundwater regimes and decreasing lengths of the annual ice road season. The Dillon report was developed in 2007 as a response to the ACIA findings and concerns, as it was well understood that all potential impacts from climate change have significant implications for GNWT Departmental budgets and also for communities and industrial developments that rely upon road and air transportation.

The Dillon study was initiated by DOT and funded in part by Natural Resources Canada’s Climate Change Impacts and Adaptation Program (CCIAP) in order to better understand climate change impacts

⁴ GNWT DOT “Green Light: Signaling The Department Of Transportation’s Commitment To The Environment” undated report

on the transportation network, assess the vulnerability of the transportation network, and to explore measures to take to adapt to these impacts. The focus in the Dillon report was on all-season roads and airports. The study highlighted key uncertainties regarding projected climate change in the NWT, and inferred general severities related to specific impacts using available data. The report offered recommendations for next steps in areas, such as:

- Consideration of potential climate change impacts for all new DOT roads and airports so that impacts can be managed more proactively
- Development of climate change adaptation strategy on a GNWT-wide basis
- Collaboration and cooperation with other territorial and federal departments to develop more site-specific climate datasets for application in design, construction and maintenance planning.
- Expansion of initial permafrost modelling efforts outside of the Mackenzie Valley to assist in planning road alignments.
- More formalized reporting of maintenance work and costs, in conjunction with meteorological data in order to analyze impacts and infrastructure responses to departures from historic normals.
- Establishing an allowance for emergency funding in cases of transport emergency, allowing DOT to respond effectively to extreme events without sacrificing capital and operational budgets⁵.

2.4.4 Stantec 2010 Workshop

DOT embarked upon a formal climate adaptation planning process in 2010, with an initial step in this process to conduct a risk analysis to determine how climate change may affect DOT infrastructure and budgets. Stantec Consulting Ltd. was retained for this assignment to lead workshop participants through a risk analysis adhering to the protocol document “Managing the Risks of Climate Change: A Guide for Arctic and Northern Communities”. The workshop outcome was a first stage of a climate change risk assessment that led to the development of DOT CCAP document. The intent of the workshop and risk analysis effort was to:

- Develop a better understanding of long-term climate change trends that will affect the NWT over the next 50-80 years, emphasizing medium-term effects that should be considered within the 20-year planning horizon.
- Identify the range of impacts that climate change will have on DOT’s operations;
- Identify what infrastructure is most vulnerable and what infrastructure is most resilient;
- Identify information gaps and priorities for R&D funding to obtain essential data;

⁵ Climate Change and Transportation in the NWT, Final Report, Dillon Consulting Limited, 2007

- Identify priorities and mitigative actions for the DOT adaptation plan; and
- Identify key stakeholders for engagement prior to implementing actions⁶.

2.4.5 BGC Engineering PIEVC Highway 3 Climate Change Impacts Assessment

The Public Infrastructure Engineering Vulnerability Committee (PIEVC) is a working group established by Engineers Canada to oversee a national engineering assessment of the vulnerability of public infrastructure to climate change. PIEVC developed a detailed, standardized protocol to assess the climate change vulnerability of civil infrastructure. A study was conducted by BGC Engineering Inc., in partnership with Engineers Canada, the Government of Canada, and DOT in order to test the effectiveness of the PIEVC Protocol in identifying climate change induced risks in Canada's north.

A PIEVC Assessment was conducted on a 100 km highway section located on Highway 3 between Behchoko and Yellowknife (km 240 to km 333). This section of highway was selected because it is a linear infrastructure constructed on warm and discontinuous permafrost. This highway was originally constructed as a gravel road in 1968, realigned and straightened from 1999 to 2006 and since this reconstruction has endured higher than anticipated damages. Degradation of ice-rich permafrost is considered the primary mechanism for road damage to this highway section. A major goal in this assessment was to quantify the role of climate change on the permafrost in the region of this highway and its effect on the road within the 100 km assessed section of Highway 3.

The study concluded that out of 276 climate interactions with Highway 3 components identified, approximately 30% of these were low risk, 68% were considered medium risk, and less than 2% were classified as high risk conditions requiring immediate action. The assessors indicated that application of the PIEVC Protocol can be feasible for northern Canadian infrastructure, however detailed site-specific characterization of specific vulnerabilities was not possible due to limited availability of data describing spatial variability of the infrastructure, terrain, ground conditions and climate factors. The study concluded that the assessment could be refined in the event that required site investigation and monitoring data becomes available in the future for this region⁷.

⁶ Climate Change Adaptation Risk Assessment Workshop Report for the NWT Transportation System, Stantec Consulting Ltd, 2010.

⁷ Highway 3 – Climate Change Vulnerability Assessment, BGC Engineering Inc. 2010

2.5 Current Climate Understanding for NWT

2.5.1 Historical Trends

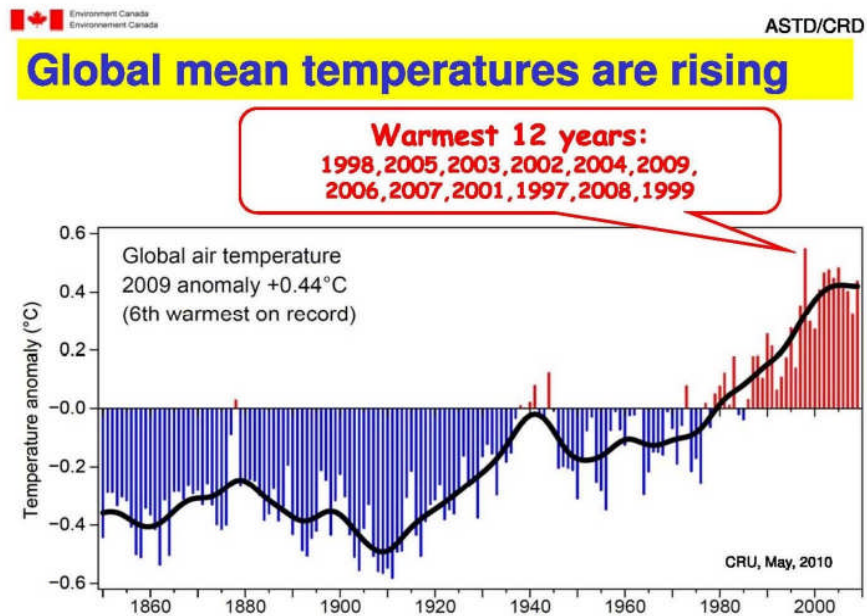
The arctic is generally defined as the area situated between 60 – 90° north latitude. There are a range of weather and climate variables that influence climate change, and numerous interactions between the atmosphere, the cryosphere, ocean, land, and ecosystems (IPCC 2007a). The relationships between these variables and their interaction can cause varying changes at global, regional, and local scales. Environment Canada reports that global mean temperatures are rising, with the warmest 12 years on record taking place between 1998 and 2010 (see Figure 2-1).

The north, including the Northwest Territories, is projected to experience temperature changes more rapidly and with more intensity than other regions of the world. Data has shown that Canada has warmed at almost twice the rate of the global average. Observed changes in the north include:

- Permafrost and ice melting in Canada’s north is occurring and creating structural instabilities for many ground components.
- Impacts in precipitation, particularly from precipitation extreme events, appear to be increasing.
- Accelerated melting and loss of summer extent arctic ice⁸. Figure 2-2 shows historical and forecast September Sea Ice cover in the high arctic. Notably, these losses are occurring faster than predictions made only a few years ago.
- Studies by NASA have reported a rising frequency and intensity of arctic storms over the last 50 years, and these storms cause the acceleration of arctic sea ice drift⁹.

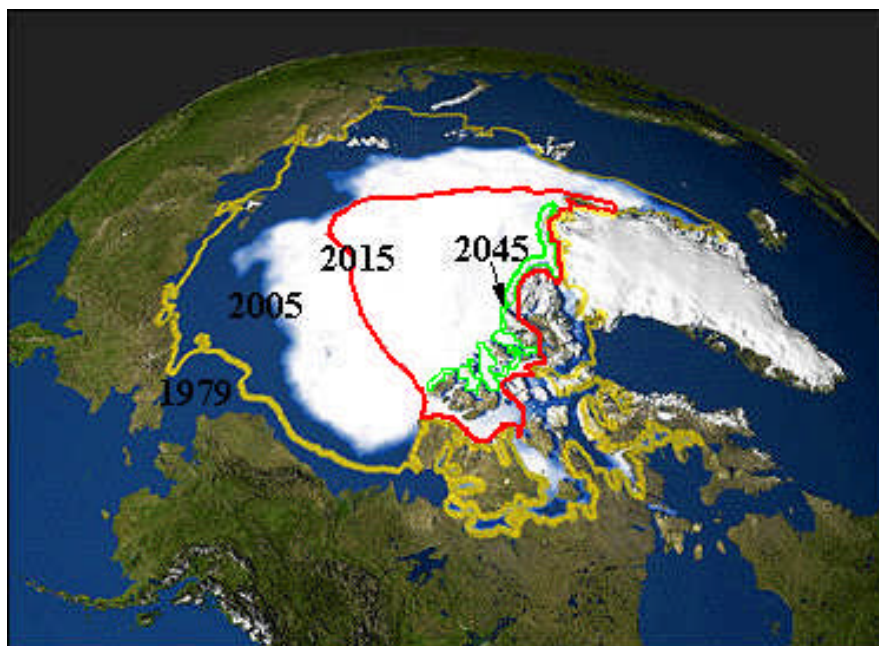
⁸ The extent of arctic sea ice continues to shrink each year, and the rate of this ice loss is much more rapid than the rate projected by most climate models. The result is that multi-year ice is thinning, resulting in a decline in older arctic sea ice. In the last 30 years, the total annual ice has shifted from a composition of 50% old, multi-year (older than 2 years) ice to a composition of approximately 30% multi-year ice, leaving 70% of the total ice pack age comprised of new ice that is less than 2 years old. The losses of this multi-year ice in turn results in an overall warming of the arctic waters, ultimately resulting in more warming in the arctic region.

⁹ Zhang, Walsh, Journal of Climate 2004



SOURCE: Environment Canada: Auld, Cheng, Comer “Climate Change and Northern Transportation”, 2010).

Figure 2-1 Global Mean Temperatures



SOURCE: Holland et. al. 2006

Sea ice cover shown as September minimum. 1979 and 2005 are historical. 2015 and 2045 are forecast values.

Figure 2-2 September Sea Ice cover (historical and forecast)

2.5.2 Predictions of Future Climate

Climate change is expected to occur in three main ways:

- Continual change through the long term trend of the climate,
- Extreme weather events, and
- New and previously unobserved weather or environmental factors.

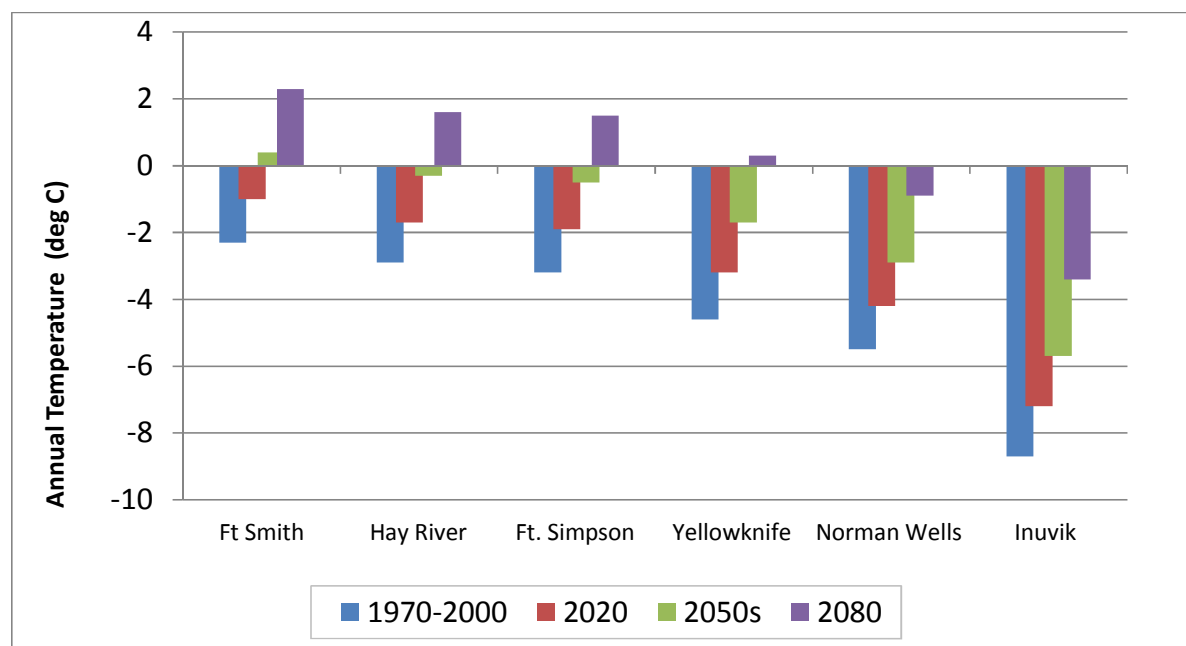
2.5.2.1 Temperature Trend Forecasts

The historical trends are expected to continue. In the most general sense the expectation of climate change is that conditions will be: (i) warmer, (ii) wetter, and (iii) more variable. While these descriptive terms are useful, climate analysis is also working to quantify the magnitude of these changes. A comparison of historical trends to future predictions (see Table 2-1) indicates that for many climate variables the trend of the past four decades is expected to continue for the coming decades.

Table 2-1 Comparison of Historic to Predicted Changes in Climate for the Arctic and Northwest Territories

Change	Observed Recent Historic	Predicted Future
Mean Air Temperature	1.6 deg C increase (1964-2004)	3.7 deg C $\pm$ 25% by 2071-2090
Seasonal Mean Air Temperatures	Greater warming in winter & spring	Greater warming in winter
Precipitation	14% increase last century (1900-2003)	12.3% increase by 2071-2090
Sea Level Rise	Global mean sea level rise of 0.1 - 0.2m last century	0.65m rise in the Arctic Ocean by 2100
Sea Ice Cover	Reduced by 4% per decade for winter & 8% for summer (1979-2005)	Increased speed of reduction anticipated due to feedback affect
Permafrost Extent	Northward retreat and thawing	Northward retreat by several hundred km's. 50% of the top 3m of permafrost could thaw by 2050
Snow Cover	Reduced by 5% -10% since 1972	Further reduction of 13% by 2071-2090
SOURCES: IASC 2004. ² IPCC 2001. ³ Holland et. al. 2006. ⁴ Shaw et. al. 1998. ⁵ IPCC 2007a. ⁶ Bastedo 2007.		

For NWT communities a key indicator will be average air temperature as this is a driver for ground warming and permafrost degradation. The estimated annual average temperatures predicted for larger communities are compiled in Figure 2-3. While just one of many variables that can be reviewed, average temperature is useful because as the annual temperature approaches and exceeds 0 °C permanent loss of permafrost is likely¹⁰. For all communities shown, the forecasts indicate substantial warming by 2050¹¹.



SOURCE: Environment Canada, CCCSN Localizer
Locations are approximately south (left side) to north (right side)

Figure 2-3 Predicted Average Annual Temperatures for Selected NWT Locations

2.5.2.2 Forecasts of Precipitation

On average, Canada has become wetter during the past half century, with mean precipitation across the country increasing by about 12%. Annually averaged, the largest percentage increase in precipitation has occurred in the Arctic¹².

¹⁰ It is acknowledged that the condition of permafrost is more complex than the average temperature. Degradation or aggradation of permafrost depends on a complex annual heat balance that is affected by local exposure, snow and other insulations effects, etc.

¹¹ Environment Canada, through a web portal for the Canadian Climate Change Scenarios Network (CCCSN <http://www.cccsn.ec.gc.ca>) has developed an analysis “localizer” tool that enables the large scale predictions of global climate models to be calibrated to local meteorological data sets in order to make predictions of future climate. This tool was used to generate these forecasts. The tool can provide forecasts for precipitation, as well as estimate seasonal values for precipitation and temperature.

¹² Impacts of a Warming Arctic - Arctic Climate Impact Assessment , Cambridge University Press, 2005

Future precipitation is more difficult to project than temperature values. Future precipitation projections indicate substantial precipitation increases for Canada's Arctic, including the NWT. An example for Yellowknife is shown in Table 2-2. These projections compare the historical averages (or 'climate normal') to forecasts over the next several decades. For the annual total, and each of the seasonal estimates precipitation is expected to increase.

Increases in precipitation of this magnitude may not seem to be of great concern. However, the forecasts are not able to define how that precipitation will occur – as increases in existing storms types, changes in the seasonality (time of year) of precipitation, or by increases in more severe precipitation events. Trends in other locations and anecdotal evidence in the NWT indicate that at least some of this precipitation will occur through more extreme storm events.

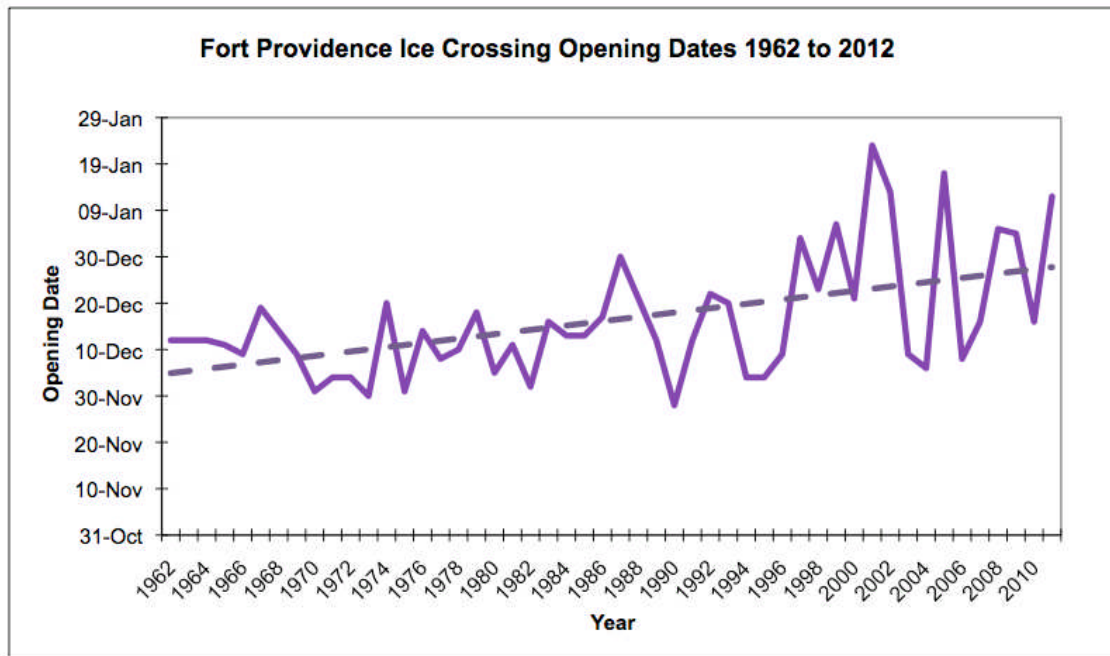
Table 2-2 Historical and Projected Precipitation for Yellowknife

mm	annual	winter	spring	summer	autumn
1971-2000	279.6	42.8	43.3	102.8	90.7
2020s	293.6 ± 12.6	44.6 ± 3.5	45.5 ± 1.5	106.4 ± 10.2	98.0 ± 6.2
2050s	308.2 ± 14.5	47.8 ± 3.9	48.2 ± 3.2	110.8 ± 9.4	102.1 ± 6.0
2080s	329.9 ± 22.5	52.3 ± 4.8	51.1 ± 4.7	115.4 ± 15.9	112.5 ± 7.4
SOURCE: Canadian Climate Change Scenarios Network (CCCSN) www.cccsn.ec.gc.ca , 2012					

2.5.2.3 Variable and Extreme Events

A second expected result of climate change will be increasing variability of climate events, and with that variability there will be more extreme events. Variability means that the future will be far less predictable than in the past.

A notable example has been the observed opening date of the Fort Providence ice bridge crossing the Mackenzie River (see Figure 2-4). Through the 1960s, 1970s, and 1980s, the opening date occurred in a narrow band in the middle of December. In the last 15 years, as shown, it appears (visually) that there is a trend towards a later opening. However, the variability is most striking, with adjacent years having markedly different opening dates. For example in 2001/2002 the opening was the latest ever (Jan 24, while in 2003/2004 and 2004/2005 the opening was in early December), while trends of the most recent years indicate a shift towards a crossing opening date later in December.



SOURCE: GNWT DOT

Figure 2-4 Fort Providence Ice Crossing Openings (1962 – 2012)

2.5.2.4 New Climate events

Finally, climate change is going to bring forward climate events that haven't been seen very often before in some locations. Documentation of these events is to-date still limited and highly anecdotal.

Examples include:

- fog where there had not been any previously, or increasing occurrences of fog. This typically is noticed at airstrips where it causes flights to be scrubbed or re-routed.
- misty rain on the Mackenzie River in the last decade that no one could really remember happening.
- “water on the land” with residents experiencing snow machines breaking through snow into water underneath.

While these types of references are reported as anecdotal, the volume of comments of “things being different” is a compelling argument that change has occurred. These must be better understood and monitored.

2.6 Climate Change and Adaptation Terminology

2.6.1 Resiliency

Resiliency can be defined as the ability of a system to recover from the effect of an extreme load that may have caused harm¹³. Resiliency can also be described as a tendency to maintain integrity when a system is subject to a disturbance¹⁴.

For considering engineered transportation infrastructure, it is useful to consider engineering resilience.

Engineering resilience is the speed of return to the steady state following an alteration to a system, implying a focus on efficiency of function¹⁵.

Two intentions are implicit in these definitions: (i) the ability of a system to recover from a given effect, and (ii) the ability of a system to tolerate a disturbance (i.e. a departure from normal operating conditions) without losing function of the system itself.

The concept of recovery and maintaining integrity are both key goals in responding to impacts to transportation infrastructure and operations. Building proactive strategies to manage impacts of climate change to NWT's transportation system requires reasonable understanding of the current resiliency within DOT's existing transportation infrastructure and operations. The information required to fully address resiliency is not entirely assembled for the NWT at this stage of identifying the challenges associated with climate change and the coping responses required to react to its impacts. Indeed, the same is true for most jurisdictions dealing with climate change and its impacts on transportation infrastructure.

This report will discuss areas where existing information is sufficient for evaluating a particular infrastructure's resiliency to climate change impacts, and will also indicate where these data do not exist or where additional monitoring may assist in advancing this understanding for critical transport infrastructure.

For the discussion of this report DCS has developed a qualitative statement of the relative resiliency of infrastructure as:

- **Low Resiliency:** Return of the asset to intended operability will take a prolonged period of time, resulting in significant duration of loss in service. A loss of an asset requiring complete reconstruction would be in this category.
- **Medium Resiliency:** Return of the asset to intended operability will require a medium-term delay, sufficient to complete modifications to restore the intended operability of the asset. An asset requiring retrofitting or modification would be in this category.

¹³ 2-UK Climate Impacts Programme (UKCIP, 2003)

¹⁴ 3- UNDP, 2005) NOTE: both sources from OECD Adaptation to Climate Change: Key Terms, 2006

¹⁵ Dalziell, McManus “Resiliency, Vulnerability and Adaptive Capacity: Implications for System Performance” University of Denmark, 2004.

- **High Resiliency:** Return of the asset to intended operability will require a short-term delay. An asset requiring rapid maintenance or application of a specific operations and maintenance (O&M) response to restore intended duty would be in this category.

The assigned resiliency ratings herein relate to the time and effort required to restore acceptable operability of the asset.

2.6.2 Adaptive Capacity

Adaptation is a process or outcome of a process that leads to a reduction in harm, or realization of benefits, associated with climate variability and climate change¹⁶.

Adaptive capacity is the ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences¹⁷.

In general terms, adaptive capacity is a system's ability to deal with exposure or risk. An effective adaptation is a confirmation and expression of the adaptive capacity for a given system. A system's coping capacity or capacity of response is its adaptive capacity¹⁸.

Sensitivity to climate change impacts will vary between different infrastructure types and locations. A specific infrastructure asset's ability to “cope” with changes in its operating conditions resulting from climate change is a measure of its adaptive capacity. A bridge deck's ability to adapt (i.e. apply more de-icing and gravel materials) to more instances of above-freezing temperatures in the winter season will be far higher than the adaptive capacity of an ice road (above freezing temperatures can shut down a given route) to handle traffic loads in a warmer operating environment. Adaptive capacity can be considered as the limit beyond which adaptation to a new operating condition is no longer possible.

There can be overlap between the terms resiliency and adaptive capacity. For the purposes of this report, the following relationship is applied:

The resiliency of a system can be enhanced by increasing the adaptive capacity of the system, either through ensuring the design includes enough redundancy to provide continuity of function, or through increasing the ability and speed of the system to evolve and adapt to new situations as they arise¹⁹.

¹⁶ UKCIP, 2003

¹⁷ 5- IPCC TAR, 2001 a

¹⁸ Adger, W.N., 2003. Social aspects of adaptive capacity. In: Smith, J.B., Klein, R.J.T., Huq, S. (Eds.), Climate Change, Adaptive Capacity and Development. Imperial College Press, London. Adaptation. Report to the Governing Council of the United Nations Environment Programme. Environmental Change Institute, Oxford, UK

¹⁹ Dalziell, McManus “Resiliency, Vulnerability and Adaptive Capacity: Implications for System Performance” University of Denmark, 2004.

For the discussion of this report we have developed a qualitative statement of the relative adaptive capacity of infrastructure as:

- **Low Adaptive Capacity:** Limited effective adaptation is possible for the asset. Reconstruction of the asset is likely for resumption of intended service.
- **Medium Adaptive Capacity:** Effective adaptations are possible for the asset. Adaptations would include modification or retrofitting of the asset.
- **High Adaptive Capacity:** Readily available and rapidly implementable adaptations are possible for the asset. Adaptations would include deployment of increased operations or maintenance measures.

The assigned adaptive capacity ratings herein relate to the extent of available adaptation options a system can offer.



SOURCE: NWT Parks

3 ALL-WEATHER ROADS

3.1 Infrastructure Description

The NWT highway system includes 2,200 kilometres of all-weather road. A total of eighteen (18) NWT communities rely upon these all-weather roads for access to the rest of the NWT highway system and southern Canada. Figure 3-1 presents a map indicating routing of the existing NWT highway system. At present, 45 percent of the highway system is paved or asphaltic chipsealed, with another 27 percent comprised of gravel surface treated with palliative dust control. Some all-weather roads experience seasonal disruption during freeze-up and spring ice breakup in the transition period between ice bridge and ferry operation.

There are significant variations of subsurface conditions within this large geographical area. Variations between different highway routes include the presence or absence of fine grained soils, the availability and quality of materials used in the construction of the road sections along a given highway route, and the presence or absence of permafrost. Adding to the variation in subsurface conditions along highway routes is the significant variation in climatic conditions along each road route and between these roads, particularly from north to south. These variations require different remediation to respond to site-specific conditions, making standardized remediation approaches largely impractical.

In addition to the variation in subsurface conditions for the routes within the DOT highway network, DOT faces challenges due to the fact that many of these roads are at different stages in their life cycle. Much of DOTs existing infrastructure was built to minimum standards of the day and these routes require extensive investment and upgrades to maintain operability and reliability.

“Change and Challenge”

Climate Change Adaptation Plan for the GNWT Department of Transportation

Section 3: All-Weather Roads

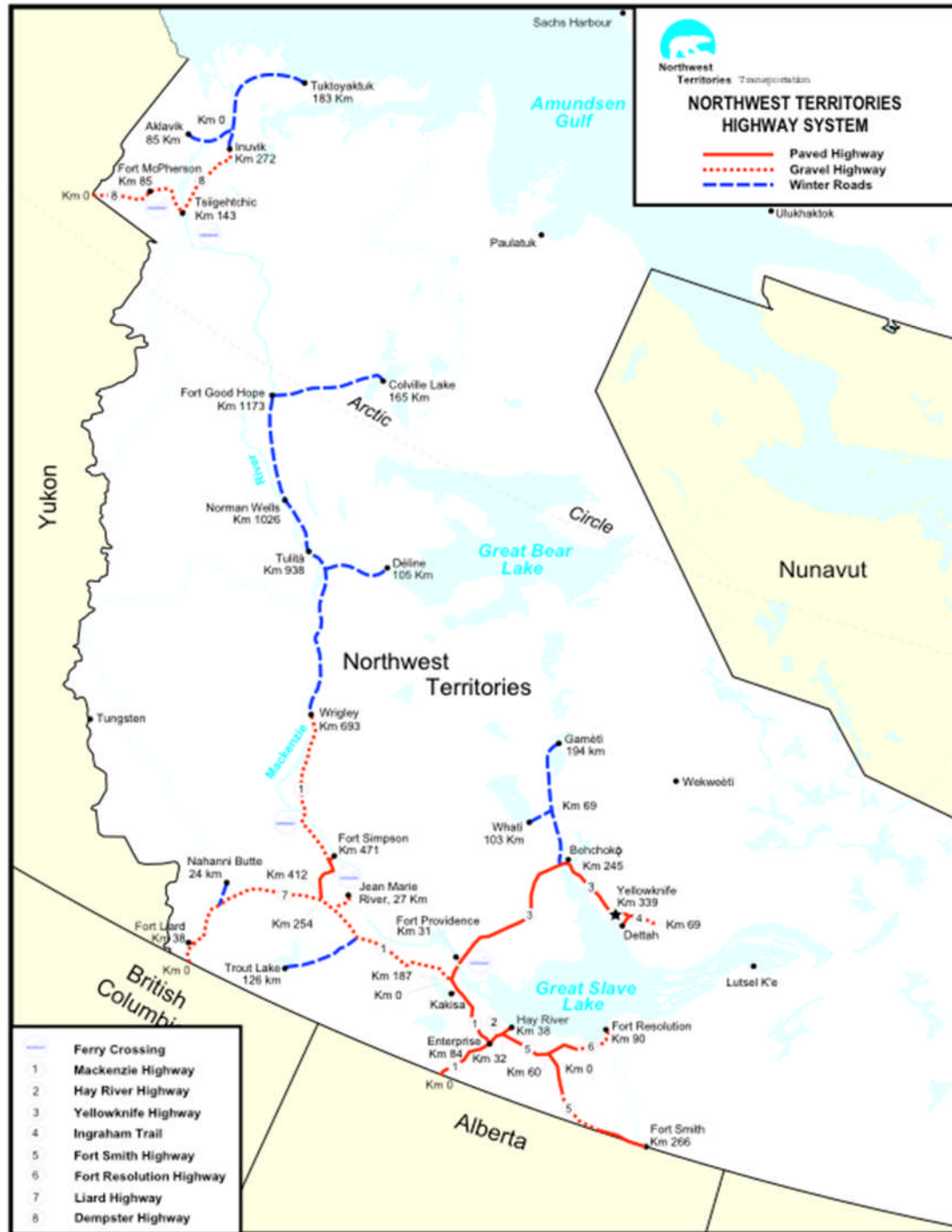
August 2013

The communities served by all-weather roads operating continuously throughout the year are:

- Fort Liard
- Kakisa
- Enterprise
- Hay River
- Hay River Reserve
- Fort Resolution
- Fort Smith
- Jean Marie River
- Fort Providence
- Yellowknife
- Behchoko
- Dettah

The communities serviced by all-weather roads with seasonal (freeze-up and spring breakup) disruptions are:

- Fort Simpson
- Wrigley
- Nahanni Butte
- Tsiigehtchic
- Fort McPherson
- Inuvik



SOURCE: NWT

Figure 3-1 DOT NWT Highway System

3.2 Impacts Observed to Date

DOT's all-weather road network is facing the multiple challenges of:

- increased traffic loads along their routes (passenger trips and transport truck industrial cargo shipments),
- degraded and aging highway routes with road sections that are nearing the end of their service life, and
- emerging climate change impacts on the all-weather roads and related infrastructure.

The combination of these factors has stressed the road network and is requiring increasing resources to maintain.

Impacts of climate change observed to date on NWT all-weather roads include:

- **Drainage:** Higher snow volumes and increases in precipitation are both altering the run-off characteristics along many road sections and increasing the maintenance effort required to service the road network. Increased demands are being felt by DOT to conduct improvements to the road surface quality and drainage conditions on highways. In some areas, culvert capacity may now be insufficient to carry the larger spring runoff and stormwater volumes.
- **Higher than normal precipitation** and associated runoff events have been problematic for highway sections established within zones of fine grained soils i.e. Highways 1, 2, & 7. Where existing culverts are now under capacity, damming of runoff can erode the road embankment where rip rap and other protective measures are lacking or insufficient.
- **Changing Spring Melt:** DOT operational staff reported at the May 2012 workshop that they are seeing a faster onset of spring melt has resulted in more rapid spring runoff conditions, leading to more frequent incidences of washouts along road sections. As well, this can create runoff before culverts and ditches are free of ice and snow. Some road flooding has been reported.
- **Permafrost degradation:** More than 50% of the permafrost in the NWT is classified as sporadic and discontinuous, and is readily disturbed by construction resulting in ground thawing and potential physical activity²⁰. NWT permafrost is considered to be warming rapidly due to climate changes.²¹ Most of NWT's AWR routes are within this discontinuous permafrost zone. Warming temperatures have induced permafrost degradation along sections of AWR routes along Highways 1, 2, 3, 4, 5, 6 and 7, resulting in road surface settlement and damage. Highway 8 is located within a more stable, continuous permafrost zone but would be prone to permafrost degradation under warming temperatures. Permafrost degradation creates thaw-settlement of the ground and subsequent

²⁰ NWT Environmental Audit Status of the Environment Report, SENES, 2005

²¹ Couture, R., S. Smith, S.D. Robinson, M.M. Burgess and S. Solomon, 2003. On the hazards to infrastructure in the Canadian North associated with thawing of permafrost. Proceedings of Geohazards 2003, Third Canadian Conference on Geotechnique and Natural Hazards, pp. 97-104. Canadian Geotechnical Society

subsidence of the road embankment in the thawed material. Thawing also leads to degradation of ground ice, often thick ice lenses or massive ice, with drainage of water, resulting in sinkholes. This permafrost degradation increases the cost of operations and maintenance and accelerates the need for capital rehabilitation.

Loss of embankment stability leads to higher instance of failure for highway sideslopes, increased sloughing, and shoulder sinking and cracking. For the road itself, permafrost degradation under the embankment creates longitudinal and transverse depressions that can range from a few centimeters to tens of centimeters in depth. This forces the driver to reduce speed, increases wear and damages to vehicles (particularly suspension components) and calls for increased maintenance efforts and costs to fill the depressions.

- **Increased icy conditions:** Warmer winters have been observed to be producing more freezing rain and “rain on snow” events. These conditions lead to icy road conditions and a higher maintenance effort (in personnel, equipment and materials) to maintain safe road surface conditions. Demand for sand, gravel and salt is growing substantially, to the extent where costs of these materials is becoming a larger budget item and the supply of these materials at all required locations throughout the NWT's vast geography is becoming increasingly difficult.
- **Increased vegetation:** Warmer temperatures in spring and summer are leading to increased vegetation growth and migration of non-native vegetation northward, resulting in additional burdens in vegetation management programs and costs. Shrub growth along sheltered portions of the road, typically at the foot of the embankment, increases snow entrapment. In the spring, this contributes to more run-off and wetness along the road. For permafrost areas, snow accumulation reduces heat loss during winter which in turn increases the mean annual ground temperature and in some cases, promotes permafrost degradation and thaw settlement at the foot of the embankment.
- **Regulatory:** Warmer temperatures are also altering the windows for conducting work adjacent to watercourses, and this in turn has resulted in Fisheries and Oceans Canada (DFO) modifying the permissible timing and regulatory permitting requirements for maintenance efforts near watercourses.
- **Public perception:** Increased “wear and tear” degradation of road surfaces leads to reduction in the public's perception of safety along these routes.

Sidebar 1 The Dempster Highway – A Partnership

The Dempster Highway (No. 8) extends 272 km from the NWT/Yukon border to Inuvik. It is an extension of Yukon Highway 5 that connects to the Klondike Highway. It is the only road connection to the western Arctic and is the key supply line for the communities of the region. The highway is used extensively for tourism and the oil and gas industry. It will be an important link during the construction of the proposed Mackenzie Valley pipeline. When the Inuvik to Tuktoyaktuk Highway is built, it and the Dempster Highway will link southern Canada with the Arctic Ocean.

The Dempster Highway traverses continuous permafrost northwards from the Blackstone Uplands. The road is in tundra in the Blackstone River region and between the Arctic Circle crossing in Yukon and the Peel River crossing in NWT. On the NWT side of the Territorial border, the road crosses a landscape with extensive deposits of massive ground ice. This area is the most representative analogue in northern Canada for terrain to be crossed by the proposed Inuvik to Tuktoyaktuk highway. A number of large-scale terrain disturbances have occurred in the ice-rich terrain of Peel Plateau during the last few years.

The Dempster Highway Vulnerability Assessment is a collaborative effort of Transport Canada, the Yukon Government and the Government of the Northwest Territories to assemble all available information on the highway to evaluate the practicality and necessity of conducting a vulnerability assessment and developing a maintenance manual that considers the impacts of climate change.

Given the projected long-term climate warming trend for the North, governments need to better understand the vulnerability of the Dempster Highway to permafrost degradation as a result of climate change to fulfil their mandates. The scoping study will be a valuable planning tool and will improve the capacity of the two jurisdictions to manage transportation infrastructure in the context of climate change. This initiative supports the principles and goals of the Pan-Territorial Adaptation Strategy that encourages collective action in partnership with all level of government.

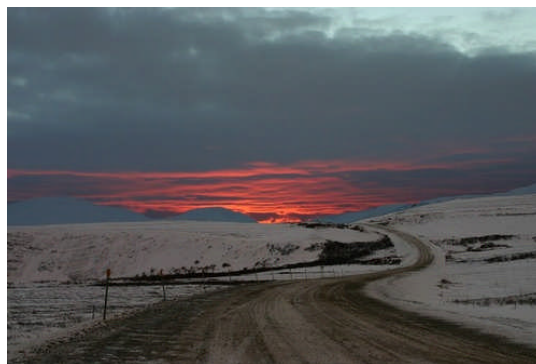


Image Source: Panoramio

3.3 DOT Response to Observed Impacts

DOT's efforts to respond to observed impacts associated with climate change have thus far focused for the most part on reactive enhancements in operation and maintenance, and proactive evaluation of technology, road section design and innovative materials that are considered and assessed for implementation on a site by site basis.

DOT continues to monitor maintenance practices and construction innovations from other jurisdictions for potential application to NWT conditions. DOT has embarked on testing programs for different materials and thermal protection approaches for all-weather road construction, however these approaches are highly specific to local site conditions, which vary considerably within DOT's operational boundaries. Successful performance of these innovative materials and designs in one location does not necessarily ensure that conditions at another location will respond as well to the same construction and design techniques.

As a result, it may be difficult for DOT to take risks on new technologies because there may be uncertainty over which technology will work for a potential situation. At the same time, DOT faces an unavoidable requirement under very limited budget allotments to test new technologies, due to the certainty that there are no solutions that can be applied system-wide (i.e. there are no “one-size –fits-all” solutions).

DOT has responded by intensifying maintenance programs to meet the increased need for repairing sites where degradation is occurring. Degradation has accelerated in recent years in conjunction with a warming climate. Highway patrols have been increased to improve monitoring for highway distress and sudden formation of sinkholes, so that DOT can take corrective action quickly to reduce risks for users. One issue of concern is that not all road degradation cases occur in a predictable and gradual fashion. In some cases, such as the sudden formation of a large sinkhole or major culvert collapse near a road section, an intensive and immediate emergency response is required to restore a vital transport link. DOT has indicated that if the frequency of failures within the all-weather road network continue to increase as climate change intensifies, additional emergency funding would be required such that other ongoing, routine maintenance programs may not maintain adequate funding. Sacrificing routine maintenance programs to fund sudden incident response results in a potentially net destructive cycle and can only be carried out for a limited time.

Enhanced drainage strategies and drainage channel improvements have been selectively applied for the purpose of keeping standing water away from road embankments as a strategy to minimize the potential for permafrost degradation.

All weather road stability and surface failures have always been part of DOT's maintenance effort, and as DOT responds to increases in failure frequency due to the influence of climate change, DOT has implemented steps within its maintenance activities and design responses such as:

- Use of insulation materials on unstable slopes to help preserve permafrost.

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- Flatter side-slopes incorporated into design in order to reduce permafrost degradation. This measure is intended to reduce snow accumulation, which reduces heat loss during the winter thus promoting permafrost degradation).
- Increased side-slope restoration efforts.
- Increased asphalt patching frequency and extent.
- Replacement of culverts with wider couplers to allow improved culvert flexibility at the time of installation
- Increased frequency of blading and re-grading of gravel road surfaces

Sidebar 2 Yellowknife Highway

Between 1999 and 2006, the final 100 kilometres of Highway 3 from Behchokö to Yellowknife, a gravel surfaced highway constructed in the 1960s, was re-aligned to be straighter and accommodate higher design speeds. This segment of the highway is located in the Canadian Shield and traverses generally flat terrain comprising of silts and clays interspersed between granite bedrock outcrops. Numerous ponds, bogs and fens are scattered across the project area. This segment of the highway is located in discontinuous permafrost. Where present, the permafrost is generally considered warm (-1°C or warmer, close to the melting point) and often contains excess ground ice.

Since reconstruction of the highway began in 1999, the state and distribution of permafrost along the highway corridor may have changed due to surface modifications, road construction, and recent changes in climate. Evidence of road instability includes cracking and depressions in the road surface, differential movements (both vertical and horizontal) in guard rail posts, ruts, potholes, and visible camber in culvert crowns.

In partnership with Engineers Canada, the Department of Transportation selected this section of the Yellowknife Highway as a case study for a climate change vulnerability assessment using the protocol developed by the Public Infrastructure Engineering Vulnerability Committee (PIEVC). The PIEVC protocol is a rigorous engineering assessment process of the vulnerability of infrastructure to climate change.

The assessment demonstrated that those sections built on ice-rich permafrost are at greatest risk, based on the low capacity to withstand the anticipated climate-related loads. Overall, the road embankment stability was found to be insensitive to climate change such that only functionality losses are expected rather than loss in capacity. Climate change will likely increase maintenance and repair efforts required to maintain safe driving conditions.



PIEVC Workshop participants on a site tour of Highway 3 (photo DOT)

3.4 Anticipated Future Impacts of Climate Change

Future climate change impacts to the all-weather road network are expected to intensify with anticipated warmer temperatures, the increased frequency and intensity of extreme weather events, and changes in the precipitation regime. For all-weather roads, future impacts are expected to continue to increase in frequency and extent. These future impacts include:

- **Permafrost degradation:** Permafrost degradation leading to intensified road surface impacts due to heaving, thawing, settlement and subsidence, sinkholes, creep of near-0° C permafrost under the weight of thick embankments.
- In locations where ice wedges are present, spring run-off can initiate thermo-erosion processes and the rapid development of gullies having the potential to “cut” the road.
- Increased settlement resulting in highway sideslope issues, sloughing, shoulder sinking, shoulder cracking and culvert failures.
- **Increased freeze-thaw cycles,** resulting in increased pothole development.
- **Drainage:** Increased precipitation levels leading to greater ground absorption, increased heat transfer via groundwater flow to permafrost situated beneath road embankments and localized drainage issues.
- Trends for ongoing **faster spring melt** events, with corresponding increase in rapid run-off events with strong potential for localized road flooding and washouts. Culverts may have to be up-sized or added.
- **Increased snowfall** amounts will introduce higher volumes of melt-induced runoff.
- **Snow removal:** Increased snowfall accumulation requiring increased snow removal programs and capacities.
- **Safety & public perception:** Ongoing degradation of road surface quality, combined with increased industrial and community traffic loads, will continue to accelerate vehicle “wear and tear” and simultaneously reduce the public’s perception of safety on these roads.
- **Regulatory:** Temperatures will continue to change the regulatory window in which in-stream maintenance can be permitted to occur along road routes.
- **Increased vegetation:** Increasing temperatures are expected to induce continued expansion of vegetative growth, with potential for new vegetation species to migrate northwards into regions of the NWT. Increased vegetation and additional vegetative species will require corresponding increases in vegetation management efforts by DOT. Vegetation will also foster accumulations of snow along road embankments, affecting heat transfer dynamics.

Sidebar 3 The status quo - isn't an option

The Liard highway is built on, and of, fine grained silty soils. The road bed has deteriorated over the years – and likely this has been accelerated by precipitation increases, drainage issues, and the loss of permafrost – all expected to continue with climate change. At the same time the demand for the road is increasing for resource extraction, tourism, and cargo transport to and from the south.

Road maintenance is estimated near \$3 million per year, and this is considered to be “barely keeping up”. There have been extensive (1 - 4 week) closures in recent years simply because the road bed was too soft for vehicle traffic and needed time to dry out. Looking forward, this is only expected to get worse and increases in the maintenance budget should be expected.

An EBA study on the Liard Highway concluded that the route “does not meet the geometric criteria and has strength deficiencies that inhibit the use of the road and contributes to high ongoing maintenance costs” (Engineering Study and Strength Analysis NWT Highway No. 7 (Liard Trail), EBA, 2011).

Rebuilding the road is an alternative – but costs are in the hundreds of millions of dollars – finding that funding will be a challenge. DOT will need to initiate planning activities now to be able to prepare for future reconstruction, and to secure the required funding. This will require better documentation of the road conditions, localized assessment of projected temperature and precipitation regimes, vulnerability assessment of the route segments, and further engineering studies.



Wet conditions on the Liard highway have caused spring closures in recent years (photo DOT)

3.5 Design and Weather-Related Vulnerability

All weather road design and weather-related vulnerabilities include:

- **Drainage:** Improved runoff management is required to control flows arising from precipitation and snowmelt. Drainage issues are a significant challenge for NWT's all weather roads as the accumulation of water near these roads can result in transfer of heat to underlying permafrost, erosion of road materials due to overland flows, load restrictions imposed during wet conditions when soft road sections can no longer sustain loads, reduced traffic speeds imposed due to soft conditions. Water accumulations (ponding) have also led to lane closures (traffic reduced to single lane) due to saturated, soft road conditions and rutting.

Drainage is currently considered a substantial problem along NWT Highways 1, 2, 3, 5, 6, 7 and 8. The issue of drainage is even more important for highways routed through regions of fine-grained soils as added moisture to these soils results in substantial losses in the load bearing capacities as well as large, differential settlements. Fine-grained soils are prevalent along Highways 1, 2 and 7.

As warming trends continue related to climate change, the alteration of precipitation patterns (more intense, more frequent precipitation), increases in rain on snow events, and trends of earlier, more rapid spring snowmelt are expected to increase the need for improved drainage management along all-weather roads in the NWT.

Drainage and runoff characteristics appear to be changing in response to observed warming climate in the NWT, and will require more aggressive management to protect permafrost, embankments and culvert systems. Drainage is occurring earlier in the season, prior to when ditches and culverts are fully clear, leading to sheet flow across roads and road washouts. Drainage impacts have the potential to simultaneously render more than one all-weather road impassable concurrently. This would create a need for major response from DOT in order to maintain operability and reliability of these critical routes.

- **Permafrost Degradation:** Highways 1, 3, and 4 are routed through regions of extensive discontinuous (50-90%) permafrost. Highways 1 (Enterprise to Fort Simpson section), 2, 5, 6 and 7 are routed through areas of sporadic discontinuous (10-50%) permafrost. Highway 8 routes through a region of continuous (90-100%) permafrost. In ice-rich soils, the stability of the underlying permafrost is a key factor in maintaining road stability. As warming trends apply more direct heat to linear infrastructure such as all-weather roads, the heat transfers into the underlying permafrost causing melting of ground ice and reduction of the load bearing capacity of these soils.

Once the permafrost becomes destabilized, road sub-grades and embankments begin to move, resulting in increased settlement of highway embankments, pavement surfaces and culverts. As permafrost degradation increases, the foundation conditions beneath the roadway become highly dynamic and extremely damaging to infrastructure built upon it, resulting in accelerated settlement, culvert failures and development of surface depressions and sinkholes. The rapid formation of sinkholes, road surface failures and other road depressions result in a reduced perception of safety,

reduced travelling comfort and increased vehicular wear and tear. In continuous permafrost areas where ice wedges occur, poor drainage results in water ponding in ice-wedge polygon troughs. This leads to the melting of the upper part of the ice wedge and linear thaw-settlement action. Where runoff infiltrates the permafrost down to the ice wedges, processes of thermo-erosion are triggered which leads to rapid linear retrogressive erosion of the underlying ice wedges. This causes development of gullies that can be meters in depth and width, extending many meters in length in affected areas.

- **Increased Vegetation:** As temperatures moderate due to warming trends induced by climate change, growing patterns and growing seasons for vegetation also change. Warmer and moist conditions encourage accelerated growth of vegetation along road sections, and within drainage ditches and near culverts. Plant material has been observed to establish earlier in the growing season, and ongoing conditions are conducive to rapid vegetation growth. Uncontrolled vegetation results in direct impacts to critical road drainage infrastructure through obstruction and reduction of flow capacities for ditches and culverts. As these drainage works are clogged with additional vegetation, runoff is not directed away from road embankments and road surfaces, leading in turn to accelerated heat transfer to permafrost soils, damage from erosion processes, overland flooding and softening of road sections and embankment stability/slumping issues. In the winter months, additional vegetation can also lead to snow entrapment resulting in thicker insulation layers on permafrost, causing a reduction of heat loss during winter, leading to a net annual warming of ground temperature. This mechanism can lead to further permafrost degradation.
- **Freezing Rain/Rain on Snow Events:** As warming trends continue in the north, the frequency of freezing rain as well as rain on snow events is expected to increase, resulting in an increase in conditions of icing, ice accretion and freeze/thaw cycles imposed on all-weather roads. This will require a substantial response from DOT in order to maintain safe travel conditions for both private and commercial road users. These conditions represent a labour response to apply granular materials to roads as well as imposing a larger demand for suitable road sand sources in regions where quarries are not plentiful.
- **Increased Wet Weather Events:** As wet weather events increase in frequency and magnitude, more water becomes available for infiltration and runoff. Infiltration of snowmelt and rainfall is expected to accelerate permafrost degradation processes while increased runoff will add more flow for drainage systems to manage in the vicinity of all-weather road sections. Where drainage cannot keep up with the additional runoff, wet road conditions will persist for longer periods of time, reducing accessibility for maintenance equipment to conduct remedial construction and maintenance work. In areas along the Liard Highway (Hwy #7), increased slope failures have been observed due to increased pore pressure from groundwater.

3.6 Summary Resiliency Statement

A summary evaluation of the all season road resiliency and adaptive capacity is provided in Table 3-1.

Much of DOTs existing All Weather Road (AWR) infrastructure was built to minimum surface and geometric standards of the day and these routes require substantial and increasing efforts and investments to maintain safety, operability and reliability. Each AWR is at different stages of their intended life cycle, is comprised of different materials and is established upon geography with a wide range of sub-surface conditions, including the presence or absence of continuous and discontinuous permafrost. Adding to the range of variability in sub-surface conditions is the variability of climate zones throughout DOT's large geographical area.

Some of the NWT roads are not up to the standards required to sustain existing industrial development nor are they capable of sustaining increasing industrial traffic that is expected in the resource extraction industries within the NWT.

As these roads are maintained to perform within this challenging geography, they are simultaneously expected to provide safe and comfortable service under a scenario of escalating industrial traffic-induced deterioration. The result is significant all weather road degradation related to differential settlements and drainage problems, in conjunction with highly accelerated “wear and tear” on the road surfaces induced by escalating industrial traffic loads. Under these conditions, community and industrial users of these roads will experience ongoing deterioration in quality of roads, potentially to the point where confidence in these roads may be jeopardized and possible curtailing of economic activity due to uncertainties in access.

In the absence of climate change impacts, the AWR network would be considered a low-resiliency road network that lacks the operability and reliability levels required to accommodate the higher industrial traffic loads it faces now, and to meet higher industrial loadings anticipated in the near future. Highways 1, 3, 4, 7, and 8 all require major reconstruction and upgrading while Highways 5 and 6 require less extensive upgrades such as asphaltic surface chip sealing and grade repairs.

In the decades ahead, climate change impacts are expected to further degrade the low-resiliency condition of this AWR network to a critical state, as warming trends are expected to accelerate the road degradation mechanisms associated with differential settlement and drainage, while industrial activity will continue to pound these low-resiliency roads with increasing loads that result in further damage to these road surfaces.

Table 3-1 All Season Roads Resilience and Adaptive Capacity Evaluation

Infrastructure	Climate Change Impact	Resiliency	Adaptive capacity
All weather roads	Permafrost degradation, side slope failures	Low	Low
	Drainage, road surface disruptions, vegetation changes	Medium	Medium
	Heavy snowfall	High	High
NOTES: Definitions of the relative rating are: Resiliency <u>Low Resiliency:</u> Return of the asset to intended operability will take a prolonged period of time, resulting in significant duration of loss in service. A loss of an asset requiring complete reconstruction would be in this category. <u>Medium Resiliency:</u> Return of the asset to intended operability will require a medium-term delay, sufficient to complete modifications to restore the intended operability of the asset. An asset requiring retrofitting or modification would be in this category. <u>High Resiliency:</u> Return of the asset to intended operability will require a short-term delay. An asset requiring rapid maintenance or application of a specific O&M response to restore intended duty would be in this category. Adaptive Capacity <u>Low Adaptive Capacity:</u> Limited effective adaptation is possible for the asset. Reconstruction of the asset is likely for resumption of intended service. <u>Medium Adaptive Capacity:</u> Effective adaptations are possible for the asset. Adaptations would include modification or retrofitting of the asset. <u>High Adaptive Capacity:</u> Readily available and rapidly implementable adaptations are possible for the asset. Adaptations would include deployment of increased operations or maintenance measures.			

3.7 Implications for Operations and Maintenance

The design and weather-related vulnerabilities and impacts indicated above create substantial implications for DOT Operations and Maintenance efforts related to All Weather Roads, including:

- **Increased requirement for snow removal:** For all routes, DOT should expect an increased burden in snow removal. Recent rising trends in snowfall accumulations are expected to intensify with time, resulting in a higher demand for snow clearing services throughout the NWT all weather road network. Routes underlain by permafrost will also require strategic management of snow piles such that insulating piles of snow are removed early in the season to promote ground cooling for enhanced permafrost stability.

- **Increased visual inspection and monitoring efforts:** For all routes, an increased effort and regularly scheduled visual inspection/monitoring program is required. Visual inspections should focus on pavement surface conditions, site stability at locations along road alignments, as well as condition/status of culverts and related drainage infrastructure and vegetation conditions affecting culverts and drainage ditches. Inspection programs should also include measurement of elevations of culvert installations for tracking movement of these components over time. Staff should obtain geo-referenced , time-stamped (in photo EXIF data) photographic evidence of issues encountered in the field during these inspection and monitoring programs for the purposes of tracking locations in a GIS database.
- **Increased requirement for sand and ice control materials:** Increases in snowfall amounts, rain on snow events and freezing rain will translate into a growing requirement for application of sand and ice control along all-weather road routes and intersections. While cost of transporting and applying traction control to roads has increased substantially over recent years and is expected to continue in growth, the sources for the required sand are limited by local availability along some routes and the difficulty in establishing new sand sources due to regulatory burdens associated with establishing new quarries for source materials.
- **Surface repair:** For all routes, an increased requirement for ongoing surface repair is required, as mechanisms of surface degradation are expected to accelerate with increasing temperature trends.
- **Guardrail repair and replacement:** Guardrail repair and replacement efforts will be necessary to address damages caused by impacts with vehicles under slippery conditions.

3.8 Needs and Gaps to Adequately Respond

The following needs address actions required to adequately respond to emerging climate change impacts on all-weather roads:

- **Enhanced operational budget allocations for road inspections/monitoring efforts.** Current operational budgets are insufficient for the appropriate level of ongoing inspection and tracking of all-weather road infrastructure under DOT’s jurisdiction. Current practice is to conduct inspections opportunistically and currently efforts spent on inspection result in a corresponding reduction of available operating budget for other essential O&M activities. The present budgeting framework prevents proper inspection programs, creating a bottleneck for adequate tracking of issues that require attention to maintain operability and reliability of all-weather road infrastructure. While climate impacts and construction on permafrost creates known challenges to all weather roads built in arctic regions, road degradation is accelerating predominantly due to large load trucking traffic associated with industrial activity, with no corresponding contribution (i.e. taxes or royalties) by the industrial users in relation to the extent of road deterioration that industrial traffic causes on these roads. Agreements should be explored where industry commits a contribution to road inspection programs conducted by DOT in order to finance inspection/monitoring efforts that are essential to the efficient upkeep and maintenance of all-weather road operability. The damage to these roads incurred by heavy industrial

loads is not currently being recovered through any industrial sector contribution which could help fund the efforts essential to maintaining the serviceability of these roads.

- **An asset management / geographical information system should be established.** This means a geo-referenced inventory of all-weather road infrastructure must be built in order to effectively track new and recurring issues on a geographic basis. DOT faces a massive challenge in managing and deploying very limited maintenance resources for sensitive all weather roads across a large, variable and harsh geography. The current lack of a GIS database that allows classification of roadbed terrain conditions, road surface status and condition assessment of related road infrastructure (culverts, shoulders, guardrails, ditches, signage) prevents efficient optimization for deployment of maintenance resources and materials. DOT's stated intention to manage its all-weather road network in a proactive fashion will not be possible without the establishment of a GIS-based asset management solution that offers ability to track asset conditions geographically and on a temporal basis.
- **Establishment of Digital Maintenance Logs and Formal Reporting Documentation Process.** In many cases, NWT all weather road records lack design drawings and related records and maintenance efforts are tracked in paper records that remain un-distributed throughout DOT's operational geography. These records and reports require real-time (i.e. filed immediately upon design/report approval) centralized storage and searchable assessment with ongoing review for effective asset condition monitoring.
- **Access to Remote Sensing technology.** This technology is available for tracking slumping and other surficial changes in vicinity of all-weather roads.
- **Hydrologic data:** There is limited hydrological data in the NWT (compared with southern basins). Better coverage of monitoring stations will allow for better interpretation of changes.
- **Ongoing implementation and evaluation of construction materials and technologies for improving road stability in permafrost zones.** This includes excavation of permafrost in areas of sporadic or thin permafrost, passive refrigeration and modeling of permafrost to establish priority zones of road sensitivity to permafrost degradation.

Sidebar 4 New Techniques for Better Roads: Building Research and New Designs into Roads

The Inuvik-Tuktoyaktuk Highway (ITH) will be a 137 km road connecting the current Dempster Highway from Inuvik to Tuktoyaktuk. The ITH is currently in the permitting stage and funding is being secured. A 10 km section of the road has already been built from Tuktoyaktuk south to a gravel source (referred to as source 177 for its km demarcation).

The road will be built through the Mackenzie Delta over forest and open tundra and entirely on permafrost, so the design is complicated and there are many opportunities to use innovative design features or construction techniques. Several activities are underway to aid the proper design of this road. These include:

- Planners used LIDAR (Light Detection and Ranging) - a type of remote sensing from aircraft - for surveying. This results in very detailed terrain information over the planned route as a way to identify potential problem areas for further study. As well this baseline will enable monitoring for future changes in the terrain.
- The design avoids disturbing existing vegetation as much as possible. Roads on permafrost often suffer from slumping as the permafrost degrades
- Bridges will be used more often than in a typical road design to avoid disturbing the existing watercourses and cover.
- The construction maximizes protection of the permafrost from changes in temperature. Before pouring gravel for the road embankment, geotextile fabric will be laid down on the surface. A thick layer of granular material will be placed over the geotextile to insulate the permafrost and avoid potential thawing.
- Water sinking into the permafrost or running over it can also lead to thawing, so the design includes numerous culverts to drain water away from the road.

A section of the route on the source 177 road has been identified for monitoring so that the impact of these design changes can be better understood and built into the complete ITH design. In the future, the knowledge gained from these types of efforts will benefit other roads – either new or rebuilt sections.



A tour of a new section of highway near Inuvik highlights a sagging culvert – issues that will have to be addressed in new roadway design. (photo from Jun 9, 2011 site tour documentation; EBA Engineering).



4 WINTER ROADS AND ICE CROSSINGS

4.1 Infrastructure Description

In addition to its all-weather road routes, DOT's road network also includes 1,425 kilometers of publicly constructed winter roads and ice crossings. DOT-managed winter road routes are shown in Figure 3-1 and include the following segments:

- One 24 km section extending off Highway 7 to Nahanni Butte.
- One 126 km section extending off Highway 1 to Trout Lake.
- The Tlicho Winter Road (TWR): a 194 km section extending off Highway 3 near Behchoko to Whati, Gameti. The road is often extended to Wekweeti for a portion of the season.
- The Mackenzie Valley Winter Road (MVWR): extends from Highway 1 at Wrigley providing service to Tulita, Norman Wells and Fort Good Hope, with spurs to Deline and Colville Lake. The MVWR is entirely on land except for an ice crossing at the Great Bear River.
- A network of winter roads extending from the end of Highway 8 at Inuvik to Aklavik and Tuktoyaktuk.

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The NWT communities serviced solely by winter roads for surface transport are:

- Whati
- Wekweeti (road establishment was previously paid for by the federal government to access cleanup operations at Colomac Mine, this ceased in 2012. DOT has announced plans to open this road in 2013)
- Gameti
- Trout Lake
- Deline
- Tulita
- Norman Wells
- Fort Good Hope
- Colville Lake
- Aklavik
- Tuktoyaktuk.

DOT constructs winter ice roads annually once freeze up conditions support the development of ice of sufficient thickness to bear anticipated traffic loads. Winter ice road seasons vary with location within the NWT, however the functional operating window for winter ice roads has historically been defined by a start to the season between December and January and winter road closure typically occurring by end of March.

Most winter roads are routed such that they traverse a blend of geographies, resulting in some road sections over water and others over portions of land. Winter road infrastructure is supplemented by installation of permanent structures including: permanent bridges over stream crossings, and occasional road bed grading at portage locations where land and water sections interface. These supplementary, permanent structures along the winter road routes allow for faster construction and more reliable operation (e.g. a permanent bridge avoids the need to wait for creek and stream freeze up prior to constructing the crossings).

Temporary structures are often used on winter roads in order to provide safe passage across watercourses with unstable beds or banks, and also for streams that are too fast flowing to establish stable ice crossings. Timber mat supports are used as bedding materials and for support at each end of the bridge crossing. Approach ramps are then built from snow, ice or granular materials to provide a smoother transition between the route and the temporary crossing.

In addition to the public winter road system established by DOT, a number of privately constructed and maintained winter roads are annually established for industrial use, serving industries such as oil and gas development and mining operation re-supply. Many of these industrial routes are used only for a short period. A notable exception is the 570-kilometre Tibbitt to Contwoyto winter road in the Slave Geologic

Province, which has operated since 1982. This road is informally called the ‘joint-venture’ or ‘JV’ Road as it is constructed as a combined effort between the diamond mine operations that it serves. DOT liaises with the JV road operations and engineering staff.

4.2 Impacts Observed to Date

Impacts on the NWT winter road system have been observed in recent years and are linked to warmer temperatures occurring during parts of the winter road season. Warmer temperatures can cause abbreviated winter road operating seasons. Warmer conditions can cause delay of formation of natural ice, and subsequent delays to construction of winter road routes. Colder temperatures facilitate construction of winter roads, allowing sufficient ice growth to support heavy construction equipment and enhancing bearing capacity in the subgrade along the land based portions of winter road routes.

Challenges experienced with establishing and maintaining winter roads in recent years have included:

- **Incomplete Re-Supply:** If a winter road is not completed early enough to allow full re-supply, the alternative could be a very expensive airlift. This situation almost occurred in Deline in 2010, and did occur with the users of the JV road (a non-DOT road) in 2006, resulting in tens of millions of dollars of extra shipping costs.
- **Late Freeze up:** Road construction has encountered lakes and streams that have not yet frozen – delaying construction.
- **Drainage Issues:** Temperature increases have also induced drainage challenges along some routes. Increased temperatures induce melting that forms ponds and adds to creek and stream flows through the winter season. In areas along the MVWR, DOT has seen drainage issues resulting in flooded road sections. Along the TWR for example, DOT was forced to shut down roads due to flooding in three of the last five years. While this issue has occurred historically in certain winter road route locations, an observed impact related to a changing climate is that DOT is now managing sites undergoing such flooding in locations that never faced this problem before.
- **Construction and Maintenance Issues:** DOT is facing growing construction and maintenance challenges over all its winter road routes. Consistently cold ambient air temperatures are often setting in later into the winter season than in the past. In conjunction with the lack of consistent cold temperatures, increased snowfalls have been experienced in parts of the NWT in the late fall and early winter. Greater amounts of snowfall occurring early in the season can create problems for DOT as the additional snow insulates and retards adequate ice formation on water bodies. For the TWR extending from Behchoko to Gameti, DOT has experienced problems in establishing winter road routes due to lakes along the route not freezing sufficiently.

Land based portions of the winter roads require a minimum amount of snow to form the base and protect the frozen ground. Typically snow is cleared early on to allow the ground to freeze, then replaced to form the base. The road cannot open until sufficient base is established. Lack of snow has delayed the opening of the MVWR in recent years

- **Earlier spring thaw:** Conditions causing winter road melt are occurring earlier in the spring in recent years, and generally occurs on the land-based portions, particularly south-facing slopes.
- **Local Weather Events:** DOT personnel have reported an increased incidence and strength in early winter storms and associated wind strengths. Storm activity and excessive winds are reported to be causing impacts to the quality of lake ice. High winds over open water bodies as they are initially freezing up moves the newly formed surface around, and new ice must re-form to replace ice that has been moved by wind. The movement of ice floes and their impact against other ice segments can also induce fractures in adjacent ice. Under these conditions, the resulting ice formation possesses less strength.
- **Variable Conditions:** Increased temperatures experienced year round have led to observations of water level changes and increased vegetation growth along the TWR at points along the route that transition from lake to portage sections. The water levels and excess vegetation typically create problems for winter road construction. Along winter road routes where shallow waters and swamps are prevalent, opening dates have been delayed, resulting in a postponed winter road season. These problematic conditions at water/land interfaces along winter road routes exert a requirement for additional and different types of equipment as well as added cost to construct and maintain.
- **Structural Stability:** Changing soil conditions related to permafrost degradation and changes in runoff regimes have impacted temporary bridge crossings, culverts and related infrastructure. Impacts observed to date include increased frequency and severity of landslide impacting bridge crossings along the MVWR, increase in damage to bridge structures due to scour and lateral channel migration in areas of localized land slumping and increases in shrinkage and expansion of soils under foundations of bridge crossings. These impacts require more frequent monitoring in order for early detection prior to closure of a crossing and also higher maintenance burdens to respond to the need to rehabilitate temporary crossing structures.

4.3 DOT Response to Observed Impacts

DOT has maintained a commitment to the winter road system and to maximizing the operational window for the winter roads. These roads were initially established for the purpose of developing essential community resupply (fuels, generators, bulk supplies, construction materials), but over time the use of these winter road routes has increased, and the roads are relied upon by a larger group of stakeholders. As this use grows, public expectations have pushed for both increased length of winter road season and improved quality of road surface along the routes. DOT has attempted to respond to these imperatives through a series of adaptive measures including:

- Pre-emptive removal of snow from water crossings along winter road routes to both reduce the insulating properties of the snow cover and promote the rapid formation of thicker ice. DOT has deployed lighter snow removal equipment for this purpose. Private winter road contractors who construct the JV Winter Road have successfully used floating snow removal equipment for pre-emptive

snow removal and enhanced operator safety. DOT is looking at a floating snow removal equipment option for potential future application to its winter roads.

- Increased use of advanced ice profiling technology on its winter roads. DOT has routinely conducted ground-penetrating radar (GPR) measurements, but is now applying advanced ice profiling equipment along the TWR and other DOT winter roads to allow for more sophisticated ice condition assessment.
- Exploration of new technologies for application on DOT winter roads. Along the TWR, initial implementation has occurred on one technology using insulating geotextile “blankets” intended to reduce heat transfer from newly placed materials to the existing ground.
- DOT has applied techniques to promote ice growth at the Mackenzie crossing by application of conventional ice auger flooding techniques, and has expanded its ice growth promotion techniques with ice-spray technology in order to accelerate development of sufficient ice thickness. DOT currently uses ice-spray technology at the Peel River and Tsiigehtchic crossings, with planned use slated for the Fort Liard crossing in the future. The use of ice-spray technology has allowed DOT to open the ice crossing earlier in the season than possible using traditional techniques.
- Along some winter road routes, DOT has strategically positioned or “cached” equipment in pre-determined areas to allow for simultaneous construction along a winter road route. In the past, DOT would wait for southern sections of a road route to freeze sufficiently to allow construction to proceed north. Along the TWR, DOT has placed equipment in Whati and Gameti so that the winter road can be built along multiple sections at once. This adaptation has removed a previous bottleneck where construction started at the southern end and proceeded sequentially along the entire route.
- Recognizing that the Tibbitt to Contwoyto JV Winter Ice Road is the largest heavy-haul ice road in NWT, DOT liaises with JV contractors for the purpose of sharing information regularly during construction and operating phases of the ice road season.
- In northern regions of the NWT, DOT is not experiencing as much delay in construction as is occurring on routes in more southern regions of NWT. Northern winter road sections are reporting earlier spring thaw however, thought to be resulting from the presence of warmer water temperatures at shallow points near sandbars in rivers or estuarine waters. This spring thawing is expected to intensify with time as temperatures increase in the region.
- Installation of permanent bridge structures on the MVWR. These are in place along the winter road route, but are also expected to be used for a future all-season road. Each installation of a permanent bridge crossing precludes the recurring need to construct an ice road crossing each winter.
- Implementing daytime travel restrictions to preserve the road integrity late in the season.
- Realignment of the TWR onto a completely land-based route that can be upgraded to an all weather road.

Sidebar 5 Winter Roads Under Stress

The NWT Winter Road system is a critical part of the transportation network. It is a key mechanism for community re-supply. In recent years there have been increasing challenges with maintaining the winter roads including more difficulty in construction (lake ice or road bed not ready), surface water overflowing the road, and spring warming softening the road during daytime.

Improvements to construction methods have been ongoing, and adaptations have been developed to allow the roads to open on time and stay open longer. These include: permanent bridge structures, building several pieces of the road at the same time; using lighter vehicles to get on ice sections earlier, early snow clearing, preparing snow caches early on for the portages, and daytime travel bans once the weather warms up to avoid degradation of soft roadbeds.

These changes have helped to maintain the current level of service but there are concerns that it will be difficult to keep up. While the service can be maintained in the short term – there are unknowns about whether some of the roads (particularly the southern roads) can still be viable 10 or 20 years into the future.

In the future, the stresses on the roads will increase and difficult questions will have to be addressed. For example: Is there a point at which a winter road is simply “not worth the effort?” Should DOT be planning for all season roads to replace winter roads? If so, how would these be funded? Will more resource exploration increase the demand for winter road access? Planning now – to understand these issues will be crucial to ensuring reliable transportation in the future.



A permanent bridge crossing a stream on the Mackenzie Valley Winter Road - shown here in summertime. (photo: DOT)

4.4 Anticipated Future Impacts of Climate Change

Based on operational experience within DOT up to the year of this report, climate change-related impacts observed to affect winter roads have been reported by operations personnel to involve worsening of past typical issues or the onset of new issues that were not typically experienced in the past. As old problems worsen and new issues arise related to winter road construction and maintenance, the GNWT is concerned about the long-term sustainability of winter roads and ice crossings, and alternatives may need to be sought.

A number of existing challenges are anticipated to intensify as warming trends continue in the north. Key issues for the Tibbitt to Contwoyto JV Winter Road are largely the same for the TWR and include:

- Problems at portage points related to water level changes and increased vegetation hindering road construction and delaying opening dates.
- Overflow and running water are present throughout the entire winter season at some portage points.
- Presence of warmer water currents and shallow waters at some portage points created difficulties in establishing roads at these locations.

Approaches used on the JV road may also be applicable to DOT winter road construction. These include: improved JV Winter Road management practices (load spacing, strict speed control etc.), which have led to better control of winter road sections over water (ice roads); however a limiting factor has been the sensitivity of portage locations related to the three key issues stated above. The JV operators are implementing features such as multiple road configurations in their road design intended to offer the flexibility of an alternate route around specific trouble spots along the JV winter road route.

Managing expectations of stakeholders who rely upon winter roads and ice crossings is a growing challenge for DOT. Industrial activity is expected to grow as climate change makes arctic exploration more accessible, and with increased industrial traffic there is concern regarding the long-term viability of establishing reliable and safe annual winter roads. Simultaneously, the public is placing a higher reliance on winter roads for more non-essential travel that were originally intended for basic community re-supply. The public expectation of more access and more roads is not compatible with the possibility of reduced service levels and more expanded road restrictions and travel bans.

The combined pressures of increased industrial traffic from expanding resource development activity, increased community traffic from higher expectation of mobility by the public, and impacts that are projected to intensify with warming temperatures indicate that the NWT's winter road system is one that is becoming more vulnerable with time, yet the loads applied to these routes continue to increase. Going forward, the winter road system will suffer from shrinking windows of reliable operability.

Finally, it is anticipated that issues with temporary crossings, culverts and related infrastructure will exacerbate and require more intensive rehabilitation. It is highly likely that some routes may only remain viable if permanent crossing structures are installed to respond to the changing site conditions that currently overwhelm the adaptive capacity of existing temporary crossings. Installation of permanent crossing structures offer the benefit of extended viability to routes undergoing climate extremes and variability, which may render routes undergoing such climate variability as no longer be appropriate for temporary crossings and their inherent low-resiliency relative to permanent crossing structures.

4.5 Design and Weather-Related Vulnerability

Winter roads are vulnerable to higher temperatures during the winter season, earlier spring thaws leading to a shorter overall window of operation for winter roads, increased effort required to establish sufficient ice thicknesses on lake (and river) portions, increased snowfall accumulations (providing insulating cover that retards freezing), and localized overflow/flooding issues along road routes. As these factors combine to degrade the quality and resiliency of winter roads, the demands placed on these roads appears to be growing in terms of community expectations of service.

As climate change results in milder climate conditions in the NWT, the interest by industry in developing natural resources is expected to grow, resulting in higher industrial traffic on some of these routes, notably the MVWR to transport oilfield equipment to the Tulita/Norman Wells area. This leads to a situation where traffic demands will increase on a winter road network that, if not enhanced, would progressively decline in operating season length and see significant reductions in load bearing capacity as ice thickness becomes more limited. On the MVWR, a program to install more permanent crossing structures has resulted in a successful expansion of the window of operations for this route.

Winter road network design and weather-related vulnerabilities include:

- **Higher snowfall accumulations over ice:** increases in snowfall amounts, particularly near the start of winter road construction season can induce significant delays in ice-growth and development of necessary load-bearing capacity. Higher snow accumulations have resulted in more extensive effort to establish winter roads due to the need to remove the insulating cover of snow to permit more rapid ice thickening and freezing of ground surface. Such delays are typically experienced in the southern winter road routes of NWT (Trout Lake and TWR roads). There have been no delays reported in establishing winter roads in the northern routes (Aklavik/Inuvik/Tuktoyaktuk).
- **Lower snowfall amounts on land:** land based portions of the winter roads require a minimum amount of snow to form the base and protect the frozen ground. Typically snow is cleared early on to allow the ground to freeze, then replaced to form the base. A winter road cannot open until sufficient base is established. Lack of snow has delayed the opening of the MVWR in recent years. As snow is the primary building material used in constructing temporary ice crossings, reductions in available snow caused DOT to introduce a bridge-crossing program that established permanent crossing structures at locations where ice crossings were becoming more difficult to establish.

- **Increased effort to establish adequate ice thickness:** as temperatures moderate and snow cover inhibiting ice formation becomes more prevalent, the need for more aggressive ice thickness construction techniques will expand throughout the winter road network, particularly in the southern half of the NWT. Techniques including early removal of snow accumulations and application of surface flooding for winter roads, and spray-ice building methods at ice crossings, are already deployed by DOT. The effort required to establish adequate ice thickness for winter roads will continue to grow, requiring the availability of additional, lighter-weight snow removal equipment (possibly float-capable) and additional personnel to establish new winter roads each year.
- **Warmer Ambient Temperatures:** trends of warmer ambient air temperatures have induced short-term melt events when load-bearing capacity of the underlying ice is still high; melt water accumulations result in formation of ponds that can create hazards for safe passage of transport trucks and passenger vehicles.
- **More frequent road segment closures:** Warmer temperatures, more precipitation and changing water levels and drainage patterns are resulting in more frequent road segment closures along the winter road network. On both the MVWR and the TWR, more frequent road segment closures have been taking place over the last five years. Another challenge is while the winter roads soften due to milder temperatures, they are become more susceptible to damage due to heavy equipment and cargo trucking traffic. DOT has implemented the practice of prohibiting daytime driving on these roads during vulnerable periods to avoid damage.
- **Earlier spring thaw:** Conditions causing winter road melt are occurring earlier in the spring in recent years, and generally occurs on the land-based portions, particularly south-facing slopes.
- **Drainage Issues:** Larger snowfall accumulations and higher ambient air temperatures contribute to ongoing melting conditions resulting in higher runoff flows in the vicinity of winter roads, portage transitions from lake/river ice to land and near creeks that no longer freeze to bottom in winter months. The MVWR has experienced substantial drainage problems associated with ponding meltwater, creeks that now flow throughout the winter resulting in localized flooding of road sections, and ponding at problematic sections near land crossings. Similar drainage issues are occurring along the Trout Lake winter road. Along the TWR system, drainage is becoming a significant problem as melt-induced overflow and flooding is becoming more prevalent.
- **Insufficient Freezing of Lakes and Streams:** Along winter road routes such as the TWR system, warmer temperatures and resulting overflow are contributing to insufficient freezing of lakes and streams, particularly in shallow areas where routes transition from over water to over land. As transition points between water and land often present conditions of inadequate freezing, they require more intensive maintenance efforts to maintain safe passage of traffic.

- **Overland Flow:** increased overland flow and runoff have been an issue along the MVWR, with erosion near bridge crossings becoming a problem. During the 1980's and early 1990's these problems contributed to a reduction in the operating window of this important route. DOT responded to challenges along the MVWR with an initiative to convert crossings from temporary to permanent structures along the MVWR on a priority basis at 36 out of 40 identified locations. These permanent crossings are developed with an emphasis on better construction techniques, pile foundations, scour protection and wider channel openings. The program to convert temporary crossings to permanent bridge crossings is considered a successful adaptation measure as it has resulted in a reversal of the shrinking operating window for the MVWR since it was implemented.
- **Reduced Operational Window:** At Norman Wells, community residents reported in stakeholder meetings that the MVWR season has been reduced from about 8 weeks to 6 weeks total in the last few years. In 2011, the winter road closed on very short notice, stranding some truck trailers in Norman Wells for the summer until re-establishment of the winter road the following season. This is also a major concern for drilling companies in the Tulita/Norman Wells area that need to mobilize equipment to site, drill and mobilize out during the winter road season.
- **Design loads and traffic volumes:** Increased industrial/commercial traffic can result in damage to the road bed, especially when drivers are inexperienced with winter road driving requirements. A recent report (January 17, 2013, CBC) out of the Sahtu region indicated the road between Wrigley and Tulita was temporarily closed for extensive repairs due to significant damage caused by large numbers of transport trucks carrying oil and gas exploration equipment that were using the road within a 48 hour period. Once the frozen surface starts to deteriorate and the ground is exposed, trucks start to have difficulty maintaining traction and chew up the road. This is most common in hilly areas. To compound matters, trucks can get stuck preventing any maintenance until they can be removed. The end result is road closure to all traffic until the road segment can be repaired.

4.6 Summary Resiliency Statement

A summary evaluation of the winter road resiliency and adaptive capacity is provided in Table 4-1.

The NWT winter road network is established annually and is relied upon by isolated communities for annual resupply efforts and by the resource development industry for bringing in heavy equipment, materials and fuel for use throughout the year. Ice roads and ice bridges are built and maintained each winter to provide a relatively inexpensive method of conducting resupply to remote locations. Shorter and warmer winters, in conjunction with higher snowfall amounts over ice, or inadequate snow cover for land-based segments, results in decreased length of ice road season, reduced ice thickness on ice roads and increased effort needed to construct and maintain these routes.

Table 4-1 Winter Roads, Bridges, Culverts and Related Infrastructure Resilience and Adaptive Capacity Evaluation

Infrastructure	Climate Change Impact	Resiliency	Adaptive capacity
Winter Roads	Earlier spring thaw and shortened operating season	Low	Med
	Construction and establishment of roadbed	Medium	High
	Construction and establishment of ice sections over water	Medium	High
	Increased Usage	Low	Med
	Changes in Water Levels, Increased snowfall, portage site sensitivity	Med	Med
Bridges, Culverts and Related Infrastructure	Alignment changes due to late freeze up	Med	Med
	Lateral channel slumping due to localized land slumping	Med	Med
	Scour of temporary crossing foundations and supports from high flows	Med	Med
	Rain on snow events for temporary crossings	High	High
NOTES: Definitions of the relative rating are Resiliency <u>Low Resiliency:</u> Return of the asset to intended operability will take a prolonged period of time, resulting in significant duration of loss in service. A loss of an asset requiring complete reconstruction would be in this category. <u>Medium Resiliency:</u> Return of the asset to intended operability will require a medium-term delay, sufficient to complete modifications to restore the intended operability of the asset. An asset requiring retrofitting or modification would be in this category. <u>High Resiliency:</u> Return of the asset to intended operability will require a short-term delay. An asset requiring rapid maintenance or application of a specific O&M response to restore intended duty would be in this category. Adaptive Capacity <u>Low Adaptive Capacity:</u> Limited effective adaptation is possible for the asset. Reconstruction of the asset is likely for resumption of intended service. <u>Medium Adaptive Capacity:</u> Effective adaptations are possible for the asset. Adaptations would include modification or retrofitting of the asset. <u>High Adaptive Capacity:</u> Readily available and rapidly implementable adaptations are possible for the asset. Adaptations would include deployment of increased operations or maintenance measures.			

Recent climate conditions have posed significant challenges to establishing and maintaining safe winter roads. As warming trends continue, it is expected that the operating season for winter road networks will reach a point where the winter road operating window is insufficient to complete annual community and industrial site resupply campaigns. When winter road resupply efforts fail due to inadequate roads, the only alternative for locations not serviced by marine resupply is extremely costly resupply by air freight service.

While DOT's winter road network has adapted recently through application of innovative ice-road construction techniques, and industrial cargo is optimized to concentrate shipping into portions of winter when ice thickness is maximized, the winter road network is expected to experience significant and more frequent failures due to increased warming conditions.

Stream crossings and related infrastructure are susceptible to changes in local runoff volumes, overland flow, and soil stabilities. Changes in local hydrology and soil stabilities have very significant impacts on the operability, service life and maintenance of crossings, culverts and related infrastructure, to the extent that temporary crossings established along winter roads such as the MVWR are being converted on a priority basis to permanent bridge structure crossings to improve the resiliency of these key infrastructure elements.

4.7 Implications for Operations and Maintenance

- **Increased effort to construct winter roads:** winter road construction will require more preparation prior to development of road segments over both water and land. More equipment and labour will be required for prompt snow removal (or snow compaction) to reduce the insulating cover of snow to encourage faster ice formation and deeper freezing of ground.
- **Increased effort to establish adequate ice thickness:** surface flooding on winter roads and spray ice techniques for ice crossings will be continued requirements in order to increase the ice thickness beyond that possible due to natural (un-aided) early-season ice growth. Increased need for equipment and personnel is expected in order to conduct this activity.
- **Changes in opening dates for winter roads and ice crossings:** previous observations for the Fort Providence Mackenzie River ice crossing indicate that opening dates for light traffic were delayed by more than 3 weeks since 1996, yet opening dates were relatively constant during the previous 30 years or more. (*Northern Climate Exchange 2006 “Effects of warmer winters in the NWT: An indication of future trends?” Weathering Change, Fall, 1-3*)

- **Unpredictability of climate anomalies/extreme events and consequences on O&M planning:**
Extreme events and seasonal climate anomalies occurring at the start of a winter road building season can create substantial delays in establishing winter road networks. Delays incur additional cost in annual construction efforts, and quality of ice will influence level of service and weight restrictions on winter roads. In 2004/2005, winter road construction conditions were colder than had been experienced in over 5 years, allowing earlier road establishment and less intensive winter road construction efforts for winter roads established north of Great Slave Lake. In that year, opening dates for these roads set new records within the previous 10 year history. However, the following 2005/2006 winter road season was the warmest on record by Environment Canada for this region, resulting in ice thicknesses on water bodies of half the yearly normal values for previous years. (*Dillon CC and Transportation in the NWT, 2007*). The warmer winter road season resulted in failed resupply of fuel and materials to northern mine sites located along the privately constructed JV winter road, requiring costly supplementary air lifts to complete the mine resupply campaign. On the same JV winter road a year later, this route reported the best operating season on record with more than 10,000 loaded truck shipments delivered during a 72 day resupply season. (*EBA “Climate Change Impacts and Adaptation: Case Studies of Roads in Northern Canada”, 2008*).
- **Increased efforts for drainage management:** efforts to manage drainage related to runoff from warmer temperatures will increase as temperatures rise in the north. This will likely require a growing response effort involving the addition of more temporary culverts, detailed tracking and reporting of drainage problem locations and incidents, adding snow in problem areas to absorb water, and eventual re-alignment consideration for chronically compromised road sections.
- **Increased frequency of inspection and reporting:** Conditions at crossing and culvert installation sites are noted but logging and tracking systems require standardization and centralization. Results from inspection of structure and drainage conditions should be documented and this information must be processed for integration into a DOT GIS-based asset management tool for ongoing tracking and assessment of crossing and culvert location conditions.
- **Vegetation management:** Future road management may require proactive vegetation management to respond to accelerated vegetation growth, which can slow down adequate ice formation at portage-lake transitions.

4.8 Needs and Gaps to Adequately Respond

- **Requirement for detailed assessment of winter road season trends:** While increasingly sophisticated techniques of winter road construction are being applied in the NWT, there is little existing scientific literature that describes the detailed effects of climate parameters on these road networks. Most relevant information on the interaction between winter roads and climate pertain to a basic discussion of winter road networks and are derived from consultant reports, government reports or accounts found in new media. Although regular records on opening and closing dates are kept for winter roads and ice crossings, no comprehensive trend analysis of these dates has been conducted. (*Royal Swedish Academy of Sciences, “Implications of Climate Change for Economic Development in Northern Canada: Energy, Resource and Transportation Sectors” Prowse et al, 2009.*) A detailed assessment of opening and closing dates for winter roads is needed to examine for trends. Trend analysis is considered an urgent need for other aspects of the winter road network such as:
 - Operation and maintenance efforts.
 - Winter road failures.
 - Service disruptions.
- **Requirement for specific thresholds relevant to winter roads:** Specific thresholds for winter characterizing winter road feasibility have not yet been established. The long-term viability of winter roads is uncertain, and roads subject to different conditions will be affected by climate change at varying rates. There is currently no applicable research that specifies the thresholds for specific climate parameters that will translate into measurable degradation in winter road viability.
- **Requirement for winter road route metrics correlated to site specific weather parameters:** Currently, aside from effective ice thickness charts relating to load limits in winter ice, there are no criteria, thresholds or correlations that exist for management of the viability of specific winter road routes. A monitoring program is needed to measure climate parameters such as temperatures and snow accumulations along specific winter road sections for the purpose of identifying triggers and winter road behaviors in response to these climate fluctuations.
- **Requirement for bathymetry data for lakeshores near ice cover/land portage transition zones:** Shallow lake depths create need for reduced speeds as transport trucks traverse along a winter road and transition from ice onto land portages along a given route.
- **Requirement for GIS-based ice data records:** While ice radar data is used for day to day operations in assessing ice thickness along winter roads, these data are not archived or stored in a central location allowing for data analysis. Documenting ice measurement data, relating it geographically and linking this to reports of service disruptions for winter roads would allow analysis of this information and possible identification of predictive trends.
- **Requirement for expanded light snow removal equipment fleet:** As the winter road construction season moves to a later start due to ongoing warming in the north, the need for early snow removal to quickly promote ice growth will increase to offset a later start and earlier season finish for winter roads.

Deployment of more equipment simultaneously during the construction window would allow winter roads to open as quickly as possible.

- **Requirement for snow caches stored near problematic land portage zones:** provision of snow caches would facilitate swift rebuilding of overland transition sections that are often the first segments of a winter road to degrade along a given route.
- **Requirement for additional equipment at strategic locations:** Prior strategic placement (i.e. caching) of construction equipment required to initiate winter road construction along NWT routes would allow road segments to be constructed concurrently instead of in a linear progression from one end of a winter road route to the other. This practice has been in place for segments along the TWR, allowing multiple sections of this winter road network to be established at once.
- **Development and Assessment of Winter Road Route Alternatives:** given the increasing uncertainty related to viable winter road establishment and the expected reduction in winter road operation season as temperatures increase in the north, DOT needs to develop and assess the feasibility of alternative options to winter road resupply over the longer term. As winter road networks are expected to have a shorter operating season, lower load capacity limits due to reduced ice thickness and faster onset of spring melt conditions, industrial and community resupply will see a higher likelihood of failure, including the possibility of multiple, consecutive scenarios where winter road-dependent resupply is not completed.
- **Condition and incident trend reporting:** Ongoing and regularly scheduled reporting of issues and incidents will help to highlight urgent needs and ongoing problems.
- **Overflow Characterization:** Data collection is required to assess and track winter overflow characteristics at problematic road sections.
- **Expansion of the Permanent Bridge Network:** The permanent bridges installed on the Mackenzie Valley Winter Road have benefitted the road construction activities. This adaptation is expensive (some of the MVWR bridges received Federal infrastructure funding) and so DOT will need to define where else these are needed and begin to secure funding.
- **Infrastructure Asset Management Systems:** Geo-referencing of key features should be recorded at regular periods for inclusion in a digital elevation-mapping database, within a GIS-based asset tracking system. Establishment of digital maintenance logs and a formal reporting process are also required.



5 AIRPORTS

5.1 Infrastructure Description

DOT operates 27 airports in the NWT. Yellowknife (YZF) serves as the NWT's sole gateway hub airport, two regional hub airports operate at Norman Wells (YVQ) and Inuvik (YEV), and the remaining 24 airports serve as community airports. A number of private airfields established to service resource extraction industries in NWT are operated independently from DOT's network. Approximately 500,000 passengers are routed through NWT airports each year, with continued annual growth in air traffic of 7% in response to demands associated with industrial expansion. Figure 3-2 provides a map indicating locations of the NWT airport network.

Air services in the NWT are provided by:

- Four major carriers (Canadian North, First Air, West Jet and Air Canada);
- Several regional carriers (Air Tindi, Northwestern Air Lease, Landa Aviation, North Wright Air, Aklak Air and Buffalo Airways)
- Charter operators (Arctic Sunwest, Simpson Air, Summit Air, Great Slave Helicopters, Trinity Helicopters, Helicopter Transport Services Canada and Canadian Helicopters).

In its role as airport operator, DOT is responsible for the maintenance and serviceability of the runways, aprons, landing approaches and parking areas. Transport Canada is responsible for regulation of airport facilities as well as air carrier operations. NAV Canada provides air navigation services using their personnel at gateway and regional hub airports. The Canadian Air Transport Security Authority (CATSA) manages passenger and baggage security through contracted security providers and DOT is responsible for the physical security of the Yellowknife Airport.

“Change and Challenge”

Climate Change Adaptation Plan for the GNWT Department of Transportation

Section 5: Airports

August 2013

The NWT's airport network consists of six (6) airport sites with at least one paved (asphalt) runway. The remaining 21 sites have gravel surfaces. Asphalt runways are provided in locations where passenger and cargo traffic warrant deployment of larger aircraft, typically Boeing 737 or equivalent²².

DOT continues to implement airport improvement initiatives in areas of improved runway lighting (LED runway lights), implementation of infrastructure/maintenance/asset management systems, responding to ongoing evolving airport security regulations, developing risk assessments of infrastructure components at airports (runways, aprons etc.), and implementing best practices for these facilities.

The impacts to and serviceability of runway surfaces differ between paved runways and gravel runways:

- Paved runways are more vulnerable to changing subsurface conditions that can cause runway buckling or slumping. Paved runways are also susceptible to frost cracking of asphalt pavement, related to cold winter conditions on exposed surfaces. Runways require tighter level tolerances than affiliated airport surfaces such as aprons and taxiways
- Gravel runways are relatively easy to respond to irregularities resulting from subsurface changes, as compromised portions of gravel runway can be re-graded and repaired to an adequately functional state with far less remedial effort than with paved runways.

²² Recent improvements have been made to extend runways to accommodate larger aircraft at the airports in Fort Good Hope, Tulita, and Fort McPherson. New air terminal buildings were established in Sachs Harbour, Paulatuk and Tuktoyaktuk and a new Combined Services Building was constructed in Yellowknife. Colville Lake and Trout Lake are undergoing aerodrome relocation to allow for future runway expansions that will allow for future landings of pressurized aircraft.

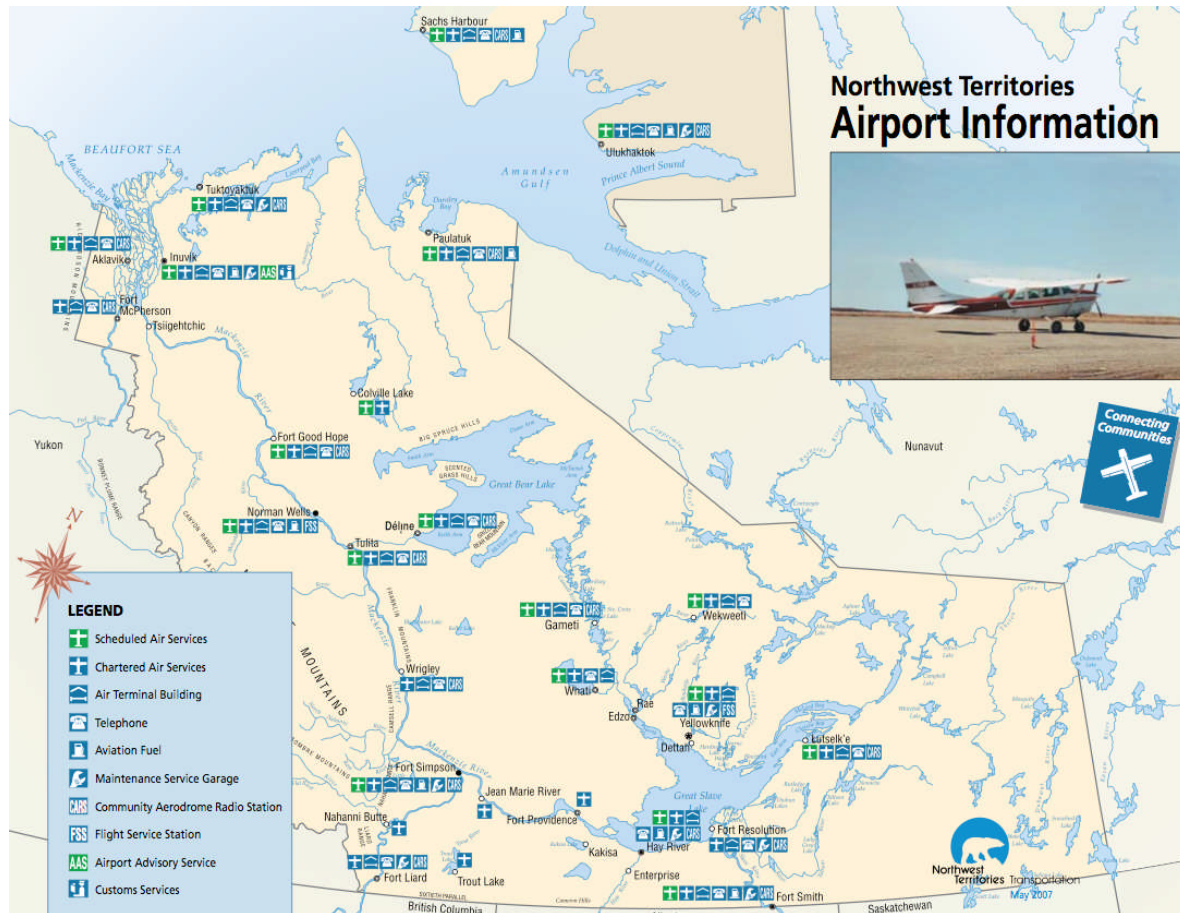


Figure 5-1 DOT NWT Airport Network

5.2 Impacts Observed to Date

DOT has observed numerous impacts to airport operations due to climate change including:

- **Structural degradation due to freeze/thaw cycles:** Changing temperatures have led to increased freeze/thaw cycles and increased formation of ice on runway surfaces. Increased freeze/thaw cycles allow water to flow into cracks within paved surfaces, and upon re-freezing, these water-filled cracks expand and induce paved runway surface damage; as well as transferring heat to permafrost below.
- **Permafrost degradation** has led to settlement of runway areas (e.g. YZF), and in some cases, sinkhole formation and runway buckling.
- **Drainage issues:** Drainage problems have resulted in some flooding of runways and taxiways. For paved runways, repair of depressions and settlement damage requires restoring the runway grade and repairing the paved surface in order to keep paved runways in safe operating conditions. For gravel runways, buckling is not an issue, as depressions in a gravel runway can be filled in and re-graded using readily available resources.
- **Weather Pattern Changes:** Anecdotally reported (but in discussions not considered contentious) conditions of: increased frequency of freezing rain events and frosting of runway surfaces (reduces necessary friction for safe operations), and more frequent extreme event-related travel delays at airports due to fog²³. Friction issues are largely limited to the Inuvik airport and to a lesser degree Norman Wells, because friction generally only limits landings of large-bodied jet airplanes.
- **Increased Loss of Friction:** DOT has observed a substantial increase in the maintenance burden required for maintaining safe airport operating conditions. Sanding requirements alone were reported to have increased at the Norman Wells airport from 10 to 15 tonnes per year prior to 2000 to over 150 tonnes per year in 2012. Other consumables required for airport operation, including glycol for de-icing, have also drastically increased in their use within DOT airport operations.
- **Increased incidents of Fog limiting visibility:** Fog has always occurred under some conditions, but DOT staff report that there appears to be more frequent fog events.

5.3 DOT Response to Observed Impacts

DOT has responded with several measures to cope with climate change impacts occurring at its NWT airport facilities, however it has been constrained from taking more action due to a lack of site-specific data on soil conditions under most of its airport runways. Only a limited number of NWT airport sites have been subjected to various degrees of geotechnical assessment. Many airports lack design and as-built information. Inuvik and Yellowknife airports have been assessed for design information and determination of airport facility substructure and soil conditions. Other reported assessments include a geotechnical

²³ In one dramatic example, a Medevac flight was delayed for an emergency evacuation.

investigation conducted along the runway in Hay River (Stantec, 2011) and a geotechnical investigation of a depression in the runway at Fort Simpson Airport conducted by AMEC in the 1990s²⁴.

DOT responses to observed impacts include the following current measures:

- **Development of a risk assessment protocol:** DOT has developed an airport climate change risk assessment protocol, which was recently piloted at Inuvik airport. The protocol provides a step-wise, reproducible process that includes desk review, site inspections, monitoring and subsurface conditions testing specifically to address the stresses that climate change may place on an airport and identify specific needs for airport rehabilitation.
- **Subgrade reconstruction:** At Yellowknife Airport, DOT addressed runway damage due to permafrost degradation by removing the in-situ sub-surface layer under a damaged runway section and replacing this with materials including an insulating layer to protect underlying permafrost²⁵.
- **Manual Water Removal:** For runway surfaces where drainage has become problematic, maintenance personnel have relied on clearing ponded water accumulations on runways with heavy construction vehicles (Figure 3-3).
- **Pavement Grooving:** At Norman Wells airport, grooving the pavement surface was applied to enhance water drainage from the runway with the unintended consequence of improving the surface friction of the runway. While this technique appeared effective, it represents a costly procedure and is not yet considered a practical solution.
- **Increased Sanding:** To respond to a growing loss of friction issue on the runways at Yellowknife, Inuvik, and to a lesser degree Norman Wells, DOT is applying more sand at these airports. The requirement for adequate sand sources is a challenge, as regulatory requirements for establishing new quarry sources are becoming stricter. Suitability of sand sources are also a challenge, as sanding material available to some locations contains a high fines content, and when this material is exposed to water, the material can become quite slippery – having a counter effect of reduced friction.

²⁴ These reports were not located during this work.

²⁵ The longer-term performance of this measure will require study. The addition of insulation may have negative consequences. The insulation does reduce heat transfer into the soil during the summer, but may also prevent heat loss during the winter. The balance between these heat flows may determine whether the insulation preserves permafrost, or accelerates the degradation.

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- **Increased Glycol Use:** Use of deicing fluid (for aircraft) and runway deicing agents has been increased. As the use of glycol increases, DOT will need to upgrade its glycol collection and retention infrastructure at airport facilities. Enhanced management of glycol will also require improved understanding of glycol degradation rates in northern locations. Glycol management strategies will require stronger priority as their use increases at northern airports; de-icing fluids may present a thermal impact on the subgrade. No assessment of this potential impact has been conducted within DOT airport network.
- **Increased Public Notification:** DOT has improved on public notification of travel delays and airport closures through real-time updates on its website (www.dot.gov.nt.ca) and is considering enhancement of its notification systems.
- **Installation of Temperature Thermistors:** Temperature measuring thermistors have reportedly been installed underneath the runways at Norman Wells and Inuvik (and possibly Hay River). These are not actively capturing data and their condition and functionality is unknown. If functional these could be reactivated affordably.



Photo Credit: K. King, DOT

Figure 5-2 Inundation of the apron surface at Hay River Airport

5.4 Anticipated Future Impacts of Climate Change

Future climate change impacts to the NWT’s airport network are expected to intensify with anticipated continued warming in air temperature, increased frequency and intensity of extreme weather events, and changes in the precipitation regime.

The nature of anticipated future climate change impacts to NWT airports includes:

- Increased frequency of unacceptable runway friction loss at Inuvik, and to a lesser degree, Norman Wells. Increased freeze-thaw cycles, freezing fog, and increased frequency of rain on snow events are anticipated to create challenges to airport personnel who are tasked with maintaining adequate runway surface conditions. It is expected that this will result in higher frequency of airport closure and cancelling of flights at Inuvik and Norman Wells due to lack of acceptable runway friction.
- Air traffic delays are expected to increase as a consequence of more extreme rain and snow events.
- Increased demand for runway traction enhancing materials such as sand and urea at Inuvik and Norman Wells airports. Increased demand for adequate sand will pose challenges to DOT in terms of sourcing this material for all airports and additional labour and equipment needed to apply to runways. Increased use of urea also comes at a significant cost.
- Increased freeze-thaw cycles are anticipated to result in more pavement damage to paved runways, aprons and taxiways. Penetration of water runoff into cracks in pavement surfaces will increase heat transfer into runway subsurface and result in localized heaving and collapse of pavement as water undergoes expansion during re-freeze and contraction during thaw events, and as heat is transferred to permafrost, inducing degradation.
- Changes in temperature regimes as a result of warming trends will push aircraft operations into a higher prevalence of temperature ranges where de-icing is mandatory for flight safety. This will result in a larger demand for glycol supplies, de-icing equipment and personnel, and glycol management systems for protection of the environment.
- Drainage management on runway surfaces will require additional effort. More frequent and more intensive rainfall events are expected in the future and as subsurface conditions on runways become more unstable due to accelerated permafrost degradation, the addition of more frequent instances of higher runoff volumes will prove more difficult to manage with existing techniques.
- The current rate of permafrost degradation at airport facilities, particularly in the continuous permafrost zone, is expected to accelerate as temperatures continue to increase in the future²⁶. DOT’s success in early intervention on runway damage will be tested as the demand for these remedial actions increases system-wide at its airports.

²⁶ The possibility that the majority of permafrost degradation for airports south of Fort Good Hope has already taken place should be confirmed to allow focus on relevant remedial action for those sites (see section 5.5).

- Visibility issues may have a small but localized impact. Forest fire events in the vicinity of any airports may result in service shutdown due to smoke and the occurrence of fog events can create limited visibility sufficient for a temporary stoppage of service.

5.5 Design and Weather-Related Vulnerability

A number of vulnerabilities exist for airport infrastructure:

Structural degradation:

- **Uncertainty over subsurface conditions:** It is not clear whether proper documentation exists of the subsurface conditions at airports. Based on location and time in service it is likely that conditions can be characterized as:
 - **Yellowknife Airport:** Degraded permafrost, likely fine-grained till over bedrock.
 - **Norman Wells Airport:** Till over bedrock at about 3 to 4 metres depth with degraded permafrost. Some springs present north of the runway.
 - **Fort Simpson Airport:** Degraded permafrost with some drainages crossing an airfield consisting of underlying lacustrine sands and silts.
 - **Hay River Airport:** Degraded permafrost with likely deltaic deposits of silts and clays.

More study is needed to confirm the possibility that airports south of Fort Good Hope, which have been in place for many years on sites with high degrees of ground disturbance, may reside in locations where there is now little permafrost remaining to degrade. The most recent studies for Yellowknife, Fort Smith and Hay River airport runway settlements were conducted by AGRA in 2000, and these were not conclusive in determining settlement mechanisms. If investigations confirm the lack of permafrost degradation at these southern NWT airport sites, then the longer-term maintenance issues that will face airports at Fort Simpson, Yellowknife, Hay River, Fort Smith and Norman Wells (airports with paved runways and aprons) may not be permafrost degradation issues but instead be issues that affect airports with deep-season frost, similar to sites operating at Fort McMurray and High Level, in northern Alberta.

Permafrost impacts on paved airport runways: Of DOT's six airports with paved asphalt runways, 4 (Yellowknife, Fort Simpson, Norman Wells, and Inuvik) are considered to be located within zones of permafrost (notwithstanding comments made above). Fort Smith airport is considered permafrost free and the Hay River Airport is believed to reside on largely permafrost free soil, but its subgrade is subject to seasonal freeze-thaw cycles. An investigation into runway settlements was conducted for Yellowknife, Fort Simpson and Hay River Airports in 2000²⁷. For all three assessed airports, runway settlements were observed and evaluated, however the investigators were unable to categorically determine the cause of the settlements taking place.

²⁷ Investigation of Runway Settlements at Yellowknife, Fort Simpson and Hay River Airports, NWT AGRA, 2000.

- At Yellowknife Airport (YZF), settlements of Runway 09-27 were noted to occur in a north-south direction, perpendicular to the runway. This runway was built on native clay subgrade, with water present in the active layer. Cracks in the runway asphalt are suspected to be a pathway for allowing precipitation to enter the active layer, further degrading permafrost beneath the runway. Settlements are expected to continue in the runway area until geothermal equilibrium has been established, likely a process requiring several years. For paved runways with chronic problems, a full or partial runway re-construction effort may be required. This level of effort was required at YZF at Yellowknife in 2002, when a section of runway was excavated and rebuilt with insulating material intended to protect underlying permafrost zones beneath the runway structure.
- Fort Simpson (YFS), Inuvik (YEV) and Fort Smith (YSM) airports were reported in DOT workshops to experience general surface buckling issues. Aircraft advisories for community airports have been issued regarding dips in the runway. Investigations of the issue have suggested that permafrost degradation along a seasonal drainage channel that crosses the cleared runway ROW may be responsible for the problem.
- The airport at Norman Wells (YVQ) was reported in workshops to experience issues associated with ice lens formation under the runway.
- Hay River Airport (YHY) is reported to suffer from dips in runways on an ongoing basis, requiring repairs every 3 to 4 years at a minimum cost of \$800,000 per repair effort. The airport experiences substantial frost heaving and thaw settlement each year, associated with extensive cracking of the runway.
- Inuvik Airport (YEV) is reported to be experiencing runway settlement due to permafrost thawing and drainage-related effects, while settlement is also taking place on the airport's service roads and culverts.

Permafrost impacts on gravel surface runways: Gravel runways are susceptible to permafrost degradation on side slopes by snow accumulation. This can create depressions along the embankment, with water ponding in depressions that can delay freeze-back in winter. Gravel runways are relatively easy to respond to irregularities resulting from subsurface changes, as compromised portions of gravel runway can be re-graded and repaired to an adequately functional state with far less remedial effort than with paved runways.

Changes in weather conditions leading to higher frequency of freezing rain and freeze/thaw cycles: Surface friction of runways is a critical concern in northern paved runway maintenance at Inuvik and Norman Wells. Loss of runway friction occurs when the weather warms to about -20C, when temperatures are too cold for Transport Canada- certified deicing agents, but warm enough for frost to form on the runway, degrading runway surface friction. If friction on the runway is lessened, the length of runway required for aircraft to land and come to a complete stop on a given runway will increase substantially. A friction coefficient is established by each airline for each aircraft in their operating fleet. DOT tests for the coefficient of friction, and then reports this value to the airlines. The airlines then make the decision regarding the sufficiency of the reported friction coefficient value for the aircraft's operation at

a given airport. Friction has affected the ability of jet aircraft to land safely at the Inuvik airport and Norman Wells airport. Airport management at Inuvik Airport (YEV) reported that above average temperatures in the winter of 2011 resulted in more pilot decisions to scrub flight landings, due to reduced runway surface friction conditions, than any other winter in their operational history.

Drainage and Runway/Taxiway Flooding: Heavy precipitation, including snow, ice and rain, as well as surface contamination (i.e. standing water, ice or snow) can create significant hazards to aircraft take-off, landing and maneuverability. Moisture accumulations on runway and taxiway surfaces result from precipitation events (snow, rain, freezing rain), and the migration of groundwater and melt water into subsurface zone, accelerating thermal and mechanical erosion of subsoils. Accumulations of water range from small localized areas of ponding to more widespread flooding. Larger water accumulations pose a more serious hazard to aircraft landing and takeoff movements, as well limiting the efficiency of ground crew operations. The accumulation of water due to inadequate drainage can also cause subsurface instability, as water can percolate into embankment and runway substructures, where it can carry heat into zones of permafrost. For Hay River (YHY) airport, it is believed that drainage systems are adequate; however settlements are creating locations for water to accumulate on runway surfaces.

Community Access and Emergency Response – Weather Related Airport Closures: Eight (of 27) airports do not have navigational systems to assist pilots in landing during their landing approach. Under poor visibility these airports suspend operations²⁸.

In situations where timely access to the community is essential, such as for Medevac flights for medical emergencies or essential ongoing medical treatments, the impacts of airport closures and restrictions to community access may be unacceptable to the community. There is an increasing expectation within community stakeholders that their airports can provide 24/7 functionality for Medevac and other critical service flights. However, this is not currently possible given current airport configurations and available resources. The Northern Air Transportation Association has indicated that they are working to upgrade navigation systems in collaboration with GNWT.

Minor Air Travel Delays: While DOT recognizes that some airport delays are inevitable there is potential for an increase in weather-related delays in air travel. These delays are possible at all NWT airport locations.

Shoreline Erosion of Airstrip: In the NWT, there have been shoreline erosion concerns expressed by the Northern Air Transport Association (though not observed to date) related to airstrips at Tuktoyaktuk (YUB) and Paulatuk (YPC). For Paulatuk in particular, there was concern reported in community consultations about potential for shoreline erosion in the vicinity of the airstrip – simply due to the low elevation of the airstrip.

²⁸ In September of 2011, the airport at Wekweeti (FJ2) was subjected to conditions of dense fog for several days, resulting in cancellation of all flights into the community for a week. This closure cut the community off from essential supplies, groceries and travel for the week-long airport closure and resulted in members of the Wekweeti community being stranded in Yellowknife until fog conditions at Wekweeti (FJ2) lifted.

Increasing Airport Demand for Key Consumables and Regular Maintenance: Maintenance is required for drainage, potholes, ruts, fencing, and vegetation. In the presence of permafrost, increased vegetation can alter the heat transfer characteristics between runways and their installed environment. A large part of ongoing maintenance at NWT airports involves snow clearing, maintaining de-icing operations and maintaining adequate runway surface friction. It is expected that maintenance efforts will increase in locations experiencing milder temperatures and altered precipitation regimes. Regulatory requirements for environmental protection continue to evolve, with an expectation that glycol management requirements will increase, representing added costs to the overall airport maintenance program. Glycol also impacts permafrost stability and quality, so an increase in use may be detrimental to airport subgrade stability in many locations.

Event driven demand: Changes or sudden closures of the road network could increase demand for air services, resulting in increased demands placed on the capacity of NWT's airports ²⁹.

²⁹ When the Tibbitt to Contwoyto road closed early in 2006, the resulting airlift required extended staffing and operations at the Yellowknife airport. While limited in duration, such an event could be problematic for staffing or supplies.

Sidebar 6 Airport Runway Vulnerability Protocol – Inuvik and Deline Assessment

Airport runways in the NWT experience a variety of climactic and other environmental conditions in addition to the effects of airplane landings. Many of the runways are built on difficult terrain, often on continuous or discontinuous permafrost. They experience a variety of problems of subsidence and settlement, including cracking. There is little information available on the specific site conditions at the time the runways were built that can be used to assess the causes of the problems.

In 2011 DOT worked with researchers from Carleton University to develop a runway vulnerability protocol to assess long-term risks to airport infrastructure built on permafrost. The protocol includes a number of steps that are carried out in sequence:

1. Identification of information needs and knowledge gaps: A desktop study to gather all relevant information to evaluate the runway: age, life expectancy, performance measures etc.
2. Site investigation to further assess hazards and monitor for airport rehabilitation needs: inspect runway, interview personnel and identify additional risks. It may include geotechnical studies, surveys, sampling or drilling.
3. Update and validate results, monitoring for rehabilitation requirements.
4. Prioritize risks: first at individual airports, then compare overall scores to prioritize among airports.

The first step of the protocol was tested at the Inuvik Airport and Deline Airport in 2011, both of which have significant ground ice. In addition to general concerns about permafrost thawing due to rising temperatures, the desktop study showed:

- Concerns at the Inuvik airport related to thawing of ice lenses where small lakes had existed previously
- Concerns at Deline were about effects of previous drainage paths in causing permafrost thawing
- Lack of climate data at small communities hampers assessment

A site investigation (Step 2) was carried out at Inuvik. It showed large extents of ground ice have deteriorated, causing significant settling. However, the settlement has largely been stabilized resulting in an intermediate to low risk rating.



Longitudinal cracks along embankment shoulder, Forward Operating Location (FOL) Inuvik. Photo credit: Lance Gelin, DND, from: Tunnicliffe and Burn, Towards a Protocol for Airport Infrastructure Risk

5.6 Summary Resiliency Statement

A summary evaluation of the airport resiliency and adaptive capacity is provided in Table 5-1.

Table 5-1 Airports Summary Resiliency and Adaptive Capacity Evaluation

Infrastructure	Climate Change Impact	Resiliency	Adaptive capacity
Paved Runways	Runway buckling and slumping	Low	Low
	PF degradation, & runway surface irregularities	Med	Med
	Loss of friction	Med	Med
	Increased freeze thaw cycles and related pavement damage	High	Med
	Excess runoff ponding	High	Med
	Increasing snowfall amounts	High	High
Gravel Runways	Excess runoff ponding	High	Med
	Increasing snowfall amounts	High	High
	Runway surface irregularities	High	High
	Permafrost degradation	Med	High
	Increased freeze thaw cycles and related pavement damage	High	High
Airport Operations	Reduced visibility (fog or smoke)	Low	Low
	Ice storms, rain on snow events	Low	Low
	Increased de-icing material management	Med	Med
NOTES: Definitions of the relative rating are: Resiliency <u>Low Resiliency:</u> Return of the asset to intended operability will take a prolonged period of time, resulting in significant duration of loss in service. A loss of an asset requiring complete reconstruction would be in this category. <u>Medium Resiliency:</u> Return of the asset to intended operability will require a medium-term delay, sufficient to complete modifications to restore the intended operability of the asset. An asset requiring retrofitting or modification would be in this category. <u>High Resiliency:</u> Return of the asset to intended operability will require a short-term delay. An asset requiring rapid maintenance or application of a specific O&M response to restore intended duty would be in this category. Adaptive Capacity <u>Low Adaptive Capacity:</u> Limited effective adaptation is possible for the asset. Reconstruction of the asset is likely for resumption of intended service. <u>Medium Adaptive Capacity:</u> Effective adaptations are possible for the asset. Adaptations would include modification or retrofitting of the asset. <u>High Adaptive Capacity:</u> Readily available and rapidly implementable adaptations are possible for the asset. Adaptations would include deployment of increased operations or maintenance measures.			

Air transport and related operations are highly susceptible to delays and shutdown of service in response to adverse weather conditions. Severe weather impacts also create reductions in service in areas such as airline scheduling, airport management, cost control, and passenger convenience. For the smaller general aviation fleets often deployed in the north, it may mean cancelling the flight, which may lead to unacceptable impacts in critical community services such as Medevac or resupply.

Due to this sensitivity of air transport to weather parameters, weather considered to be “extreme weather” to the aviation sector may correspond to weather conditions under which surface-based transport sectors can still run unaffected. Modest ice build-up on a marine cargo vessel may create limitations in function or access to facilities on deck, while modest ice buildup on an aircraft can lead to loss of ability to maintain flight.

5.7 Implications for Operations and Maintenance

NWT airport operations and maintenance implications focus on maintaining safe operating conditions for efficient taxiing, take-off and landing of aircraft. A growing focus of operations and maintenance efforts will be to regularly monitor and inspect for conditions requiring remedial maintenance. For airport surfaces, early onset detection of issues should be a primary focus, in order to prevent further degradation and take remedial action as soon as possible. Early detection and action offers the benefit of minimizing progressive damage to runways. before degradation advances to a stage that could cause interruption in airport operations. Implications for operations and maintenance planning include:

- Controlling snow accumulations along runways and preventing water infiltration along runway embankments are priority interventions for runway preservation.
- A formalized inspection program of paved runway surfaces for cracks, early formation of settlement
- For paved runways, in order to reduce the amount of surface water intrusion (and resulting thermal and physical erosion) into subgrade beneath the asphalt, cracks detected in runway pavements must be sealed as soon as possible after detection.
- For gravel runways, frequent inspection and rapid infill of areas of longitudinal cracking and depressions from settlement.
- For areas along runways where settlement is chronic or recurring, removal of native subgrade soils and replacement with granular fill will be required.
- With warming trends and increased potential for snow and intense rain events, the burden to maintain northern airport facilities will grow substantially. An increase in maintenance effort at airports will be required, resulting in added costs in both staff and material resources.

- Prompt inspection of runways for ponding of runoff due to heavy precipitation events. Inspection and prompt removal of water accumulations along edges of runways, particularly in zones prone to settlement. Ponded water must be removed as soon as possible to prevent accumulated water presenting hazards to aircraft operation.
- Substantial and increasing strategic snow clearing practices will be required on runways, aprons and shoulder areas in order to maximize integrity of permafrost beneath these surfaces. As more snow clearing is required due to trends of higher snowfall amounts, there is a corresponding increase in labour needs and heavy equipment needed to conduct snow clearing.
- Maintenance crews may need to consider preservation of snow cover in later portions of the winter season to assist in preserving cold ground conditions that limit rates of permafrost degradation for these facilities.
- Installation of snow fencing to reduce snowfall accumulations along runway embankments.
- Some NWT airports (e.g. Norman Wells, Inuvik) have reported a ten times increase (from 15 tonnes per year prior to 2000 to current use of 150 tonnes per year at Norman Wells) in sanding materials required for runway and other maintenance requirements. Operations and maintenance budgets must consider higher allocations for labour and materials costs associated with sanding efforts. Sourcing of adequate gravel materials will also be a concern, as regulation of quarry sources for these materials is evolving to a more restrictive framework. Additionally, the need to maintain adequate runway friction under increasingly slippery conditions resulting from higher snowfall accumulations, milder temperatures and additional freeze/thaw cycles will result in higher airport demand and reliance on sanding materials at Inuvik and Norman Wells.
- Due to expected increases in conditions conducive to icing of aircraft, increased reliance on and application of additional de-icing products for aircraft and runway de-icing are expected. Additional planning will be required to meet supply and management needs. Increased de-icing demands will require increased efforts in glycol management and other environmental management systems such as glycol collection ponds. In addition to increased need for de-icing due to trends related to shifting climate in the north, de-icing agent use on aircraft and runways is also anticipated to grow as air traffic increases to these locations (as climate moderates in the north, resource development industry activity is expected to increase). Regulatory requirements for environmental protection continue to evolve, with an expectation that glycol management requirements will grow, representing added costs to the overall airport maintenance program.

5.8 Needs and Gaps to Adequately Respond

- To detect and respond to variations in ground temperatures near runway surfaces, horizontal thermistor cable systems should be implemented at airports with severe ongoing asphalt runway settlement issues. Both vertical and horizontal temperature measurements are required. Additionally, monitoring of settlement, depression development and road subsidence should be done to identify priority maintenance and for estimating granular material needs and related costs as a function of degradation rate.
- DOT may be constrained from taking more comprehensive action to respond to climate change related impacts to its airports due to a pervasive lack of engineering, hydrological, and geotechnical data that would permit a more refined understanding of a specific airport's local site conditions.
- Assessment of impacts of climate change and climate variability on airport operations and maintenance tasks, starting with airports with long-standing weather data records.
- Assessment of airport runways through application of DOT's airport climate change risk assessment protocol.
- Requirement for increased use of ground penetrating radar (GPR) tests to assess failure mechanisms along runway segments. Electrical resistivity should be used in conjunction with GPR tests. Electrical resistivity allows for identifying potentially frozen and unfrozen areas in the subgrade.
- Implementation of tracking systems for sand/gravel usage, de-icing materials usage related to temperature and snowfall accumulations at all airports.
- Research relating increased freeze/thaw cycles with wear and tear on airport infrastructure, with a goal of establishing estimates of likely reductions in expected service life.
- Ongoing tracking of characteristics and locations of snowbanks, snowfall accumulation areas and water ponding areas for each airport, with ongoing data recorded on site and submitted to DOT headquarters for inclusion in GIS-based asset management and condition tracking system. Digital photos must accompany tracking of information.
- Ongoing tracking of characteristics and locations of defects along runway surfaces and embankments, recording locations, lengths, width and depths for cracks and depressions at each airport, with ongoing data recorded on site and submitted to DOT HQ for inclusion in GIS-based asset management and condition tracking system. Digital photos must accompany tracking of information.
- Revising studies conducted initially in 2000 for Yellowknife, Fort Smith and Hay River to establish runway damage rates and mechanisms. Detailed study of airports located on sites suspected of being sited upon highly degraded permafrost locations (airports south of Fort Good Hope) should be conducted to establish if permafrost degradation has proceeded to depletion of permafrost. If this is confirmed, it would allow DOT to manage runway surface quality in response to other runway degradation mechanisms such as deep season frost.

- Georeferencing of key features should be recorded at regular periods for inclusion in a digital elevation mapping database within a GIS-based asset tracking system.
- Drainage assessments at airports with ponding along runways to allow modification of drainage as necessary to protect runway surfaces and embankments.
- Identification of alternate sand/gravel quarry sources to meet growing widespread need within the airport network, starting with airports such as Inuvik and Norman Wells that are reporting increased need for sanding, for large volumes of sanding materials used to maintain adequate runway friction values for safe aircraft operation.
- Tracking scrubbed flights by location and reason
- Effectiveness of insulation at Yellowknife airport as a stabilization mechanism. There is some debate whether this is effective adaptation.



6 FERRIES AND FERRY CROSSINGS

6.1 Infrastructure Description

DOT currently operates and maintains four ferry crossing sites³⁰:

- Highway 1 (Mackenzie Highway): Liard River, km 457 near Fort Simpson with the vessel M.V. Lafferty. Operations are mid-to-late March through October. Service is on demand from approximately 8 am to 11:45 PM.
- Highway 1 (Mackenzie Highway): Mackenzie River, km 548 (N'dulee crossing between Fort Simpson and Wrigley) with the vessel M.V. Johnny Berens. Operations are late May to late October. Service is on demand from 9 am to 11 am and 2 pm to 8 pm.
- Highway 8 (Dempster Highway): Peel River near Fort McPherson with the vessel CF Abraham Francis. This is a cable ferry. Operations are early June through late October. Service is on demand from approximately 9 am to midnight.
- Highway 8 (Dempster Highway): Mackenzie River near Tsiigehtchic with the vessel M. V. Louis Cardinal. Operations are early June through late October. Service is on a demand schedule from approximately 9 am to 1 am.

Each crossing site consists of gravel landings on either side of the crossing. DOT is responsible for all maintenance, operation and improvements for its fleet of ferry vessels and support facilities.

³⁰ The year 2012 was the final operating season for the Merv Hardie Ferry Vessel operating on the Highway 3 crossing, as the completion of the Deh Cho Bridge and opening of the bridge to traffic on November 30 of that year has removed the need for this ferry crossing. The Merv Hardie vessel will remain as a resource to deploy within the DOT fleet.

6.2 Impacts Observed to Date

DOT ferry captains and support staff have observed climate change related impacts to their operations in areas related to river bank stability, river water level fluctuations, river ice dynamics, ferry load capacity reductions and ferry crossing site drainage.

River bank stability: has been compromised in recent years as sloughing of banks takes place. Scour action on riverbanks from rapid flows and spring ice breakup dynamics contributes to a reduction in riverbank stability.

Reduced ferry carrying capacities: Lower water levels create conditions requiring reduced ferry loads, as vessel draft become constrained by shallow conditions. When water levels in the river are too low, ferry captains must reduce their ferry carrying capacities to allow a loaded ferry vessel to operate in shallower water conditions.

Damage to landings: Ferry landing sites and ramps have experienced more frequent damage due to more severe water level fluctuations. Ferry ramps are constructed from gravel, and as such, are subject to scour but are easily adjusted to current local water levels as required. As water levels change labour and fill materials are needed to repair damage to the landings and adjust the level of the ferry ramps to match the current water levels.

Drainage at landings: Ferry site drainage has been a growing issue of concern as localized flooding can occur in response to intense rainfall events. Temporary flooding can affect ferry loading areas, work yards, staging areas for traffic awaiting boarding to a ferry vessel, and efficient access to other ferry crossing infrastructure. Under wet conditions the landings and approaches for some ferry crossings can be prone to extreme softness and slippery conditions, resulting in temporary service disruption until conditions are stabilized.

Increase in large debris: DOT ferry staff noted increasing amounts of larger debris in watercourses, primarily trees and woody debris entering from the Liard River. The presence of large debris such as trees can disrupt ferry service temporarily until the obstacles pass. Large debris also poses a danger to infrastructure along the shore of the ferry crossing.

Increased operating seasons: DOT has observed changes to its ferry operating season in recent years, due to longer ice-free periods late in the ferry operating season. While opening dates for ferry service have remained relatively static, closing dates for ferry service are reported to have extended by about 1-2 weeks over the past 20 years.

6.3 DOT Response to Observed Impacts

DOT personnel have implemented specific responses to adapt to observed impacts on ferry crossing operations including:

- landings and ramps are more frequently re-shaped and re-established to levels matching the current water levels. Gravel is applied using heavy equipment and staff labour. Requirements for “clean” gravel material to restore the ramps has been noted as an issue – both in the supply of aggregate, and regulatory (and stakeholder) concerns to limit turbidity caused in the watercourse. Ferry staff are under a requirement to only use ‘clean’ gravel for supplementing and reconstructing ferry crossing ramps, and increases in ramp rebuilding requires more material – sometime exceeding the on-site availability.
- Under conditions of high water levels and large debris approaching a given ferry crossing, DOT staff have winched a ferry vessel onto shore to avoid damage to the vessel.
- In response to water fluctuations and changes in flow dynamics, the cable-driven Abraham Francis near Fort McPherson undergoes additional inspection in order to establish if excess wear is evident in the cable system.
- In response to localized drainage problems at ferry crossing sites due to intense rainfall events, ferry staff conduct local modifications on an ad hoc basis to resolve the issue. To date, site drainage modifications have been relatively minor.
- In particularly low water levels, ferry operators reduce the load they carry to minimize the draft requirements. During high demand periods, this capacity reduction results in delays in service to waiting ferry traffic. To date, staff did not note that this required increased operating hours.
- As adequate ice for initiating ice bridge crossings has been occurring later in the fall, ferry service has been extended to reduce the “shoulder season” where no crossing service is available between ferry shutdown and ice bridge opening. Extension of ferry season results in added budgetary requirements.
- A research project is planned by DOT to evaluate the impacts of climate change on water levels on the Mackenzie River.

6.4 Anticipated Future Impacts of Climate Change

Future climate change impacts to the NWT's ferry crossing operations are expected to intensify in response to continued warming in temperature, increased frequency and intensity of extreme weather events, changes to vegetation and land cover within river catchment areas, slumping of riverbanks, and changes in the hydrology of rivers. These may include:

- **Increasing operating season:** It is expected that ferry service operating season will continue to lengthen, due to later onset of ice formation and earlier breakup.

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- **Water level fluctuations:** are expected to intensify and become more frequent in response to more intense and more frequent extreme rain events, changes in the winter snowpack and an increase in speed of the spring melt.
- **Increased damage to landings:** Ferry crossing site response to water level fluctuations will intensify, creating a need for more labour resources, and additional sources of “clean” gravel for repair and re-positioning of landing ramps. DOT will likely face higher costs and environmental management burdens.
- **Potential for increasing operating hours:** Hours of ferry service operation may eventually require expansion under conditions of reduced ferry carrying capacity (from low water levels).
- **Shoreline degradation:** Continued, or increasing, shoreline sloughing and erosion, resulting from permafrost degradation. This may affect hydrology of rivers or debris in the river. These have potential to increase service disruptions or damage downstream ferry crossing facilities.
- **Increasing drainage issues:** Ferry crossing sites are expected to experience more severe challenges in terms of site drainage and softening of landings due to excessive moisture conditions.

Sidebar 7 Keeping What Works: Ferries Crossings an Adaptable System

Ferries provide vital river crossings for the highways system. Ferries operate from just after spring break up in May until freeze up late in the year. The access point for each ferry is a gravel ramp from the shore to the boat landing location. The ramp is constructed each spring and extended and modified as the river level fluctuates. The system was developed in response to the severe river conditions of ice and high flows which would damage permanent structures. It is affordable, and flexible.

Climate change may have several impacts on ferry services including service disruptions due to changing river conditions, an longer operating season due to later freeze-up, more drainage requirements at the loading areas, and more effort for ramp maintenance. The risks from these changes is low and the primary concern is a temporary interruption of the Ferry service. This happens currently, and staff have been responsive to ensuring that the service is operational as much as possible.

The current system of using temporary loading ramps has proven to be a flexible, and adaptive system. Modest changes will be required – these include increasing staff time, more effort and cost for building the ramps, and efforts to ensure that gravel is clean. Periodic review and feedback planning will allow staff to stay current with evolving conditions.



Loading ramps and vehicle staging areas are constructed from gravel and are an adaptable system. Future adaptation might require more permanent drainage.

Photo credit: <http://cranialexhaust.files.wordpress.com>

6.5 Design and Weather-Related Vulnerability

Specific vulnerabilities at each ferry crossing include:

- The Lafferty Ferry Crossing (Highway 1 Liard River Crossing) can be subject to sudden service shutdown under conditions of water level fluctuations or presence of floating debris. In addition, under conditions of excess precipitation, the landings and approaches at this crossing can be prone to extreme softness and slippery conditions.
- The Johnny Berens Ferry Crossing (Highway 1 N'dulee Crossing) is subject to sudden service interruptions due to changing conditions such as water level fluctuations, soft shore landings, and migration of floatable debris along river channels. (the presence of larger debris under conditions of high water levels is reported to be more prevalent than it was in the past).
- The Abraham Francis Ferry Crossing (Highway 8 Peel River near Fort McPherson) is subject to delays under wet conditions due to soft landings.
- The Louis Cardinal Ferry Crossing (Arctic Red River near Tsiigehtchic) is subject to sudden service shutdown or long delays under conditions of high water and floating debris. Along the Arctic Red River, DOT operators are reporting large amounts of trees being carried downstream in the river flow under conditions of high water levels, creating obstacles and hazards for the ferry vessel. The presence of larger debris under conditions of high water levels is reported to be more prevalent than it was in the past.

6.6 Summary Resiliency Statement

A summary evaluation of the ferries and crossings resiliency and adaptive capacity is provided in Table 6-1.

Overall the ferry crossing system utilizes a highly adaptable and flexible system of gravel ramps that are built each year and modified to suit conditions presented throughout the season. This system is generally suitable for the level of traffic and delays are expected to be intermittent and of relatively short duration. Features of this system are that:

- It is responsive to localized changes in water level or flow, as well as short term scouring of the ramps. Ramps can be readily re-built.
- Operators can adjust ferry crossing ramps to suit most conditions and can cease operations temporarily under conditions of floatable debris.
- In wet conditions soft areas in the vehicle approaches can be readily filled with aggregate.
- Some drainage problems might become severe enough to require more permanent drainage infrastructure.

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Overall, with a steadily increasing allocation for time and gravel fill material, the system should be able to respond to climate related impacts. Overall the ferry crossing system is considered resilient and responsive to the impacts of climate change.

Table 6-1 Ferries and Crossings Resilience and Adaptive Capacity Evaluation

Infrastructure	Climate Change Impact	Resiliency	Adaptive capacity
Ramps	Fluctuating water levels	High	High
	High water, shoreline scour, debris in river	High	High
	Soft landings	Med	Med
Drainage systems	Excess runoff, soft conditions	Med	Med
Vessel Operations	Low water levels	Med	Med
	Ice and Debris	High	High
	Longer operational season	High	Med
Ferry Cable systems	Greater load or wear on cable from high water flows	High	Med
NOTES: Definitions of the relative rating are: Resiliency <u>Low Resiliency:</u> Return of the asset to intended operability will take a prolonged period of time, resulting in significant duration of loss in service. A loss of an asset requiring complete reconstruction would be in this category. <u>Medium Resiliency:</u> Return of the asset to intended operability will require a medium-term delay, sufficient to complete modifications to restore the intended operability of the asset. An asset requiring retrofitting or modification would be in this category. <u>High Resiliency:</u> Return of the asset to intended operability will require a short-term delay. An asset requiring rapid maintenance or application of a specific O&M response to restore intended duty would be in this category. Adaptive Capacity <u>Low Adaptive Capacity:</u> Limited effective adaptation is possible for the asset. Reconstruction of the asset is likely for resumption of intended service. <u>Medium Adaptive Capacity:</u> Effective adaptations are possible for the asset. Adaptations would include modification or retrofitting of the asset. <u>High Adaptive Capacity:</u> Readily available and rapidly implementable adaptations are possible for the asset. Adaptations would include deployment of increased operations or maintenance measures.			

6.7 Implications for Operations and Maintenance

Implications for operations and maintenance of climate change include:

- **Increasing landing maintenance:** Additional time effort and aggregate costs for grading and rebuilding of landing ramps. This will include a greater degree of regulatory and public communication care.
- **Increasing operating hours and length of season:** Gradually increasing operational season requiring additional operating hours
- **Service interruptions:** Intermittent or incident-based service interruptions of short duration.

- **Service reductions:** Intermittent service reductions due to carrying capacity limitations.
- **Increasing efforts to manage local site drainage:** Additional effort for maintaining site drainage and vehicle approaches to the ferry landings. This may eventually require some capital expenditures if permanent drainage infrastructure is required.

6.8 Needs and Gaps to Adequately Respond

The following needs are required to adequately respond to emerging climate change impacts on ferry services:

- **Additional granular materials:** Ferry operations will need provision of sufficient supplies of clean source gravel for use, and this need is expected to continue to increase as water levels at crossings increase in variability and as wet conditions create soft soil conditions at ferry landings.
- **Additional Staffing:** Ferry crossings will need additional staffing allocations to extend ferry service in response to longer ice-free periods in rivers.

In the future more sophisticated assistance may be required, if conditions of debris, and shoreline erosion are exacerbated along the rivers including:

- **Proactive forecasting:** Current operator response is based on observations at the crossing site. To respond proactively instead of reactively, additional monitoring data for ferry crossing sites is required. Predictive information would permit better real-time updates of expected ferry service interruptions, allowing more precise notification to ferry service users of expected delays or service interruptions. These could be empirical methods, modeling results or enhanced observational information.
- **Improved understanding of river dynamics and flows:** The Mackenzie, Liard, Peel and Arctic Red Rivers are highly dynamic with fluctuating water levels, damaging ice breakup movements and river morphologies heavily impacted by sedimentation and river bank sloughing. Water level monitoring data upstream of ferry crossing locations can assist operators of trends of rising or falling river water levels. Water level data should be tracked and correlated with details regarding the ferry crossing response to adequately prepare for the anticipated river water level. Tracking water levels in this manner would allow identification of trends in labour and materials (i.e. clean gravel for ramp supplementation) required to maintain ferry service for given water levels.
- **River research and study:** DOT can leverage its presence in the ferry system through cooperation with academic and research institutions to develop predictive models for river flow and stage³¹.

³¹ In recent years modeling and empirical work has been explored along the Mackenzie River in partnership with the University of Alberta and this has allowed ferry-crossing personnel to pull a ferry vessel in advance of the arrival of damaging debris and ice fields upstream.

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- **Remote sensing:** Satellite (or airborne) imagery of river ice breakup and progression upstream of ferry crossings can assist operators to anticipate ice jam formations, localized flooding and large-scale debris mobilized by ice scour.



7 RIVER TRANSPORTATION AND BARGE TRAFFIC

7.1 Infrastructure Description

During the ice-free season, the Mackenzie River serves as a major cargo shipment route through the NWT, handling barge traffic tasked with transporting goods for resupply to numerous communities along the river, the Mackenzie delta, and the Arctic coast.

Hay River, located on the south shore of Great Slave Lake, serves as the staging hub where truck and rail shipments are transferred to Northern Transportation Company Ltd. (NTCL) barges.

Loaded barges travel north from Hay River, across Great Slave Lake and along the length of the Mackenzie River in connected “train” formation of up to 15 barge vessels. River barges travel as far as Tuktoyaktuk, and then return. The journey is approximately two weeks in each direction from Hay River to Tuktoyaktuk. Another barging company located in Fort Nelson carries loads down the Liard River to service a number of Mackenzie River communities.

At Tuktoyaktuk, cargo is transferred from river barges to ocean barges for service to marine locations (see section 8).

Tugboats tow or push individual barges and barge trains (see example in Figure 7-1). Along the route, there are narrow and shallow sections of the Mackenzie that force barge captains to uncouple barge trains in order to take barges individually through difficult reaches of the river. Once barges pass through the problematic river reaches, individual barges are reconnected and the barge resumes travel along the river.

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The Canadian Coast Guard provides navigational aids. Each year it installs hundreds of markers and buoys along the river and collects them again at the end of the season. The Coast Guard has two vessels that service the River. During spring installation one vessel begins at Hay River installing navigational aids, while the second proceeds to Norman Wells and works northward. In the fall, the two boats work in tandem from Tuktoyaktuk to Hay River to remove the navigational aids – commencing in October. The Coast Guard uses equipment caches along shore to store much of the equipment over winter.



SOURCE: Horizon North Logistics Inc.

Figure 7-1 Barge shipments along the Mackenzie River

7.2 Impacts Observed to Date

Barge port personnel at Hay River and barge pilots are observing climate change related impacts already along the Mackenzie River. Noted changes include:

- **Variable water levels in Great Slave Lake:** varying water levels have contributed to lower water depths at the Hay River harbour. Reduced water levels cause impacts to barge operations due to a need for lighter barge loads in order to maintain barge draft within the ranges that will allow for safe passage out of Hay River and along the Mackenzie River ³².
- **Siltation in harbours at Hay River and Tuktoyaktuk.** Dredging has not been done for many years, since the federal government ended its program in the mid-1990s in a cost cutting move. Available draft for barge vessels is decreasing (note that this may not be climate change related per se, however it is a growing problem when considered with water level fluctuations).
- **Changing River Conditions:** River barge pilots report changes to the Mackenzie River channel from year to year, requiring barge pilots to continuously adjust their navigation routes along the river. Warming temperature trends within the Mackenzie River Valley have resulted in longer open water seasons than in the past, with the resulting impact being longer periods where shoreline erosion can occur and additional changes to the river channel geometry and the water depths within it. Shoreline erosion has also damaged mooring anchors relied upon by barges, and navigation aids established by the coast guard.
- **Shoreline permafrost degradation and slumping:** landmasses that slough into the river channel, have caused obstructions and route adjustments for barge pilots. Since the Mackenzie River is not actively charted, these continuous, ongoing physical changes to the cross section of the river channel create significant challenges for even experienced barge pilots to navigate.
- **More intense precipitation:** During periods of intense precipitation the river is observed to receive higher volumes of woody debris which is eroded off the shoreline and deposited into the river.
- **“Dynamic” break-up:** a spring break up characterized by more sudden and damaging ice movement, as opposed to a thermal melting and gradual loss of the ice. Ice processes have also created concern for damage due to ice scouring land-based infrastructure and has narrowly missed damaging fuel manifolds. Ice blocking of landing locations early in the barging season was reported.
- **Dropping water levels:** Later in the open water season, operators have reported river levels dropping beyond traditional levels.
- **Fog:** Loss of visibility due to more frequent fog events.

³² Data compiled by Environment Canada indicate that water levels can fluctuate on the order of 0.5 to 1.0 m from year to year. A study by the Marine Group indicated that requirements to lighten barges could result in substantial increases in shipping costs – up to 45%

- **Wind:** On Great Slave Lake, increased severe wind events have resulted in unsafe wave heights for barge operation on the lake. Waves create problems for navigational control of the barge vessels and risks to the cargo stowed on deck.

These weather conditions, individually or as cumulative events, have impacted barge operations by creating difficulties in control of barge navigation, increased effort and difficulty in loading and unloading barges at landing sites, increased need for unplanned mooring of barges along shore to wait out dangerous conditions, increased presence and need to avoid large floatable debris within the river channel, and water level deficiencies preventing loaded barges from clearing river bottom in problematic reaches.

7.3 DOT Response to Observed Impacts

DOT plays only a support role in barge traffic operations but has an interest in understanding the activity and issues with river transport. They provide planning support to communities as part of GNWT's resupply operations (primarily the Petroleum Products Division of the GNWT Department of Public Works and Services providing generator fuel to select communities).

Barge operators and communities reliant upon barge transport of resupply goods have taken steps to adapt to observed impacts experienced at Hay River, along the Mackenzie River and to communities along the barge supply route. These steps include:

- Moving mooring points further into the shoreline such that barge mooring can be achieved on more stable locations closer to shore.
- Periodic review of barge handling facilities in order to track conditions and incidents where barge cargo receiving is impacted by climate impacts.
- Constant adjustment of routes and slower passage through difficult reaches of the river.
- Re-establishment of gravel ramps after ramp-washout events
- Relocation of fuel manifold equipment that is located too close to the levels reached by shore ice and debris during break-up.
- Reduced cargo loads on barges to allow for reduced water level in river reaches.
- Higher frequency of shoreline mooring of barge vessels along river to “wait out” extreme events such as storms and lightning.

7.4 Anticipated Future Impacts of Climate Change

Future climate change impacts to the NWT's barge operations at Hay River and through the Mackenzie River are expected to intensify. Specific future impacts include:

- **More fog:** Higher incidences of visibility-limiting fog, resulting in increased delays and navigational challenges

- **Increased damage to docking and mooring locations**
- **Wind:** Increased instances of high wind events on Great Slave Lake leading to delays to barge traffic.
- **Reduced cargo capacity:** Reducing, or variable cargo carrying capacities on barge vessels due to reduced draft in the River, and at the Hay River barging facilities.
- Increased risk of damage to infrastructure such as fuel manifolds located in areas prone to shoreline damage processes associated with shoreline slumping, more damaging river ice breakup dynamics and presence of large wood debris (trees, etc.) present in the river.
- **Loading challenges:** Increased difficulties in loading and unloading barge vessels at community landing sites.

7.5 Design and Weather-Related Vulnerability

Design and weather-related vulnerabilities are primarily related to availability of adequate water levels to allow safe passage of loaded cargo barges, wind setup causing waves on Great Slave Lake, slope failures and other processes altering river channel morphology, and river ice dynamics that involve more violent ice breakup leading to scour damage and ice deposits blocking shore-side barge infrastructure access for cargo processing. Specifically:

- **Barge Navigation:** Strong winds can result in wave setup on Great Slave Lake, creating navigation and cargo hazards for loaded barges as they depart from the main Hay River port. Along the Mackenzie River, operators are reporting high variability in river water levels, and indicate that river levels are dropping earlier in the shipping season than previously experienced. At Norman Wells, dropping Mackenzie River water levels are causing barge maneuverability problems, with reports of barges getting stuck.
- **Barge Cargo Payload Capacities:** Despite the use of low-draft barges, cargo payload capacities will be increasingly vulnerable to reduced water levels along the shipment route later in the season.
- **Harbour depths:** Hay River harbour has been struggling with lower water levels, and silt deposits exacerbating lower water levels for several years. This problem is getting worse due to cessation of dredging operations at Hay River since the mid 1990's. Dredging to counter siltation processes and low water levels was also previously conducted at Tuktoyaktuk, but was also ceased in the mid-1990's once Transport Canada relinquished this role. Dredging operations require substantial resources which DOT does not currently budget for, and face tighter regulatory scrutiny than in the past.
- **Erosion Processes and Changing River Morphology:** The operating conditions along the Mackenzie River are highly dynamic; the river changes to a significant extent each year, requiring barge pilots to continuously adjust their routes. Permafrost degradation along the Mackenzie Valley has resulted in slumping shorelines, which can impact river reaches and cause navigational challenges for barge pilots attempting passage. Navigational aids have frequently had to be moved further inland in recent years as a result of shoreline erosion.

- **Debris:** The Mackenzie River is also prone to flushing through significant woody debris in response to ice breakup and intense precipitation events. These conditions can also impact access to shore for mooring barge offload points along the river. Climate change may increase river debris through further land slumping
- **Ice-Induced Damage and Delays:** Ice dynamics on the Mackenzie River are becoming a concern for some cargo shipments, as operators have described the annual presence of more frequent ‘dynamic’ spring ice breakups. That is, breakup through ice movement – creating more scouring, and more shoreline ice deposition. Previously a ‘thermal’ breakup (the ice thins more before breaking up) was more common. The more violent dynamic ice breakup has resulted in near damage to fuel manifolds, scouring of loading ramps and access to shore facilities. At Tulita, ice accumulations of several metres in size were deposited on shore near barge landing areas, potentially obstructing shore access and safe channel passage. Near Inuvik, the presence of late spring ice chunks has created navigational hazards for barge operators in this area.

7.6 Summary Resiliency Statement

A summary evaluation of the river transportation resiliency and adaptive capacity is provided in Table 7-1.

The river shipping system is generally resilient and adaptable to changing conditions. The resiliency is generally provided by readily modifiable, basic infrastructure – simple mooring points (sometime even a tree) and gravel ramp style offloading. The adaptive capacity is provided by barge operator skill, and sufficient contingency in the scheduling of deliveries – which together minimize the impact of temporary disruptions and factor these into scheduling.

River shipping and barge traffic are susceptible to temporary disruption due to weather-related impacts, as well as long term changes in the weather and hydrological environment.

The barge transport system is resilient to fluctuations in lake and river levels through operator practices such as load lightening and separating barge trains into individual segments for difficult river reaches. There are limits to this adaptation as minimum drafts in the range of 1.5 meters are still required. Route planning is vulnerable to changes in river morphology exacerbated by sloughing and slope stability problems, and rapidly changing and poor charting within the Mackenzie River. Barge traffic is highly sensitive to low water level conditions, as cargo capacities are restricted to amounts determined by minimum draft requirements for the loaded barge vessel. At present the system provides resilience to climate related changes due to the presence of experienced operators, and proactive delivery scheduling.

Table 7-1 River Transportation Resilience and Adaptive Capacity Evaluation

Infrastructure	Climate Change Impact	Resiliency	Adaptive capacity
Barge Cargo loading and	Variable water level Siltation	Low	Med
Barge Passage and Navigation	Mackenzie River water levels	Low	Med
	Changing shoreline anchorage due to slumping and erosion	High	High
	Extreme rainfall events and waterborne debris	High	High
	Fog, loss of visibility	Med	Low
	High winds and wave set up on GSL	Med	Low
Landside barge infrastructure: anchorage, fuel manifolds	Debris or ice damage	Med	Med
	Flooding	Med	Med

NOTES:

Definitions of the relative rating are:

Resiliency

Low Resiliency: Return of the asset to intended operability will take a prolonged period of time, resulting in significant duration of loss in service. A loss of an asset requiring complete reconstruction would be in this category.

Medium Resiliency: Return of the asset to intended operability will require a medium-term delay, sufficient to complete modifications to restore the intended operability of the asset. An asset requiring retrofitting or modification would be in this category.

High Resiliency: Return of the asset to intended operability will require a short-term delay. An asset requiring rapid maintenance or application of a specific O&M response to restore intended duty would be in this category.

Adaptive Capacity

Low Adaptive Capacity: Limited effective adaptation is possible for the asset. Reconstruction of the asset is likely for resumption of intended service.

Medium Adaptive Capacity: Effective adaptations are possible for the asset. Adaptations would include modification or retrofitting of the asset.

High Adaptive Capacity: Readily available and rapidly implementable adaptations are possible for the asset. Adaptations would include deployment of increased operations or maintenance measures.

7.7 Implications for Operations and Maintenance

Skilled, experienced barge pilots who know the local conditions have largely countered barge route hazards such as shallow water levels, unmanaged river sedimentation and increasing presence of river debris. As climate continues to warm in the north, it is expected that processes affecting water levels, riverbank stabilities and movement of debris within the river channel will intensify. Measures by DOT operations and maintenance can reduce the impacts to timely, safe barge cargo shipment. These include:

- **Infrastructure inspection:** Additional inspection of barge landing facilities and related land-side infrastructure, with relocation of potentially vulnerable infrastructure (i.e. fuel manifolds, etc.) to higher ground or temporary de-installation to avoid damaging water levels, ice fields and debris.
- **Incident tracking:** Tracking of incidents resulting in barge grounding at community barge landing areas.
- **Reporting ice movement:** Tracking and reporting to communities of water level and ice movement data related to barge movement and community resupply deliveries.
- **Notification system:** Establishing an ice and debris notification system when ice and debris hazards pose risk to landside barge cargo infrastructure.

7.8 Needs and Gaps to Adequately Respond

A number of key needs are essential for sustained, reliable and safe transport from Hay River along the Mackenzie River route. These include:

- **Hydrological data:** Assessments related to climate change impact on runoff volumes, evaporation rates and water levels for Great Slave Lake and the Mackenzie River.
- **Navigational controls:** Improved navigational controls. Delays in deployment of shipping buoys along the Mackenzie River was reported to have delayed one barge contractor
- **Navigation aids:** Exploring an extended transport season with the Canadian Coast Guard (CCG). This would require the CCG to adjust their navigational aid programs.
- **Permafrost degradation monitoring:** The impacts of the loss of permafrost on river hydrology are not completely understood. In order to understand the relationship between permafrost degradation, excess pore water pressure and runoff flow, monitoring of these parameters in strategic locations may allow identification of key parameters or thresholds for predictive analysis.
- **Ice monitoring:** Better availability of satellite imagery or some form of remote sensing data to understand movement and condition of river ice formations. Research and development initiatives in ice monitoring and tracking have been initiated near Inuvik focusing on the Mackenzie River as part of International Polar Year initiatives. Expansion of access to satellite mapping datasets monitoring river ice formations will be required to proactively manage risk associated with ice breakup, ice deposition and localized flooding hazards along the Mackenzie River.

- **Water level monitoring:** Establishment of a water level monitoring network and ice/debris advisory service to inform barge crews and downstream communities on barge cargo routes of potential passage risks or risks to shore-side infrastructure.
- **Pilot training:** Establishment of a barge pilot training and succession program. Successful vessel passage relies upon familiarity with unique conditions along the Mackenzie River, a high level of operator skill, and a number of years of experience. At present the shipping companies have not formalized any plans for training and succession.
- **Assessment of feasibility of large module cargo shipment:** Industrial interests servicing the Alberta oilsands have expressed interest in shipping large industrial project modules “over the top” from overseas, via the Bering Strait to Tuktoyaktuk. There the loads would be transferred to river barges and shipped up the Mackenzie River, across Great Slave Lake and up the Slave River to Fort Smith. From there they would be portaged around the Slave River rapids to Fort Fitzgerald and continue by barge down the Slave River and on to Fort McMurray. Assessment of cargo barge draft requirements for these modules is required to determine the feasibility of large module shipments. The recent completion of the Deh Cho Bridge is also a factor, as the new bridge currently offers 23 metres of clearance between the water surface and the bridge deck, while some modules are reported to require 30 metres of clearance. Finally, there may be draft limitations on the Athabasca River portion of this particular routing option for large cargo modules.



8 ARCTIC MARINE AND COASTAL RESUPPLY

8.1 Infrastructure Description

Travel and shipping in the arctic marine environment falls largely outside of DOT jurisdiction. Navigation support is provided by the Canadian Coast Guard. Private operators provide shipping services to communities, DEW line stations (now called the North Warning System), and various resource exploration and development activities across the arctic. Tourist and cruise ship traffic has increased in recent years, and there may be more possibilities for resupply from the eastern arctic in the future.

DOT does have an interest in the services of the river barge transport and arctic marine transportation systems.

The GNWT manages fuel re-supply to three NWT northern coastal communities: Sachs Harbour, Ulukhaktok and Paulatuk, through the Petroleum Products Division (PPD), and some shore and mooring facilities for (mostly) container-module delivery of building materials, food products and other essential supplies.

Arctic navigation and coastal resupply efforts are impacted primarily by the influence of weather events and the extent of ice coverage in shipping routes.

8.2 Impacts Observed to Date

The arctic marine environment is already a challenging one to operate within – characterized by variable and swiftly changing conditions. Climate change has been presented in the popular media as making travel easier as a result of a longer ice-free season. While this may be true, there will also be negative or at least unpredicted impacts. These pertain primarily to navigation, maneuverability and access to coastal community ports, increased frequency of higher wind conditions, increased likelihood of intense and difficult to forecast arctic marine storms, reductions in land-fast ice, and changes in the distribution of multi-year ice.

Impacts affecting arctic coastal community resupply observed to date include:

- **Changing ice dynamics:** The changes in ice dynamics, combined with shallow conditions and presence of sandbar formations near NWT coastal communities. The potential exists for vessel maneuverability disruptions or damage.
 - **Decreased sea ice coverage:** Arctic sea ice coverage (extent) has been decreasing since the 1950s in all seasons, this has led to high year-to-year variability in regional sea ice coverage.
 - **Decreasing multi-year ice:** Changing distribution of multi-year ice as this ice is degrading, detaching and migrating into areas that are unexpected, creating potential obstacles and hazards to cargo vessel traffic.
 - **Mobile ice:** ice that has degraded and detached from larger formations is released in segments that migrate throughout cargo vessel routes, posing potential obstacles to vessel safety and navigation.
- **Increased damage to piers/ramps:** Increased incidence of pier and ramp damage due to reduced land fast ice (land fast ice was formerly more prevalent and offered some protection from erosion and wind process damage).
- **Storm surge challenges:** Storm surge inundation and damages at community landing facilities, when taking place while a cargo vessel is approaching port, has led to disruptions in vessel entry into harbour and disruption to cargo off-loading.
- **Increased high winds:** Increased incidence of high wind events. Excess winds create unsafe conditions for harbour entry in shallow waters, and restrict cargo transfer activities from cargo vessel to community shore.
 - Increased incidence of extreme arctic marine storms.

8.3 DOT Response to Observed Impacts

DOT has embarked upon improved procedures to minimize impacts while launching studies to assess adaptations to respond to severe challenges such as coastal inundation and limitations to harbour access due to shallow waters and unpredictable ice. These include:

- A high level of cargo vessel operator prudence and skill for navigation to communities and into their shallow harbours. Careful scheduling, contingency planning, and route planning has enabled an adequate resupply window to each of the three communities.
- Conducting assessments into relocation of coastal fuel manifold facilities such that access to this fuel transfer infrastructure is more reliable and safe.
- Conducting assessments into options such as lightering, where a cargo vessel moors in deeper waters near a coastal community and offloads cargo directly to smaller community vessels. This would avoid the growing problem of shallow water access into confined port areas.
- A determination by DOT that improved navigational charting of arctic coastal resupply routes is a top priority.
- Attempts to ensure that critical community supply shipments are initiated sufficiently early to accommodate delays such that the possibility for resupply failure is minimized.

8.4 Anticipated Future Impacts of Climate Change

Anticipated future impacts include:

- **Damage prevention:** Potential need for relocation of shore-based cargo resupply infrastructure such as fuel manifolds and piping infrastructure due to intensified coastal impacts, including shore erosion, mobile ice and storm surge damages.
- **Increasing vessel groundings:** Increased prevalence of vessel groundings due to higher rates of vessel traffic once the Northwest Passage is routinely ice free and considered more accessible to vessel captains unfamiliar with these waters. This will create obstructions for safe passage of coastal resupply vessels. It will also increase the burden for ship to ship support for experienced vessels encountering grounded vessels piloted by crews unfamiliar with arctic navigation challenges and risks.
- **Increased need for lighterage:** Increased reliance on lighterage services in order to efficiently unload cargo vessels in confined or shallow harbours due to more frequent high wind events.
- **Changes to scheduling:** New scheduling regimes for changing delivery patterns. Specifically, the increasing ice-free period has encouraged delivery companies serving the eastern arctic to serve more westerly communities.

- **Increased need for places of refuge:** Due to intensified storm events, an increased need for designated places of refuge for cargo vessels along shipping routes to coastal communities is anticipated.

8.5 Design and Weather-Related Vulnerability

Design and weather-related vulnerabilities relate to onset of unfavorable weather conditions such as high wind events, unpredictable ice conditions including unexpected migration of multi-year ice, and navigational constraints associated with confined and shallow waters near communities.

Unfavorable weather conditions: Sudden onset of unfavorable weather conditions such as high winds disrupt delivery and off-loading of critical supplies from cargo vessels. Wind-bound cargo vessels must wait out windy conditions and suspend cargo transfer until conditions moderate to allow for safe cargo transfer to resume. Increases in the frequency of weather conditions unfavorable to cargo deliveries could result in delays and backlog of necessary supply delivery.

It is expected that temporary delays in cargo transfer operations may be countered by a longer shipping season for arctic coastal resupply communities. For example, the shipping season was 63-69 days per year in the 1980's for Paulatuk, Sachs Harbour and Ulukhaktok, and has stretched to 82-84 days per year in the last decade.

Sachs Harbour has an adjacent coastline that is exposed, with entry to the bay where the community is located built into a sandbar with a very limiting draft of 2-3 m. Currently, a tanker would need a calm weather window of approximately 30 hours to safely transfer fuel requirements to Sachs Harbour. Prevailing wind and wave conditions for the area indicate that such calm weather windows may be infrequent (Reorganization of Pipeline Manifolds & Laydown Areas for Paulatuk, Sachs Harbour & Ulukhaktok, Sept 2011 GNWT).

Ulukhaktok differs from Paulatuk and Sachs Harbour, as it has deep water close inshore. However, King's Bay is very narrow at 300m width, and a tanker may not be able to safely swing or turn in the bay. Maneuvering into the bay astern would require calm weather and a guarantee of low wind conditions for the duration of the fuel transfer activity.

More intense, more extreme weather conditions: Support infrastructure related to arctic marine community resupply are vulnerable to wave action generated by high winds, erosion and flooding associated with intense rain and storm surge events, and loss of land fast ice that provided some protection against coastal erosion. With conditions of increased sea level rise, high winds will generate increased wave action against coastal shores which in turn leads to increased shoreline erosion. Coastal regions with underlying permafrost are especially vulnerable as ice beneath the shoreline thaws in contact with warmer air and water. Coastal erosion will pose increasing problems for port facilities, including land-side infrastructure such as fuel manifolds and related lines/tankage. Coastal erosion related damage is an added risk to pipeline, manifold and laydown areas for the communities of Paulatuk,

Sachs Harbour and Ulukhaktok, which are getting more difficult for vessels to access due to shallow waters.

Unpredictable ice conditions: As multi-year ice degrades, breaks up and migrates with currents, vessel captains are reporting more unforeseen ice conditions. The operators are reporting that the movement of this ice is less predictable and the multi-year ice is migrating into unexpected areas. The movement of this loose multi-year ice poses risks of damage to vessels and related equipment due to collision with this difficult to detect, high-strength ice.

The changing nature of ice in the arctic has other impacts on arctic coastal marine operations. Thinner, less extensive sea ice creates more open waters, resulting in stronger wave generation by winds, and consequently more wave-induced erosion. As shore ice becomes less prevalent and is no longer sufficient to provide shoreline armoring against wave action, full effects of erosion on coastal shorelines are expected to accelerate, resulting in potential for damage to facilities and infrastructure sited on unstable coastlines.

Poorly charted, shallow coastal waters: Cargo vessel maneuverability is constrained by poorly charted, shallow waters. Paulatuk, Sachs Harbour, and Tuktoyaktuk are all difficult to service with larger ocean vessels due to shallow bottoms. Shallow waters are considered a growing concern in the Northwest Passage as the lack of ice is opening up this shipping route to more recreational, tourism and industrial traffic. For example, in 2010, three vessel groundings occurred involving two fuel tankers and one cruise ship.

Charts for community harbor and approach lanes are poor for arctic coastal resupply locations, and the lack of charting combined with shallow water conditions makes vessel maneuverability and navigation a growing problem. Bathymetry is poorly charted at the community ports/landing areas and the presence of sand bars and processes of siltation create problems for efficient access to communities for vessels to unload cargo. Maintenance dredging has not taken place in these waters. Estimates to dredge a channel sufficient to allow cargo service via ocean vessels exceed \$100M for Tuktoyaktuk alone. Paulatuk, in particular possesses extreme shallow draft conditions at the entrance to Paulatuk Harbour, therefore DOT is evaluating a proposal to relocate the sealight anchorage from Paulatuk Harbour to the southwest embayment of Darnley Bay.

8.6 Summary Resiliency Statement

A summary evaluation of the Arctic marine and coastal resupply resiliency and adaptive capacity is provided in Table 8-1.

Table 8-1 Arctic Marine and Coastal Resupply Resilience and Adaptive Capacity Evaluation

Infrastructure	Climate Change Impact	Resiliency	Adaptive capacity
Vessel maneuverability	Shallow water	Low	Med
	More frequent storms	Low	Med
Vessel Integrity	Variable ice dynamics	Low	Med
Landside cargo infrastructure	Damage due to reduced landfast ice	Med	Med
Cargo Transfer	Winds	Low	High
NOTES: Definitions of the relative rating are: Resiliency <u>Low Resiliency:</u> Return of the asset to intended operability will take a prolonged period of time, resulting in significant duration of loss in service. A loss of an asset requiring complete reconstruction would be in this category. <u>Medium Resiliency:</u> Return of the asset to intended operability will require a medium-term delay, sufficient to complete modifications to restore the intended operability of the asset. An asset requiring retrofitting or modification would be in this category. <u>High Resiliency:</u> Return of the asset to intended operability will require a short-term delay. An asset requiring rapid maintenance or application of a specific O&M response to restore intended duty would be in this category. Adaptive Capacity <u>Low Adaptive Capacity:</u> Limited effective adaptation is possible for the asset. Reconstruction of the asset is likely for resumption of intended service. <u>Medium Adaptive Capacity:</u> Effective adaptations are possible for the asset. Adaptations would include modification or retrofitting of the asset. <u>High Adaptive Capacity:</u> Readily available and rapidly implementable adaptations are possible for the asset. Adaptations would include deployment of increased operations or maintenance measures.			

Arctic marine cargo service and coastal resupply efforts are susceptible to the temporary disruption caused by sudden onset of adverse weather events that can prevent safe transfer of cargo. Arctic marine resupply vessels operate in waters with challenging navigational constraints posed by poorly charted waters, and face increased risk of damage due to the changing nature of ice conditions as climate conditions change. Shoreline structures may be affected by reduced land fast ice and/or accelerated wind/wave erosion. At present the system provides resilience to climate related changes due to the presence of experienced operators, and proactive scheduling.

8.7 Implications for Operations and Maintenance

Implications for operations and maintenance efforts pertain primarily to regular inspection of coastal infrastructure for evidence of potential damage due to shoreline instability, erosion processes, permafrost degradation and settlements, and flooding associated with short-term, intense rain events. Costs related to inspection of these infrastructure assets will increase marginally. However, maintenance costs for additional servicing or repairs will be more substantial. Coastal erosion management costs will likely increase as conditions such as higher temperature and high winds degrade shorelines through mechanisms of permafrost degradation and thermal/mechanical erosion.

It is anticipated that winds and elevated sea levels will result in problematic storm surge inundation, and this has become an issue for communities such as Tuktoyaktuk, where storm surge has flooded port facilities and suspended their operation from time to time. Additional maintenance effort and cost associated with recovery from storm-surge induced flooding is expected.

8.8 Needs and Gaps to Adequately Respond

Due to the nature of arctic coastal resupply vulnerabilities, the needs to adequately respond to impacts to resupply operations consist of time and better data. Additional time will be required for completion of community resupply efforts as unfavorable weather conditions arise and suspend cargo transfer operations from ship to shore. Logistics for resupply will need to factor in the stronger likelihood of longer weather-induced delays. Efficiencies of time and enhanced safety can be gained through development and provision of accurate, up to date navigational charts for arctic coastal waters. Increased shipping traffic, potentially including vessel operators who are not experienced in navigating arctic waters, will further drive the need for accurate, up to date navigational charting for coastal NWT communities.

- **Critical need for charts and navigation aids:** There is a critical need for better navigational aids and charts for navigating and docking near coastal resupply communities. The presence of sandbars and siltation effects create a challenge for vessel operators who are not highly familiar with operating in these difficult waters.
- **Improved monitoring:** Improved monitoring data network for application in improved route planning to avoid unfavorable weather and other unexpected conditions.

9 ADAPTATION ACTIONS

This section defines the actions recommended for DOT to initiate as a formal program to address climate change. These actions have been developed from analysis and synthesis that includes:

- Literature reviewed including the 2010 climate change risk assessment of DOT highways and airports
- Marine and Ferry risk assessment workshop from January 2012
- Stakeholder engagement and expert input
- Compilation of risk assessments with review by DOT staff
- Impacts, responses, resiliency statements and needs identification in chapters 3 to 8 of this report.

Section 10 provides an implementation approach for these actions.

9.1 Data, Analysis, and Research

Defining the actions to address climate change immediately identifies a number of unknown issues including “What changes are to be expected?”, “Are issues we see related to climate change, or to other factors?”, and “What research and study is needed to understand infrastructure issues better?”.

This section identifies a number of data, analysis, and research opportunities DOT should embark upon. Results from these efforts will inform the implementation of measures defined for specific transportation sectors in the remainder of this chapter.

9.1.1 Meteorological Data

For Canadian northern and arctic regions, climate data and weather forecasting services are not of the same accuracy, resolution and reliability as similar services provided in southern Canadian regions. Monitoring stations are sparse. For example environment Canada reports for only 13 stations for the entire territory^{33,34}. For the MVWR there are only three meteorological stations (see Figure 9-1).

Other facilities and operations maintain their own meteorological stations, but this data may not be readily accessible, consistently collected, reliable and complete, and may not even be retained or archived.

From a climate change transportation planning and operations perspective meteorological data is required to:

³³ Data extract from <http://www.climate.weatheroffice.gc.ca/>

³⁴ While environment Canada reports thirteen stations, only six meet the World Meteorological Organization (WMO) standards.

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- Improve the quality of near term forecasts
- Provide an historical record that can be used to assess seasonal conditions and variability and to identify longer-term trends.

In order to meet this need and obtain a better understanding of the climate-induced changes within the NWT, an expanded and integrated network of environmental and climate observations is required.



Figure 9-1 Environment Canada Reporting Weather Stations in the NWT

Core data requirements for any installation would include:

- Air and surface temperature readings
- Precipitation
- Winds (speed and direction)
- Snow
- Rain on snow events

Quality data may require facilities that meet the World Meteorological Organization (WMO) standards. At present only six sites in the NWT meet this standard. Important parameters to be measured would include:

- Air temperatures
- Precipitation
- Winds (speed, gusts, direction, duration)
- Snow
- Sea-ice thickness and extent
- Height of waves
- Coastal erosion rates
- Storm surge and rising sea levels for coastal areas
- Storm activity (affects inland and coastal areas)
- Water levels on lakes, rivers and streams
- Air Thawing Index (ATI – for design engineering, often calculated on basis of average ATI for warmest three summers in latest 30 years of record)
- Extreme weather events
- Flooding events
- Freezing Precipitation

Finally, a number of transport-specific parameters may also be useful to capture. Specifically for extreme events and analysis, understanding key event parameters would be important. As well, some transport modes (e.g. aviation) require more precise and detailed information. Parameters to consider include:

- Hail events (hail with diameters exceeding 2 cm)
- Severe precipitation events related to transport-mode safety thresholds:
 - Precipitation > 150mm over a 24 hour period
 - Precipitation > 100mm over a 48 hour period
 - Precipitation > 90mm over a 12 hour period
 - Precipitation > 60mm over a 6 hour period
 - Precipitation > 30mm over a 1 hour period

- Wind gusts (direction and duration)
 - Wind gusts > 15m/s
 - Wind gusts > 20m/s
 - Wind gusts > 15m/s
- Snow accumulations
 - >10 cm over a 24 hour period
 - >20 cm over a 24 hour period
- Visibility limited by onset of fog
 - Visibility limited to <1000m for a period greater than 6 hours
 - Visibility limited between 500-1000m for a period greater than 6 hours
 - Visibility below 500m

The availability of regional datasets of climate data projected from global climate models is an issue for many regions in Canada. The existing monitoring networks are not sufficiently robust to meet current needs, and in fact many of these are degrading due to withdrawal of government-funded resources allocated to monitoring networks. To engineers and scientists involved in adaptation planning and impact assessment, the loss of these networks is of concern as the need for better understanding of climate parameters to plan for and respond to future climate extremes is significant and growing. Government funding will always be restrictive, and so alternate funding arrangements may be required including industrial partnerships or support funding from transportation users.

9.1.2 Analysis and Interpretation Requirements

DOT personnel have responded to climate change to date without much of the climate data required to conduct detailed trend analyses for application in engineering risk assessment of their infrastructure. Many anecdotal reports have been compiled in various locations within DOT, of incidents and evolving issues. These are largely held within staff knowledge, or documented in regional files and activity reports. Much of this information could be more valuable if the anecdotes could be used to direct data analysis to determine the magnitude of the anecdotally described trends. This report captures some of this information and recommends a single, accessible documentation system for all such information.

Atmospheric drivers and operational issues are obviously connected, though the relationships have rarely been defined and assessed in detail over DOT system. In 2010, some work was done in identifying climate conditions that lead to operational impairments, however frequencies for these conditions were not determined. For many of the reported changes (e.g. more fog on airstrips, ice road failure, etc.) there has not been an analysis of the trends and frequency of these events, and the weather/climate conditions. Trend analysis and event frequency data are seen as an important data needs to pursue.

Effective and detailed central collection of data and observations are essential for informed risk management of impacts to DOT infrastructure. Analysis of this data could allow for:

- Determination of trends in system reliability, O&M costs, capital requirements
- Assessment of threshold conditions that would define a change in conditions.
- Data support to increased funding requests by documenting trends in maintenance and infrastructure failure.

9.1.3 Research Needs

DOT has and is participating in a number of initiatives to address infrastructure needs, research gaps, and information sharing opportunities. These include:

- **National Forums:** DOT is working with other federal/provincial/territorial departments to develop Canada-wide strategies for climate change adaptation and is a member of two national forums: (i) Climate Change Task Force – Transportation Association of Canada, and (ii) Northern Transportation Infrastructure in the Presence of Climate Change Subcommittee – Council of Ministers Responsible for Transportation and Highway Safety
- **Networks of Expertise:** Transport Canada (TC) is funding two networks, one on permafrost and the other on Arctic waters, to foster northern expertise and conduct research necessary to provide Canada and the NWT with the capacity to manage transportation infrastructure in the context of a changing climate.
- **Network of Expertise in Northern Transportation Infrastructure Research (NoENTIR):** The Network is a forum for collaboration and mutual understanding between the research community and northern-based practitioners, drawing on nationally-recognized representatives with expertise in permafrost science and engineering, and practitioners responsible for northern transportation systems. The NoENTIR will focus its activities around two main functions:
 - (1) Fundamental and applied research: Focused on developing practical solutions for the management of existing infrastructure (e.g. maintenance strategies, rehabilitation measures, techniques for location, design and construction of new transportation infrastructure.); and
 - (2) Outreach and education: Supporting annual workshops to showcase the progress of research projects and encouraging and supporting student participation including field excursions to engage Network members and discussed with local practitioners.

- **Network of Expertise on Transportation in Arctic Waters (NEXTAW):** NEXTAW is an active forum for inter-disciplinary collaboration and enhancement of working partnerships between the research community and Northern-based practitioners. The NEXTAW's primary roles and focus will be on finding improvements and adaptive approaches to existing and potential future Northern marine transportation infrastructure and operations. The emphasis will be on developing national and regional expertise and to facilitate communication and cooperation between industry, local users, researchers, practitioners, operators and service providers relating to marine transportation in the North.

DOT also engages in its own strategic planning activities and funding proposals. These recognize climate change and have incorporated adaptation into their frameworks. These include:

- Corridors for Canada II: Building on Our Success – a DOT funding proposal to the federal government for investment in transportation infrastructure – focused on road improvements to all season roads and improvements to winter road construction;
- Connecting Canada Coast to Coast to Coast – DOT proposal to the federal government for the construction an all-weather highway through the Mackenzie Valley to the Arctic Coast from Wrigley to Tuktoyaktuk;
- Northern Connections: A Multi-Modal Transportation Blueprint for the North – a pan-territorial perspective on the transportation need of Northern Canada;
- On Track; and
- Annual departmental strategic and business plans.

DOT is an active participant in the development of standards and guidance documents including:

- Through the Transportation Association of Canada (TAC) the Department collaborated on a Best Practices Guide for the construction, maintenance and operation of winter roads. The guide includes a chapter on climate change.
- DOT has collaborated with TAC on a Best Practices Guide for the construction of transportation infrastructure on permafrost (see Appendix E for a summary). The guide includes a chapter on climate change.

A number of specific data collection, analysis, and research needs are defined in Table 9-. These have been identified through a range of sources including: needs identified in assessing risks to transportation networks in the context of climate change impacts, proposals for current funding programs, items deemed valuable for asset management, and items identified by staff as useful for planning and operations activities.

Sidebar 8 One Road, Many expectations: Defining levels of service for road users

“In the old days people were prepared when they travelled on the winter road. They drove a big truck and carried chains, tow ropes, jack-alls, jumper cables, shovels, spare tires, lots of spare fuel and emergency clothing and supplies. And they expected the road to be rough and that they’d have to drive slow, maybe even take the ditch if a big truck came on a narrow stretch. Now you see them in little cars wearing a light jacket and running shoes, maybe with one of those fake little spare tires at best.”

In the past winter roads were put in by those who needed the road for a specific purpose and only kept open as long as required for that purpose. In some cases the road would be put in to re-supply isolated communities with fuel for power generation and heating or to bring in building supplies and other large quantities of bulky and/or heavy materials. On other winter routes, a private operator such as a mine or exploration company might have built the road.

The roads constructed each year by DOT have become part of the NWT Transportation system. Expectations by users of NWT roads are increasing, whether it be by individuals or corporations, and meeting these comes with a significant cost. The Tlicho winter road, connecting the communities of Whati and Gameti to the permanent road system, has evolved from a rough, narrow trail adequate to allow heavy trucks and tankers to bring in loads, into a modern winter road travelled frequently by pickup trucks, cars and other motorized vehicles. The connection to Wekweeti has evolved from a sporadic road constructed by users in years when it was needed to a road built annually for re-supply. As it gets more regular use, public expectations are rising to improve the quality of the road and the length of time it is open.

The public expect a smooth road cleared of any snowfall and open for as long as possible. Exploration and mining companies generally need the road to be open long enough to bring in a year’s supplies and exploration equipment, complete the winter’s exploration, and remove the equipment before the road closes. To meet this expected level of service requires more flooding, and more maintenance and plowing over a longer period.

Meeting all these needs may not be affordable in the future under current budgets. DOT will need to engage the users and stakeholders to define each road’s purpose and objectives. Issues that might be defined are the service level and capacity, minimum operational period and load transport, and innovative funding models for road users that require additional service. Engaging communities and stakeholders now will help to manage expectations and plan for the future.

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Table 9-1 Research and Data Collection Actions

Activity Type	Action Number	Description	Example Projects or Potential Areas of Study
Data Capture	Action - 1: Highways' Condition and Incidents	• More formalized infrastructure assessment records are needed to ascertain areas of infrastructure vulnerability. This information is currently captured within staff expertise, or in regional office files, or maybe held only temporarily and not retained. Current practices are serving the needs of operations staff, but it is likely that trends and other insights that could be gained from a longer-term analysis are being lost. • Into the future, requests for more operational resources will need to be supported by data. As importantly, the compilation of data will help to identify the types of events that might be climate change related from those that have other causes. • Data and incident tracking systems are challenging in that they are an additional burden to operations staff. When busy, staff naturally focus on maintaining system function first, and tracking is often limited to the minimum requirements. • There is the potential that new technologies (e.g. GPS trackers, automatic systems etc.) could be deployed.	• A careful review of data needs and appropriate methodology to track would be required. As a start, the data that should be tracked would relate to: • Locations and incidents of overflowing (e.g. this was noted as a chronic problem on the MV winter road); • Winter road close out meeting reports;³⁵ • Road closures • Ferry service interruptions • Highway and runway maintenance activities • For permafrost areas: major depressions/shoulder cracking/road subsidence

³⁵ Operations staff conduct a winter road season-ending review meeting. DOT planning staff would benefit from greater participation and receipt of documentation and notes.

Table 9-1 Research and Data Collection Actions (cont’d)

Activity Type	Action Number	Description	Example Projects or Potential Areas of Study
Data Capture (cont’d)		It is acknowledged that this type of data capture is challenging and it is suggested that any system developed be simple, and well aligned to whatever current scheduling / work order systems are in place. Ideally this information would be compiled into a GIS format that could identify problem sites and areas, trends and a rudimentary predictive ability both for locations and costs of future actions.	
	Action - 2: Planning and data collection (culverts)	- Updating of infrastructure inventories and condition assessments will help to identify problematic areas. As an example culvert inspection frequency has been increased on the Dempster Hwy. More robust inspection practices are needed throughout the system. - A formalized asset management system should be developed. These can range in robustness but could be database archive systems, or could include GIS – based data capture. Use of GIS systems would allow other features (drainage, hydrology, or climate factors to be included).	Incident and condition assessments are currently done informally with record systems within each regional office.

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Table 9-1 Research and Data Collection Actions (cont'd)

Activity Type	Action Number	Description	Example Projects or Potential Areas of Study
Analysis	Action - 3: : Climate Change Predictions Review	- Modeling and prediction of the future climate are frequently updated by new knowledge and analysis. DOT must stay current with these predictions. This action proposes to conduct a periodic (e.g. every 3 – 5 years) comprehensive review of the most recent climate predictions of temperature and other climate variables for NWT communities. - The outcome would be to define a set of climate variables for NWT communities looking forward in the short and long term. The benefit of this activity is that it creates a set of “working numbers” (or climate design variables) that DOT can use in its planning. This can avoid effort spent to develop new climate variables for each activity or project, allow for better comparisons of transport options (by using the same forecasts), and enable DOT effort to be spent on defining the needs and actions for the future.	This is the mandate of other agencies – already Environment Canada is taking this role with the Canadian Climate Change Scenarios Network (CCCSN http://www.cccsn.ec.gc.ca).
	Action - 4: Winter road service level review.	Winter roads were initially developed to provide basic community re-supply (diesel generator fuel, bulk supplies, etc.). Over time the use has increased, and by a greater number of stakeholders. Public expectation has become a driver for increased length of season and quality of road surface. A service review would define the key objectives and purpose of each winter road segment.	- Questions to be posed might include: - What are the purposes of the winter road? - What are the desired operational windows? - Where does road funding come from? - What are the community expectations of the road? - Is usage expected to increase or not? - Are there safety issues? - Is a winter road the best way to deliver the services? - What are the different expectations for different roads?

Table 9-1 Research and Data Collection Actions (cont’d)

Activity Type	Action Number	Description	Example Projects or Potential Areas of Study
Analysis (cont’d)	Action - 5: Data analysis and Correlation Review	- There are vast datasets of atmospheric and operational data that may be correlated to operational parameters. (A compelling example has been the opening and closing dates of the Ft Providence ferry over time that provides insight into both the trend of climate change and the increased variability of the transport system in response.) - As an example, the short JV winter road season in 2006 was a warm winter, but not radically different from some other years which had a full re-supply season. Exploration of some of these correlations could yield insight into trends or threshold levels for some parameters.	- Winter road operational parameters correlation to weather variables. - Ice breakup correlations to weather variables.
	Action - 6: Review and Update Climatic Design Criteria	- Design criteria for new road construction should include an allowance, for enhanced robustness in design to account for climate change. - Specifically, designs for rainfall and drainage culvert sizing etc. may be erroneous if they use historical climate normals as these may not represent future conditions. Design storms will need to be reviewed to determine whether they are suitable for future predictions. The desire is to accommodate potential changes in performance drivers (temperature, rainfall etc.). - A key feature would be to link the design consideration directly to specific climate variables to ensure the most appropriate action is taken.	Guidelines to adapt road design to specific terrain conditions which include geomorphology, eco-climatic variables (vegetation, air temperature, precipitation, drainage) and type of permafrost (sporadic, discontinuous, continuous; ice-rich/poor).

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Table 9-1 Research and Data Collection Actions (cont'd)

Activity Type	Action Number	Description	Example Projects or Potential Areas of Study
Research	Action - 7: Culvert and drainage system designs	Culverts pose a unique challenge to roadbeds located on permafrost soils. They can be conduits for heat transfer (both into and out of the embankment) and can allow for water (and associated heat) to drain into the embankment. Many road issues have been noted with failing culverts, though it is not always clear if these are due to climate change, or simply the age of the culverts.	- Understanding thermal regimes around highway culverts (proposed by researchers, supported by DOT) - Understanding of changing freeze-thaw cycles on culvert lifespan (noted at the DOT staff workshop Oct 2010) - Understanding the impact of permafrost degradation and associated subsidence on culvert performance/lifetime
	Action - 8: Climate change Impact on Permafrost and Road Systems	- A number of issues require further investigation to understand the extent of permafrost changes from climate change. While not a research agency, DOT can assist and support research by other agencies and academic researchers to create better knowledge of permafrost dynamics. Specific areas where better understanding is required include: - What will be the range of permafrost zones (continuous, discontinuous, sporadic) changes as the climate becomes warmer? - How, if any, recent climate change (since 70s) in the western Arctic has affected permafrost zones? - Will ice wedges become inactive (stop cracking or crack very rarely) in tundra areas of NWT? What is the time frame for this? - If rain precipitation becomes more common, will it be a heat source and will it affect the thermal regime of the permafrost in the various zones?	- Establishment of baseline data collection sites and assessment of permafrost response to climate warming for transportation infrastructure in the Yukon and NWT (has been proposed). - Vulnerability and mitigation of the Dempster Highway to the impacts of climate change. Scoping level analysis and data sufficiency review for a PIEVC vulnerability assessment (funding proposal under development with Yukon). - Impact of snow on embankments (also identified as a study area for airport aprons). - Impact of groundwater flow on thermal regime of permafrost and road embankments. - Typical active layer depth, hence potential ground ice location below and along highway.

Table 9-1 Research and Data Collection Actions (cont'd)

Activity Type	Action Number	Description	Example Projects or Potential Areas of Study
Research (cont'd)	Action - 9: Application of Remote sensing techniques in northern transportation	- A range of remote sensing technologies could be applied to improve the transportation system. As an example, the Canadian Ice Service uses satellite data to provide frequent ice reports. Aircraft-borne LIDAR, satellite, and other technologies could be deployed. - Specific areas where remote sensing has been considered to be applied include: - Route planning and design (e.g. ITH) - River Ice breakup forecasting - Landform change - Road condition monitoring	- Evaluation of radar interferometry to monitor surface and road subsidence and heave. - Air-borne lidar to develop precise DEM for snow, hydrological and hydrogeological modeling. - Air-borne thermal imagery at given, critical periods to evaluate the near surface thermal state of roads. - Historical, multi-year landsat image (free) interpretation to identify changing conditions (river changes, permafrost changes, snow condition changes etc.). - Thermal state of the permafrost along and under highways using airborne electrical resistivity (done recently on the Alaskan side of the Alaska Highway) - Thermal state of the permafrost using GPR/electrical resistivity for recurrent problematic areas in order to diagnose the extent of the problem

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Table 9-1 Research and Data Collection Actions (cont'd)

Activity Type	Action Number	Description	Example Projects or Potential Areas of Study
Research (cont'd)	Action - 10: Winter Roads Viability Research	A fundamental unknown that remains is: “When is a winter road no longer viable? This activity would develop a better understanding of the future prospects for the winter roads. Activities would include: • A winter road “resiliency” workshop with experts to identify the key research questions. • Data analysis to better understand if thresholds or correlations exist for specific roads between operational parameters and meteorological parameters. (e.g. 2006 when the JV road failed, was a warm winter – but not by very much. What caused that year to be a problem when other similar years were not? Then in 2007, a record number of truckloads were delivered) • Meteorological data analysis of relevant stations (examples include Ft Simpson and Ft Nelson (BC) where different climatic changes appear to be occurring) • The overall approach to the winter roads may need review. What are the acceptable service levels and users’ needs. • Are there climate parameters that can define the successful length of the winter road season. In particular, are there thresholds that make the operation of a winter road non-viable?	• DOT seeking resources for the winter road resiliency workshop

Table 9-1 Research and Data Collection Actions (cont'd)

Activity Type	Action Number	Description	Example Projects or Potential Areas of Study
Research (cont'd)	Action - 11: Mackenzie River Dynamics	The impact of more frequent dynamic break-ups is still not well understood. Facilities at river communities could be impacted by unusual or extreme ice dynamics.	- River ice center at the University of Alberta has done work assessing the Mackenzie system. - Ice forecasting systems would enable DOT ice bridge and ferry systems to be operated more effectively.
	Action - 12: Road Monitoring Programs	- All new roads constructed should include monitoring of specific road sections, construction techniques sections, and sub-surface conditions. Typically this is accomplished through test sections. - The ITH provides an opportunity to pilot test and evaluate a number of new construction and design techniques. New construction practices should be implemented with the objective in mind to include a capability for monitoring and evaluation of the feature. Possible techniques might include improved road and embankment design or new drainage and culvert design (e.g. arch culverts). - Rehabilitation sections also allow for test sections of different technologies.	- The route from Tuktoyaktuk to the Source 177 gravel location is a new road – and will eventually be part of the ITH. At present there are proposals to develop a monitoring initiative for this section of road. The benefits of establishing a monitoring program include: - Providing fresh evaluation of how a new road will perform; - Informing the design of the ITH; and - Providing feedback to DOT about what is a reasonable level of data capture that can be expected - Yellowknife Highway #3 Construction Test Sections (a program proposal has been assembled)
	Action - 13: Pilot Testing of construction technologies	More than simply monitoring conditions, pilot testing can allow for the evaluation of different techniques for construction and stabilization (e.g. similar to Beaver Creek test section in Yukon). All sections must comprise a reference section that is similar to the general design adopted for segments of the road.	

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Table 9-1 Research and Data Collection Actions (cont'd)

Activity Type	Action Number	Description	Example Projects or Potential Areas of Study
Research (cont'd)	Action - 14: Groundwater and surface water Heat Flows	The heat flows carried by ground water and surface water may be important for understanding permafrost degradation. As precipitation and runoff may increase, these could become important factors affecting permafrost integrity.	- Evaluate the impact of groundwater flow on the thermal regime of subgrade: how and where is heat being carried by groundwater in the natural permafrost (active layer) setting and around the road embankment. This is required prior to any work to drain wet terrain conditions. - Evaluate the impact of water ponding on the freeze-back of the active layer. - Evaluate the impact of sub-permafrost talik
	Action - 15: De-icing fluid impacts	Runway urea and plane deicing fluids could have an effect on permafrost as they infiltrate into the ground.	Understand the thermal impact of de-icing fluid infiltration into runway embankment and subgrade.

9.2 All-Weather Roads and Related Infrastructure

Five major climate change impact areas were identified for all weather roads (see Table 9-2). These highlight an exacerbation of the trends of recent years. In the future it is expected that there will be more issues with drainage, culvert and roadbed failure, and demands on staff time and resources.

Table 9-2 All Weather Roads Climate Change Risk Areas

Risk Area	Description
R- 1: Drainage Issues	Drainage issues can undermine roads. Current examples include fine grain soils which hold water, summer rainfall washouts, and delays in road openings due to wet roadbed conditions. In permafrost areas, wet conditions delay freeze-back of subgrade, and groundwater flow can act as a heat source (advection) during the spring-summer early fall.
R- 2: Culvert collapse, road slumping due to changing permafrost conditions	Degradation of permafrost results in slumping and settlement of road surfaces.
R- 3: Changing demands on staff, equipment, and costs	Changing conditions are changing the demands on DOT staff and equipment for operational activities. Examples include longer operational hours, more material requirements (sand, etc.).
R- 4: Changing window for construction and maintenance of roads	Changing climate factors will cause a change in the regular construction and maintenance windows of roads. Issues that might present themselves include delays to initiate winter road construction, wet conditions preventing maintenance on some all-weather roads (e.g. Liard Highway).
R- 5: Degradation of Embankments and Road Structures	Permafrost thaw results in slumping, subsidence and degradation of road embankments.
R-6 Travel delays	Extreme events can cause disruption to road travel. This category refers to events that are not directly damaging to infrastructure, but could result in a temporary impact to the transportation network. Direct weather-related events would include intense storms or freezing rain. Events that might be climate-induced – which may change in frequency or intensity with climate change – include forest fire closures of road segments.

Actions identified to address these impact areas (see Table 9-3 and the descriptive legend to the attributes below the table).

These actions are all led by DOT as the responsible agent for roads in the NWT

Most of these actions are short term actions to maintain the functionality of the road network. This reflects the degree of uncertainty over climate change impacts and responses. As such these actions are closely related to many of the data, analysis, and research actions defined above. That is, these actions are the starting point, and the results will be informing decisions made in the medium term (e.g. from 5 years outward).

Table 9-3 All Weather Roads Actions

Impact Area	Risk Rating	Action	Description	Type of Action for DOT	Locations / areas	Time Frame	Lead Agent	Partners	Operational Cost Impact (to DOT)	Capital Cost Impact (to DOT)
R- 1: Drainage Issues	Medium	Action - 16: Increased Maintenance	- Increased maintenance will address some of the impacts. Examples would include more frequent road grading, increased surveillance of infrastructure. - DOT does this already.	Operations	All	1 - 5	DOT Highways	--	M, H	n/a
		Action - 17: New technologies.	Repairs and replacements should consider new practices and road bed technologies. DOT has started this with a number of research initiatives	Operations	All	1 - 5	DOT Highways	--	M	L, M
R- 2: Culvert collapse, road slumping due to changing permafrost conditions	Medium	Action - 18: Culvert Replacement	Culvert replacement upon failure (or near failure) is a status quo practice. In the short term it maintains the roads operational. In the long term, the increasing demands to replace failing culverts due to age (and exacerbated by climate change via embankment subsidence/strain) will become an increasing burden.	Capital	All	1 - 5	DOT Highways	-	L	S
		Action - 19: Updated Facility Condition assessments	Regular or ongoing facility condition assessments will identify long term infrastructure requirements	Operations	All	1 - 5	DOT Highways	-	M	n/a
		Action - 20: DOT practices review and documentation	Some informal activities might need more formal procedures guidelines. An example cited is that some gravel pits have resulted in degrading surrounding lands. DOT might need to establish some guidelines to operate and decommission these sources after use	Planning, Operations	All	1 - 5	DOT Highways Corporate	-	L	n/a
		Action - 21: Roadbed Stabilization Program for Highway 7 (Liard)	- The Liard is built on fine grained soils which have poor strength – particularly under wet conditions. The route can be closed for 1-2 weeks during breakup. A complete reconstruction estimate is in the range of ~200 million dollars. Funds of this magnitude will be a challenge to secure. However, the need for action is pressing. Spring closings of 1 – 2 weeks have occurred in recent years. - This action proposes that DOT develop an incremental rehabilitation program – focusing on the most problematic sections. This requires some engineering analysis of studies, followed by (likely) a multi-year implementation capital program.	Planning	Liard	1 – 5 Studies 5 – 20 (Implementation)	DOT Highways	TC Private operators	M (Studies) H (Implementation)	L (studies) H (Implementation)

Table 9-3 All Weather Roads Actions (cont'd)

Impact Area	Risk Rating	Action	Description	Type of Action for DOT	Locations / areas	Time Frame	Lead Agent	Partners	Operational Cost Impact (to DOT)	Capital Cost Impact (to DOT)
R- 2: Culvert collapse, road slumping due to changing permafrost conditions (cont'd)		Action - 22: Road surface rehabilitation Program for Highway 3	- Highway 3 Behchoko to Yellowknife was rebuilt in the last decade and is showing accelerated degradation in permafrost sections. The permafrost is discontinuous, and the roadbed itself traverses permafrost and bedrock areas. - Studies should include an alternative routing assessment to deviate the road towards bedrock or thin sediment cover where possible. The road might become longer due to this but maintenance cost, service life and road stability/safety could be dramatically improved. This can be cost-effective in the long-term if we take into account the scenarios of warming. - Implementation: A multi-year funding and rehabilitation program.	Planning	Hwy 3	1 – 5 Studies 5 – 20 (Implementation)	DOT Highways	TC Private operators	M (Studies) H (Implementation)	L (studies) H (Implementation)
		Action - 23: Dempster Monitoring and Planning Initiative	- Dempster Highway sections are deteriorating and reports of culvert failure are reported to be increasing. - Also reported are sections that could be vulnerable to river erosion in the coming years if slumping occurs. The highway does not seem to be impacted by this yet, but this could be a long-term impact area. - There is also concern voiced that conditions on the Peel plateau section may be deteriorating and that some stabilization initiatives will be required.	Planning	Dempster	1 – 5 Studies	DOT Highways	TC Private operators YT?	M (Studies)	L (studies)
R- 3: Changing demands on staff, equipment, and costs	Medium	Action - 24: Define Service baselines	Establishing service level baselines or minimum needs can help to define and communicate acceptable condition to users.	Operations	All	1 - 5	DOT Highways	-	M	-
		Action - 25: Increase equipment capabilities and utilization	- Meeting increasing servicing effort may require additional machinery. Future needs and operational windows might require an expansion of DOT (or contracted) equipment fleets. - More operational hours requires more resources for staff, consumables, and equipment replacement. However, it is a highly responsive activity that can allow for the extension of current services, while other longer term decisions are made. - Operations groups do this naturally as part of their jobs. However, planning and management groups may not have full appreciation of the effort undertaken or the nature of the changing demands.	Operations	All	1 - 5	DOT Highways	-	M, H	-
		Action - 26: Increase budget for consumables	Increased spending on consumables and materials can provide a swift response to changing conditions. Activities might include increasing sanding material purchases/production, increasing storage locations.	Operations	All	1 - 5	DOT Highways	-	M	n/a

Table 9-3 All Weather Roads Actions (cont'd)

Impact Area	Risk Rating	Action	Description	Type of Action for DOT	Locations / areas	Time Frame	Lead Agent	Partners	Operational Cost Impact (to DOT)	Capital Cost Impact (to DOT)
R- 4: Changing window for construction and maintenance of roads	Medium	Action - 27: Equipment and staff scheduling for road work	- Planning should be considered for longer work windows. In order to keep up with maintenance DOT had identified certain times of year where the equipment was being used 24 hours/day, and that as maintenance increases they will likely need to move to doing maintenance at any time of the year. - Construction and excavation of roads should be considered for the winter to maximize heat loss. (e.g. Alaska DOT has done this).	Operations	All	1 - 5	DOT Highways	-	M	-
R- 5: Degradation of Embankments and Road Structures	Medium	Action - 28: Snow clearing and management for vulnerable permafrost areas	- A component of permafrost preservation is the ability of the ground to sufficiently cool through the winter. Snow acts as an insulator and evidence indicates that early season snow accumulation can delay ground cooling, and late season snowfall can preserve cooler ground against warming. Possibilities include: - snow clearing from the road shoulders in the early winter to preserve permafrost quality, and - compaction of snow on shoulders to remove insulation value. - These actions might require specialized adaptations to machinery or changes in road plowing practices. Test programs should be initiated in selected areas to define the impact and benefit of this strategy. (For example In Russia, trains in Siberia are equipped with extended arms with blade that allow for the removal of snow from the side slope of the embankment).	Operations Planning	TBD	1 - 5	DOT Highways	-	H	-
		Action - 29: Road Restrictions	- Road closures have already been incurred (e.g. two week closures of the Liard Hwy have occurred due to soft conditions during breakup). These can be complete or selective to certain weight classes of vehicles. - Continuation – or expansion – of these closures, is a short term measure that can preserve some of the road bed quality, traded off against inconvenience to users. - In the long term this is not a suitable strategy as DOT is committed to a reliable network, and users expect year round operations.	Operations Planning	Liard	1 - 5	DOT Highways	-	L	-

Table 9-3 All Weather Roads Actions (cont’d)

Impact Area	Risk Rating	Action	Description	Type of Action for DOT	Locations / areas	Time Frame	Lead Agent	Partners	Operational Cost Impact (to DOT)	Capital Cost Impact (to DOT)
R- 5: Degradation of Embankments and Road Structures (cont’d)	Medium	Action - 30: Monitoring and reporting	- Monitoring/Reporting of: - Site stability - Re-vegetation - Erosion				DOT Corporate Highways	-	M	L
		Action - 31: Innovative financing	- Evaluate funding model and consider changes. Currently there are a range of models including: (i) DOT builds road, (ii) DOT builds but specific users make a contribution (e.g. oil exploration companies) and (iii) users build their own road (e.g. the JVR) - NEW example in the Liard: Prairie Creek mine (in Mackenzie Mtns. to west) will build winter access off Hwy 7. Other options include requesting that road users pay to support maintenance.		Liard	1 - 5	DOT Corporate Highways	-	M	L
		Action - 32: Review road construction and design criteria	- Design embankment and ditches to accommodate fine grain soils as construction material - Import material instead of using local silt - Employ snow modeling (precipitation and drifting) using near-surface wind models in interaction with embankment geometry to identify potential problematic snow accumulation along new roads (e.g. ITH)		Liard ITH	1 - 5	DOT Highways	-	L	M
		Action - 33: Evaluate new construction practices	Need for different structures in future (example geotextile reinforced soil – GRS).			5 - 20	DOT Highways	TAC, JV AK,YT,NU	L	M
R-6 Travel delays		Action - 34: Reporting and Public information	Public notifications systems could be reviewed to identify new methods of reaching system users. Particularly advances in smart phone technology might be deployed for information distribution.	Operations	All	1-5	DOT Corporate Highways	-	M	-

Legend to Table 9-3, Table 9-5, Table 9-7, Table 9-9, Table 9-11, and Table 9-13

Column	Description
Impact Area	Risk Element Identified
Risk Rating	Risk Rating: An evaluation of the risk as determined by the compiled information from the October 2010 workshop, the Ferries and Marine workshop (Feb 2012 workshop) or one of the studies conducted. The rating is a traditional risk = (probability of occurrence) * (severity of impact). Each are scored on a 1-5 scale.
Action(s)	Action number and title
Description	Description of the Action
Type of Action	The action can be one or more of (i) a capital project, (ii) and operations action, (iii) a planning department action, or (iv) a research project (which may include other stakeholders or partners - e.g. universities etc.).
Locations	Specific geographic locations where this action is relevant
Time Horizon for Actions	Time span for <u>initiation</u> of this action (years from plan adoption). These are based on the short (1-5), medium (5 – 20), and long (20 – 40) year time frames defined for the plan outlook. These groupings are not intended to indicate that an action cannot be initiated sooner, but rather to indicate when it is most likely to be needed. Future conditions and evaluations may result in the initiation of an action being accelerated or deferred.
Lead Agent	The Agency most suitable to implement this action.
Partners	Agencies, stakeholders and participants that will support the implementation of this action.
Relative Cost: Operational	The relative magnitude of the cost of the action on operations budgets. While there are many unknowns in costs, there are some indications about the nature or type of activity. The costs here are for the implementing agency – and do not represent societal or cost benefit analysis. The assessment system used here is: L LIMITED: Occasional extra costs due to an incident, or small event occurrence. Possibly some staff overtime or other additional staff costs. M MODEST: Frequent or regular extra effort requiring increases in either budget or staff time. H HIGH: Sustained and continued increase in time or budget expenditures beyond normal year to year fluctuations
Relative Cost: Capital	The relative magnitude of the capital cost of the action. Increasing capital costs actions will typically take longer to implement, and may require a number of funding partners. The assessment system used here is: L Small Capital: Small capital requirements that can be captured by prioritization of annual capital spending within the department. At present a definition of <i>small capital</i> for projects under 400 k\$ is used within the GNWT. Capital allocated as small capital is prioritized at the departmental level and can be allocated to projects based on the departmental priorities. Examples of small capital might include: replacing an aging culvert at a stream crossing, contracting a desk study (e.g. using the airport protocol review), or a field monitoring study. M Medium Capital: Capital projects not fundable by small capital. In the GNWT, medium capital projects are in the range from 400 k\$ to 50 million\$ and are allocated at the governmental level rather than by the department. Examples might include : the installation of a permanent bridge crossing (e.g. the MVH), the purchase of a new ferry, the reconstruction of a pier/wharf, or excavation and rebuild of a problematic highway or airstrip section. H High: Projects that require large capital expenditure, potentially many years of planning, and almost always require funding from other levels of government. In the GNWT this magnitude of project is referred to as “partnership capital” and is for projects in the range of 50 million\$ and up.

9.3 Winter roads and Ice Crossings

Three major impact areas were identified for winter roads (see Table 9-4). These highlight an exacerbation of the trends of recent years. In the future it is expected that there will be more issues with winter road viability. Concerns over the long term viability of the winter road network under conditions of climate change, and increasing user demands have been raised.

Table 9-4 Winter Roads and Ice Crossing Climate Change Risk Areas

Risk Area	Description
WR- 1: Changes to Winter Road Season and Operations	Changing conditions are affecting the construction, and operational duration of the winter roads. Observed environmental factors have included delayed freezing of water crossings, new challenges with winter road construction, and a shorter operational season.
WR- 2: Problems with ice crossings (winter roads)	Winter roads experience difficulties with ice crossings of water courses (streams, rivers, and lakes). Issues noted to date include crossings being less stable and less predictable in terms of development (e.g. lakes and streams freezing later, or unpredictably); areas of ice crossings that have been moved to land.
WR- 3: Road Integrity and Quality	Winter road integrity and track quality can be damaged by transit during warm conditions (soft road bed, lack of snow cover). This has been identified on exposed and sunnier areas – particularly in the later winter.

Actions identified to address these impact areas (see Table 9-5 and descriptive legend to the attributes below Table 9-3).

Table 9-5 Winter Roads and Ice Crossing Actions

Impact Area	Risk Rating	Action	Description	Type of Action for DOT	Locations / areas	Time Frame	Lead Agent	Partners	Operational Cost Impact (to DOT)	Capital Cost Impact (to DOT)
R- 1: Changes to Winter Road Season and Operations	High	Action - 35: New operations strategies	- New operations strategies are being employed and will need to be expanded as conditions change. Strategies deployed that may require broader implementation include: - Pre-emptive snow removal: Removal of snow from water crossings as early as possible to enhance ice thickness formation. Requires lighter equipment, and sometimes floating equipment in order to ensure operator safety. - Advanced ice profiling equipment: Ground penetrating radar (becoming routine) allows for more sophisticated condition assessment. - Snow caches: Established at troublesome land crossing areas to allow for swift rebuild of overland sections. Suggestions have included hauling of snow along the route. (NB: Care would be required so that large snow accumulation wouldn't in turn affect the thermal regime of the ground adjacent to the road). - Equipment Caching: Positioning equipment can allow for swifter construction. (e.g. Tlicho Road, the bottleneck was waiting for southern end to freeze to allow construction northward. Recently DOT has placed equipment in Whati and Gameti and Wekweeti so road can be constructed in a number of locations at once) - Routing review: Route review may allow for better planning of road construction at scales ranging from individual water bodies to larger scale re-alignment. Potential activities include: (i) Bathymetry (lake bottom profiling) to choose where to exit lakes, and (ii) moving selected road segments onto land (NB a Tlicho road re-alignment study is being undertaken)	Planning Operations	All winter roads Equipment caching for TWR	1 - 5	DOT Highways	-	M	-
		Action - 36: Increased manpower and equipment	Construction window could be shortened by deploying more equipment simultaneously during the construction window. This would allow the road to be opened as early as possible, given a later start to the construction window.		All	1 - 5	DOT Highways	-	H	-
		Action - 37: 'Hybrid' Winter Road	- Place a shallow embankment on the winter road route on selected sections of the road (e.g. the portages). - All-weather road embankments are 1.5 m thick and more. Anecdotal evidence suggests that on the Trans-Alaska pipeline (TAP) the 'workpad' / service road (about 2 ft. thick) has in some locations evolved to be suitable as an all-weather road work, and in other locations has at least extended the operational window of the winter road by providing a stable bed. (JV road operators have indicated that they are evaluating this technique for some of their problematic portages).	Planning Operations Capital	TWR MVWR	1 - 5	DOT Highways	-	M	L, M
		Action - 38: Vegetation Management	Vegetation management to reduce the amount of snow cover required to establish the portage sections of the roads.	Operations	TWR	1 - 5	DOT Highways	ENR	-	M

Table 9-5 Winter Roads and Ice Crossing Actions (cont'd)

Impact Area	Risk Rating	Action	Description	Type of Action for DOT	Locations / areas	Time Frame	Lead Agent	Partners	Operational Cost Impact (to DOT)	Capital Cost Impact (to DOT)
R- 2: Changes to Winter Road Season and Operations (cont'd)		Action - 39: Review of design and construction protocol	- Suggested that the TAC guidelines may have components that are too conservative for the NWT situation. The question is whether under a controlled construction environment, could a safe road be opened sooner? Is DOT's ice factor too high/rigid (noted that JV road has a lower factor than DOT) - This would require specialized engineering input.	Planning Operations	General	1 - 5	DOT Highways Corporate?	TAC YT NU TC	L-	n/a
		Action - 40: Selected replacement of winter roads	- The Source 177 access road is being constructed to provide all season road access to a gravel supply from Tuktoyaktuk. - ITH has completed environmental assessment and is undergoing engineering design. - The access road to Aklavik is being evaluated to be replaced with an all season road.	Planning Capital	ITH MVWR Aklavik access road	5 - 20	DOT Highways Corporate	-	M	M, H
R- 3: Changes to Winter Road Season and Operations	High	Action - 41: Information sharing	More information sharing activities to improve everyone's knowledge base – both within DOT, and between jurisdictions. This includes documenting and sharing the types of service disruptions, and communications with other jurisdictions (e.g. Alaska, US military). Some activity is underway – Yukon and NWT staff communicates informally and information-sharing conferences have been held in recent years. TAC has several working groups on northern transportation. DOT staff meet with JV operator regularly during construction and operating ice road season	Planning Operations	All winter roads		DOT Highways	YT, NU, AK, Federal agencies	L	-
		Action - 42: Proactively reduce overflow onto road beds	- Water Overflow could be reduced through better knowledge, tracking, and intervention. Activities would include: - Incident tracking - Temporary culverts - Adding snow to absorb water - Leveling / regrading of roads - Realignment around susceptible areas - This requires more operational effort but could reduce overflow incidents. This is already being done on the MVWR simply to enable road construction as some stream crossings only freeze late in the season.	Operations	MVWR		DOT Highways	-	M	L
		Action - 43: Route change for JV road	Suggestion that if the JV road becomes untenable, then a seasonal overland route could be built north from Yellowknife, or alternatively, south from Bathurst inlet. This would be viable only if accompanied by expanded mining activity between the diamond mines and Bathurst Inlet.	Planning Capital	TWR / JV Roads	5 – 20	JV	ENR, DOT, NU	-	H
		Action - 44: Sun shielding structures	Construction of embankments on the south side of winter road portages. These would act to reduce exposure to the sun on the road bed. The JV road operators have indicated that they are already doing this.	Operations	TWR / JV Roads	5 - 20	DOT Highways	-	M?	M, H

Table 9-5 Winter Roads and Ice Crossing Actions (cont’d)

Impact Area	Risk Rating	Action	Description	Type of Action for DOT	Locations / areas	Time Frame	Lead Agent	Partners	Operational Cost Impact (to DOT)	Capital Cost Impact (to DOT)
R- 4: Changes to Winter Road Season and Operations (cont'd)		Action - 45: Winter Road Alternatives	Given the uncertainty with the future of winter road viability it is likely that some roads may become chronically difficult to construct and maintain. Over the next few years, better information may become available to indicate the climate features that may affect winter road viability. As more information is obtained DOT may have to develop and assess alternatives for each winter road.			5 - 20	DOT Highways	?	-	H
		Action - 46: Replace winter road with an all season road	- Plans are currently underway to expand the all season road network. - EA is complete and engineering has been started for the ITH and funding is being secured. - The GNWT is committed to building an all-weather MVH to connect to the Dempster - Other roads may have to become all season as winter road viability declines. – (e.g. TWR)		All	1 – 5 (ITH) 5 – 20 (MVH) 20 - 40 (TWR?)	DOT Highways	-	?	H
R- 5: Problems with ice crossings on winter roads	High	Action - 47: Permanent crossings	- Create permanent stream crossings along the MV winter road route. 36 crossings have been installed to date. Four more are required over the next 5 years	Planning Capital	MVWR	1 - 5	DOT Highways	-	L	M
		Action - 48: Crossing Design Changes	- Review design of permanent crossings. Considerations include: - Avoiding disturbance to the surface topography at crossings (prevents overflow). - Increasing the heights and spans of permanent crossings. Has greater cost but avoids scour. - Changing the structural systems such as moving from footings to piles - These have recently been implemented at the MVWR permanent crossings.	Planning Operations	MVWR	1 – 5	DOT Highways	JV operators, Consultants	L	L
		Action - 49: Use more permanent culvert crossings	Convert temporary culvert crossings to permanent culverts. It has been proposed to install multiple levels of culverts (stacked culverts) so that when the lower culvert ices up, a culvert at a higher elevation through the road embankment will remain open and allow spring flows to pass. Already being done on an as needed basis	Operations	MVWR	1 - 5	DOT Highways	-	L	L
R- 6: Problems with ice crossings on winter roads	High	Action - 50: Raise grade level to reduce overflowing	Higher-grade level will reduce the amount of stream flow that overflows the road bed. This has benefit of reducing disruptions to natural stream course flows.	Operations	MVWR	1 -5	DOT Highways	-	-	M
		Action - 51: Ft Providence equipment redeployment	Move ice bridge equipment that has been used for Ft. Providence ice crossing to be used on MV road crossings.	Operations	MVWR	1 – 5	DOT Highways	-	L	-
R- 7: Road Integrity and Quality	Medium	Action - 52: Time of day travel restrictions	Winter road travel is controlled (typically limited to nighttime travel late in the season) on selected road sections to preserve road quality.		Primarily the MV road, but also others as required.	1 - 5	DOT Highways	-	L	-

9.4 Airports: Landside and Airside Facilities

Six risk areas were defined for the air travel system (see Table 9-6).

Table 9-6 Air Travel Climate Change Risk Areas

Risk Area	Description
A- 1: Runways buckling due to changing runoff soil/ permafrost conditions	Changing substructure conditions will result in paved surfaces buckling or slumping. The greatest sensitivity is for runways, which require tighter level tolerances than aprons and taxiways.
A- 2: Runways / taxiways flooded	Slumping or soils creates depressions and pooling of water on runways and aprons.
A- 3: Loss of Friction	Water or ice accumulation may result in loss of friction on the runways. As a result flights can be scrubbed. While this has happened for many years, there is anecdotal evidence that this seems to be a more chronic problem in recent years.
A- 4: Increasing Maintenance burden	Additional materials use (sand, urea, de-icing fluid) will require more operations and maintenance effort.
A- 5: Travel delays: Extreme Weather /Fog/ Fires	Extreme events can cause disruption to air travel. This category refers to events that are not directly damaging to infrastructure or aircraft, but could result in a temporary impact to the transportation network. Direct weather – related events would include intense storms, freezing rain, and in particular fog. Events that might be climate-induced – which may change in frequency or intensity with climate change – include forest fire closures of flight operations.
A- 6: Shoreline Erosion of airstrip	Shoreline erosion could affect low lying airstrips. Paulatuk was identified as an example. Note that no threat to the airstrip has yet been identified.

Table 9-7 Airports and Aviation Actions

Impact Area	Risk Rating	Action Number	Description	Type of Action for DOT	Locations / areas	Time Frame	Lead Agent	Partners	Operational Cost Impact (to DOT)	Capital Cost Impact (to DOT)
A- 7: Runways buckling due to changing runoff soil/ permafrost conditions	Medium	Action - 53: Complete airstrip risk assessments	- DOT has developed an airport climate change vulnerability protocol. It has been piloted at Inuvik airport. The protocol is a step-wise process that starts with a desk review, and progresses to site inspections, and even subsurface condition testing. At each step a decision can be made whether to proceed to further analysis. For each runway an analysis must be done to the terrain analysis stage. - It is recommended that all the GNWT airstrips be assessed through the protocol - likely over a period of several years. A few runways should be assessed, and then the protocol revised as needed.	Planning	Yellowknife Norman Wells Inuvik Fort Simpson	1 – 5	DOT Airports	-	L	M
		Action - 54: Strategic snow clearing	Snow clearing on aprons and shoulder areas has (anecdotally) been found to preserve the permafrost integrity. Preservation of snow cover in the later season may preserve cold ground conditions.	Planning Operations	Paved airstrips	1 - 5	DOT Airports	-	L	L
		Action - 55: Runway rebuild	- For runways that have chronic problems, a runway (full or partial) rebuild may be required. At Yellowknife airport in 2002, a section of the runway was excavated and rebuilt with insulating material included to protect the permafrost area. - The paved runways are typically expected to require a major rebuild every 25 years, so at these points, subsurface evaluations and reconstruction should be considered. - Note that the use of insulation may not be an effective technique. Below the arctic circle (rule of thumb) insulation may be detrimental as the permafrost requires heat loss in winter to stay cold.	Capital	TBD through runway vulnerability assessment	5 - 20	DOT Airports	-	-	M
		Action - 56: Re-activate airport thermistors	Temperature measuring thermistors have reportedly been installed underneath the runways at Norman Wells and Inuvik (and possible Hay River). These are not actively capturing data and their condition and functionality is unknown. If functional these could be reactivated affordably. Data collection as soon as possible would be useful to subsequent geotechnical analysis.	Capital Operations Planning	Norman Wells, Inuvik, (possibly Hay River)	1 - 5	DOT Airports	-	L	L
		Action - 57: Periodic regrading (gravel strips)	- Gravel strips can be periodically regraded. This has a cost, and may be an adequate response. - A Life Cycle cost analysis would enable the determination of the equalization point of more extensive upgrades against the cost of continued regrading.	Capital	Gravel strips	5 - 20	DOT Airports	-	L	M
A- 8: Runways / taxiways flooded	Medium	Action - 58: Drainage assessments	- Some strips may require upgrades to drainage infrastructure. - In particular there should be a risk assessment regarding potential flooding of the airstrip + context where thermo-erosion could evolve into gullies cutting the airstrip. For example in Pangnirtung in 2008, the Duval river eroded the abutment of 2 bridges (more than once) resulting in a state of emergency for several weeks.	Planning	All	5 - 20	DOT Airports Corporate?	-	L	L

Table 9-7 Airports and Aviation Actions

Impact Area	Risk Rating	Action Number	Description	Type of Action for DOT	Locations / areas	Time Frame	Lead Agent	Partners	Operational Cost Impact (to DOT)	Capital Cost Impact (to DOT)
A- 9: Loss of Friction	Medium	Action - 59: Increased chemicals use	An immediate measure will be to apply more sanding and de-icing fluids (acetate – example product names “E36” and SF7”). Note that increased use of runway deicing (as well as aircraft deicing (glycol products), has required more vigilant management (and associated costs). This is currently done as needed.	Operations	Paved airstrips	1 - 5	DOT Airports	-	H	M
		Action - 60: Runway Grooving	Grooving has been used to enhance water drainage from runways, including at Norman Wells. Runway grooving appears to have also improved friction in dry and frost conditions.	Planning	Paved	5 - 20	DOT Airports	-	-	M
		Action - 61: Develop a business case for sanding vs. grooving.	Loss of friction events can be reduced by either more sanding material; or possibly by grooving the (paved) runway. The Norman Wells runway was grooved several years ago and so records could be pulled of the sanding and deicing purchases etc. A review would highlight the saving in materials from an investment in grooving. Note that the savings re not trivial – the sand for Norman Wells is a high grade sand that is trucked in from Northern Alberta as no suitable supply is available locally.	Planning	Inuvik Others?	?	DOT Corporate Airports		L	
		Action - 62: Runway extensions	Extending runways can increase safety in low friction conditions.	Planning	Paved	5 - 20	DOT Airports	-	M	M
A- 10: Increasing Maintenance burden	Medium	Action - 63: increase budgets for staff and materials	Increasing resources to apply more traction material where needed is an obvious first step. This is a low capital and flexible response.	Operations	Inuvik Norman Wells Others?	?	DOT Airports		L	
		Action - 64: Increased glycol management.	Increasing the use of glycol and ground de-icing agents will require more management activities. In some locations this might require additional capture or holding facilities to be built. Regulations require collection/treatment of glycol over a specific amount and at present only KY meets this threshold.	Operation Planning	?	?	DOT Airports		L	
A- 11: Travel delays: Weather / Fires	Low	Action - 65: Notification system	Some delays are inevitable. DOT can review and enhance notification systems.	Operations		1 - 5	DOT Airports Corporate?	-	M	L
		Action - 66: Improved instrument landing systems	Instrument landing systems could be implemented at more airstrips	Planning		5 – 20	DOT Airports	TC	H	?
A- 12: Shoreline Erosion of airstrip	Low	Action - 67: Monitoring of airstrips near shorelines for signs of erosion.	Monitor airport infrastructure for signs of degradation. (Storm surge simulation might give an indication of the probability of this occurring)	Operations	Paulatuk	5 - 20	DOT Airports	-	L	n/a

9.5 Ferries and Ferry Crossings

The marine and arctic supply workshop defined eight specific impact areas that presented risks due to climate change (Table 9-88).

These impact areas represent an exacerbation of the current operating challenges. Adaptation will be driven by a program of incremental adjustment and effort – likely requiring gradual increases in staff time and material costs.

Eight actions were identified for the impact areas defined. These are described in Table 9-9. Actions in this area fall almost completely to DOT as they are the service provider for ferry crossings.

Table 9-8 Ferries and Crossings Climate Change Risk Areas

Risk Area	Description
F- 1: Infrastructure damage or travel disruptions	Ferry landings are damaged resulting in temporary loss of service. Potential causes would be the scour or erosion of the gravel loading ramps. Other infrastructure could also be damaged – e.g. drainage or parking areas by rainfall or snowmelt.
F- 2: Weather Related Ferry Service disruption	Ferry service is disrupted by weather or climatic events. These disruptions range from hours to days and are the result of short term weather events.
F- 3: Loading Ramp Activities Disruption	Loading ramp activities disruption. This impact results from damage or interference with the loading ramps. Potential causes could include water level fluctuation, deposition of debris on the ramps, scouring of the ramps. Intense short term rainfall may also affect the ramp condition.
F- 4: Changes to bank stability and location	Changes to bank stability and location of banks can affect ferry operations. Reasons for these changes can be due to sloughing of banks, water scouring, or ice dynamics in the winter or during breakup.
F- 5: Cable ferry damage or disruption	The Peel River ferry cable could be damaged – resulting in service disruption. Identified climate variables that could cause this include: excessive water level fluctuation, river borne debris, or ice dynamics
F- 6: Drainage Impacts to Ferry Facilities	Ferry waiting areas can become flooded or problematic due to poor site drainage or excessive rainfall.
F- 7: Reduction of ferry load capacity	Reduction of ferry loads may be required for short periods of time. This might result in minor service disruptions, though it is possible that travelers could be inconvenienced overnight. Causes would be due to water level issues (low level) or possibly highly variable flows. As well, wind and storm events might temporarily hinder ferry capacity.
F- 8: Changing operational season	Ferry seasons are being extended due to longer ice free periods. To date, the closing dates for the ferries have been extended in the range of 1-2 weeks over the past 20 years.

Table 9-9 Ferries and Crossings Actions

Impact Area	Risk Rating	Action Number	Description	Type of Action for DOT	Locations / areas	Time Frame	Lead Agent	Partners	Operational Cost Impact (to DOT)	Capital Cost Impact (to DOT)
F- 1: Infrastructure damage causing travel disruptions	Low / Medium	Action - 68: Operational prudence	Operators on site respond to situations as they arise. This is currently done through normal operations, though additional staff time may be required for maintenance activities.	Operations	All ferry crossings	1 - 5	DOT Marine	-	L	n/a
F- 2: Weather Related Ferry Service disruption	Low / Medium	Action - 69: Notifications and Public Information	- If closures and service suspensions become more frequent, a more robust notification system for users may be required. Currently the GNWT website and road signage provide information. - Future improvements could include mobile apps and twitter feeds.	Operations	All ferry crossings	1 – 5	DOT Marine Corporate	-	L	n/a
F- 3: Loading Ramp Activities Disruption	Low / Medium	Action - 70: Increased ferry operations resources.	- Increased resources may be required for maintaining the ferry services. Resources would include staff time for activities (e.g. longer shifts, more overtime, etc.) as well as more disbursement costs for gravel for ramps, and possibly underground drainage at staging areas. - If gravel requirements increase dramatically, then there may be a need to expand gravel storage or quarry operations. - This is currently done on an ad hoc basis as required to keep the system operational. Monitoring and reporting should be put in place to quantify needs.	Operations	All ferry crossings	1 - 5	DOT Marine	-	M	-
F- 4: Changes to bank stability and location	Low / Medium	Action - 71: Improve understanding of what future break-up conditions will be (more ice, less ice, more jams?)	Modelling and empirical work to improve predictive abilities, (e.g. working with Dr. Faye Hicks at University of Alberta)	Planning	Mackenzie River	5 - 20	DOT Marine Corporate	EC, Academic researchers	L	L
F- 5: Cable ferry damage or disruption	Low / Medium	Action - 72: More maintenance as required	The cable ferry may require more maintenance, including more inspections and, potentially, more frequent replacement of the cable.	Operations	Peel River Crossing	1 - 5	DOT Marine	-	L	n/a
F- 6: Drainage Impacts to Ferry Facilities	Low / Medium	Action - 73: Review and upgrade vehicle areas for drainage	Problems would be typically addressed on site and informally. Modifications may become needed if problems are chronic.	Operations	All ferry crossings	1 - 5	DOT Marine	-	M	L
F- 7: Reduction of ferry load capacity	Low	Action - 74: Longer operational hours as required.	Additional operating hours may be required during periods when capacity is limited and traffic is substantial.	Operations	All ferry crossings	1 - 5	DOT Marine	-	L	n/a
F- 8: Changing operational season	Low	Action - 75: Prepare for longer ferry operations	Warmer conditions will result in a longer ferry season. To date the closing times have extended about 2 weeks over the past two decades. Further late season operations are to be expected in the future.	Operations	All ferry crossings	1 - 5	DOT Marine	-	M	n/a

9.6 River Transportation and Barge Traffic

The marine and arctic supply workshop defined three specific impact areas that presented risks due to climate change (Table 9-10).

These risks are inherent in the barging and river transportation system due to the challenging conditions and isolated locations. The impacts of climate change are expected to exacerbate these impacts – to create more variability and uncertainty year after year³⁶. Adapting to these issues will be an incremental process of altering practices and selected facility modifications.

There is some risk that a unique or sudden event could be dramatic enough to prevent a community resupply or other important transport activity. Examples might be an ice pile-up damaging a fuel transfer manifold, or low water preventing a barge from unloading. These cannot be foreseen specifically, but monitoring and reporting actions can be established to provide some indication of where these issues might be relevant and pre-emptive action can be taken.

Four actions were identified for the three impact areas defined. These are described in Table 9-11. Actions in this area fall primarily to other participants in the transport system – specifically the private operators. The Petroleum Products Division (PPD) of the GNWT is an active participant in community resupply activities focused on ensuring sufficient generator fuel supplies.

Table 9-10 River Transportation Climate Change Risk Areas

Risk Area	Description
B- 1: Damage or loss of facilities	Shore facilities for barging and river transportation are more disrupted by climate change. Examples include increased damage to piers and moorings structures. Causes are related to: GSL shoreline erosion and silting (Hay River); shore erosion along the Mackenzie River (largely suspected to be due to loss of permafrost and subsequent slumping); dynamic breakup conditions on the Mackenzie River, and intense precipitation events.
B- 1: Disruptions to capacity or utility of barges	Barge serviceability or operations can be impaired by temporary or seasonal events. Damage could include damage to manifolds (bulk fuel), or other shore side or barge side equipment. Potential causes of this damage include: spring break-up, washout of ramps, or blockage of landing locations.
B- 1: Service Interruptions	Weather and climate related events can disrupt operations of barge services. Examples of disruptions can include: cargo relays through the rapids; general operational control difficulties, scheduling, loading & unloading, mooring, navigation systems, navigable hazards (debris), and cargo limitations on barges. Causes identified for these disruptions include: winds, water levels, fog, rain / snow, waves, slope and permafrost changes creating more in-river debris, and lightning

³⁶ Anecdotal comments that indicate new or changing conditions are commonplace. Comments noted during the workshop from barge operators included “I’ve seen a lot more exposed ice wedges on the shores recently” and “we’ve been getting a misty kind of rain that we didn’t used to see”. These comments were from operators with 20+ years of experience on the river.

Table 9-11 River Transportation Actions

Impact Area	Risk Rating	Action Number	Description	Type of Action for DOT	Locations / areas	Time Frame	Lead Agent	Partners	Operational Cost Impact (to DOT)	Capital Cost Impact (to DOT)
B- 1: Damage or loss of facilities	Low / Medium	Action - 76: Reconstruction of structures	Hay River site may require dredging and / or reconstruction of structures.	Capital	Hay River	1 - 5	DOT Marine	CCG, private operators?	L	M
		Action - 77: Relocation of navigational aids or mooring anchor points	- Navigational aids are relocated further onto shore in response to shoreline erosion and slumping. - Mooring anchors are relocated further ashore along the river. Note that many of these are informal (e.g. trees), but some are specifically constructed.	n/a	General through the river	1 - 5	CCG Private operators	--	none	none
B- 2: Disruptions to capacity or utility of barges	Low / medium	Action - 78: Facilities Assessments	Periodic review of facilities, and tracking of conditions and incidents.	Operations	Re-supply communities	1 - 5	DOT Marine PPD	CCG	L	L
B- 3: Service Interruptions	Low / Medium	Action - 79: Load and trip planning.	- Winds create large waves on GSL that may cause delays. - Load management (load lightering operations) may also be required at some locations on the river, if low flow conditions are exacerbated.	Planning	GSL river	1 - 5	Private operators	--	None	none

9.7 Arctic Marine and Coastal Community Resupply

The marine and arctic supply workshop defined five impact areas that presented specific risks (described in Table 9-12).

These are not new risk areas and are part of current operations. They are addressed through operator prudence, pre-planning, as well as having a sufficient contingency in the delivery window. Climate change may impact these issues by creating more variability in events and conditions.

Table 9-12 Arctic Marine Climate Change Risk Areas

Risk Area	Description
M- 1: Damage to props and rudders	Vessel equipment damage through changing or unpredictable ice conditions. More frequent incidents of “not previously seen” ice conditions are reported due to movement of formerly non-mobile ice.
M- 2: Challenges to vessel maneuverability, docking and mooring	Vessel movement may be disrupted by ice conditions not previously seen – such as migration of multi-year ice to new areas. Responses may be challenged by insufficient charting which may limit choices of route options and access to offloading facilities.
M- 3: Disruptions to re-supply activities	Variable or unexpected ice and weather conditions, or high winds etc. disrupt community re-supply efforts to arctic communities. These might be temporary disruptions to re-supply efforts (e.g. being wind bound, or having to suspend unloading), or could affect seasonal scheduling.
M- 4: Damage to support infrastructure	Support infrastructure can be damaged. Examples cited include: loading and unloading equipment (cranes, winches, and conveyors); vessel landing and mooring facilities, and bulk fuel shore-based storage. Causes of this include: wind waves, high peak temperatures (for fuel storage), mean temperature changes (long term increase affects soil and ground conditions, intense rain (erosion, flooding), increased annual rainfall, sustained high wind, and land fast ice movement (pier damage etc.)
M- 5: Impairment of Arctic Passage support operations	All activities in the high arctic are weather dependent. Activities that support transportation and passage may be affected by climate change. Identified examples are: search and rescue; and navigation. These may become more relevant as traffic increases in the arctic.

Eleven actions were identified for the five impact areas defined. These are described in Table 9-13.

Actions in this area fall primarily to other participants in the transport system – specifically the Canadian Coast Guard, the Canadian Ice Service, the Canadian Hydrographic Service, and private sector operators.

The Petroleum Products Division (PPD) of the GNWT is an active participant in community resupply activities focused on ensuring sufficient generator fuel supplies.

Table 9-13 Marine Resupply Actions

Impact Area	Risk Rating	Action Number	Description	Type of Action for DOT	Locations / areas	Time Frame	Lead Agent	Partners	Operational Cost Impact (to DOT)	Capital Cost Impact (to DOT)
M- 1: Damage to props and rudders	High [Note 1]	Action - 80: Route Planning	Operational prudence and skill is a key response to these conditions. Future conditions may require more planning and preparation than at present.	Planning	All destinations	1 – 5	Private operators	PPD CCG	L	none
		Action - 81: Larger Vessels	Future resource development or community re-supply could pool shipping to create larger quantities. This would create a market for use of larger, more ice capable ships	n/a	All destinations	5 – 20	Private operators	--	none	none
M- 2: Challenges to vessel maneuverability, docking and mooring	High [Note 1]	Action - 82: Improved harbor charting	Accurate charts and weather / ice information can reduce chances of encountering unexpected conditions.	n/a	All destinations	1 – 5	CCG CIS	Canadian Hydrographic Service	none	n/a-
		Action - 83: New vessel types	Different vessels might need to be deployed. Features might include: advanced maneuvering capabilities (e.g. side thrusters for large vessels servicing a new resource operation) or other assistance to barge operations.	n/a	All destinations	5 - 20	Private operators	-	L	?
		Action - 84: Upgraded shore facilities	- Permanent shore facilities may be required. - For example the GNWT established a permanent landing ramp at Paulatuk.	Capital	All destinations	5 - 20	Private operators, MACA	CCG	L	M
M- 3: Disruptions to re-supply activities	Medium	Action - 85: Planning	Operator prudence and planning can reduce the risk of these events disrupting supply. Ensuring that critical supplies are delivered as early as possible.	n/a	Three re-supply communities	1 - 5	Private operators	PPD	L	-
		Action - 86: Develop greater reserve supplies and capacity	- Redundancy and extra capacity can be built into the systems. Cited examples include: - Maintain (and increase) the strategic fuel reserves in Tuktoyaktuk. - Ensure to have a backup option for each location (e.g. substantial air lift might require large planes and airstrip upgrades).	Planning	Three re-supply communities	5 - 20	PPD	DOT MACA	L	none-
M- 4: Damage to support infrastructure	Medium	Action - 87: Infrastructure monitoring	Continued tank farm inspections. Facilities are currently inspected regularly and events (e.g. damage or leaks etc.) are reported.	n/a	Three re-supply communities	1 – 5	PPD	MACA	none	None
		Action - 88: Standards and design	- Ensure that construction standards stay current with new codes (e.g. for tank farms and generation facilities). Currently infrastructure management is ongoing and several upgrades have been made in recent years). - Evaluate structural design of facilities.	n/a	Three re-supply communities	5 – 20	PPD, MACA	-	L	L
		Action - 89: Ice monitoring	Evaluate if land fast ice characteristics are changing (e.g. any inter-year movement).	n/a	Three re-supply communities	5 – 20	Canadian Ice Service	CCG	none	None
M- 5: Impairment of Arctic Passage support operations	Medium	Action - 90: User activities and requirements	- A greater understanding and coordination may be required as exploration and transportation activities increase. - New technologies may need to be deployed for tracking, monitoring and search and rescue.	n/a	All areas	5 - 20	CCG	DOT, MACA, ENR, PPD	L	None
NOTE: [Note 1]: Risk ranking does not reflect the impact of operator prudence which would be expected to reduce the probability of occurrence of an event, and thereby reduce the risk.										

10 IMPLEMENTATION

10.1 Key Themes

Chapter 9 details a number of data and research needs as well as specific actions for each transportation mode. The sector-based actions address specific impacts that have been prioritized by their relative risk. Despite the broad range of activities and transport sectors a number of “key themes” emerged. These themes reflect the general nature of each activity. They have been given informal titles of: learn, cope, plan, and build.

- **“Learn”:** There is a need for more data and research into the physical processes affecting the infrastructure. This includes:
 - **Infrastructure and asset management data.** Records of facility condition and maintenance tracking within DOT. An area for immediate pursuit is to formally document the increasing operational and maintenance burden that the operations staff has been dealing with. This impact is noted anecdotally many times in discussions with staff but the information is not consolidated in any format suitable for identifying overall trends, developing a business case or for supporting increased budget requests.
 - **Applied research through pilot testing of new designs.** New design features have been implemented through operational need, and DOT staff are actively communicating with other jurisdictions, agencies, and operators to share information.
 - **Engineering studies and evaluation methods.** The planning group has been very active for several years evaluating engineering approaches, testing assessment protocols (e.g. PIEVC), and even developing a procedure for risk evaluation (airports).
 - **Climate and hydrological data.** DOT does not directly do meteorological monitoring but there is a need for more data. As well, there are opportunities to glean insight from the evaluation of the existing data sets.
- **“Cope”:** DOT operations group (and other transportation players), have been addressing the evolving needs of the system in an incremental fashion by maximizing existing systems, increasing existing effort, and making some changes to current practices. This has meant some additional staff time and/or materials. In the short term (1-5 years) these activities are appropriate adaptation strategies (not all impacts require a dramatic adaptation measure). All the information presented in this report indicates the demands will continue to increase. The value of continuing with incremental operations is that it is based on familiar practices, and maintains serviceability while future options are assessed, and provides time for project development and funding to be established for longer term and more capital intensive adaptations.

- **“Plan:** There are a number of initiatives that DOT must prepare for. During the next 5 (perhaps 10 years) some major decisions, and accompanying investments will have to be made (e.g. a strategy for the long term viability of the winter road network, investments for reconstruction activities on the Liard and Dempster, and the possibility of an all-weather Mackenzie Valley road).
- **“Build”:** Some capital investments have been made to change infrastructure. DOT is just completing a major set of capital programs – funded partially through Federal stimulus programs. The permanent bridges on the MVWR are almost completed, but in the future other infrastructure changes or repairs have been and will be required. Some of these may be smaller in scale (e.g. a culvert replacement program, etc.).

10.2 Priorities

DCS has applied a risk assessment methodology to an immense range of information from a variety of sources, and identified high, medium and low areas of impact for DOT. For each of these impact areas a number of response actions are proposed. While the identified high risk impacts do highlight issues that should be “at the top of DOT’s list” to focus on for adaptation, there is an overall sense that all of the actions identified are important, and are likely to increase in importance.

Due to the large number of unknowns, many actions are focused on data collection and research. This emphasis will allow development of key datasets, GIS and infrastructure management analysis tools and confirmed understanding of mechanisms that DOT will be required to understand and respond to in longer-term operational and capital planning. These data and research findings will assist to confirm the urgency of additional funding and investment in establishing, maintaining and operating transportation networks that are critical to the sustainability of communities and industrial development in the NWT.

DCS’ strategic assessment is that DOT does not face an immediate crisis but that the potential for multiple urgent issues to emerge in the short term does exist; these issues are linked to climate change, and deterioration of infrastructure. The looming burden of climate change over the next 5 – 10 years will exacerbate - and are interconnected to - existing challenges DOT faces:

- Rebuilding aging and failing infrastructure ranging in scale from individual culvert replacement to major reconstruction of large segments of highways
- constructing critical resupply mechanisms annually in the face of ever more challenging conditions and shrinking operating windows
- maintenance that requires increasingly greater effort to achieve the same or less acceptable results than in the past
- public expectations of an increasingly high level of service

The result is that climate change is, and will continue to, induce expensive damage and reduce the service life of existing infrastructure designs, and new approaches must be implemented to offer residents and investors in the NWT region the reliable and safe transportation links that is critical to a successful, sustainable future for the territories.

DCS commends DOT for optimizing its limited resources to maintain the infrastructure it has, but the transportation system as a whole is increasingly stressed. It is our assessment that current funding and resources will not be sufficient to address the combined effects of climate change, renewal of existing infrastructure, and development of new infrastructure in the long term.

10.3 Resources

Substantial changes in funding programs, private and government partnerships, research, collaboration and application of knowledge are required in order to develop a new understanding of how the NWT is changing, what the changes will do to its critical transportation infrastructure, and how engineering designs and operational planning must adapt to this rapidly changing operating environment.

10.3.1 Implementation Resource Requirements

This section defines the staff and resource requirements expected for implementation.

- **Existing staff budgets:** A subset of the actions defined within this report can be implemented by existing staff and budgets. Other actions will require additional levels of effort, and due to current budget limitations, prioritization of some essential efforts will be necessary. Where ever possible staff should try to integrate some of the new activities, data collection and research within existing activities. This may be possible in the short term.

Past experience suggests that freeing up staff time is unlikely to occur. It should be anticipated that the current staff complement will be fully utilized with existing operations. However, data capture and incident reporting and tracking are activities that will require existing staff participation. DOT management will need to commit such that some level of participation with these activities is to be expected from existing staff, and establish new user-friendly systems of data capture to mandate mandatory and comprehensive reporting and incident tracking logs.

- **New Staff:** It is proposed that at least one new full-time transportation planner position be created within the department. The climate change activities could be shared between more than one staff person, but the objective is to recognize that the workload is substantial and will not be easy to accomplish through existing staff compliment. It may be beneficial to designate the position to have a key focus (via the job description or title) as a “climate change transportation impacts manager”

- **Existing Operating budgets (disbursements):** Material and supply costs – gravel, glycol, etc. - are expected to increase going forward. This will require continued, incremental increases in operation budgets. While the material cost may be small compared to the total budget of the department, these increases should be identified and in particular noted where they drastically change. There will be some additional labour costs as well to execute this additional maintenance. This might be as simple as a few extra hours of overtime, or may require more staffing.
- **Small Capital Program:** Small capital budgets (projects < 400k\$) are allocated to the department based on need, and the department has the opportunity to establish priorities. It should be expected that more and more of projects identified in this category have a climate change connection – relating to the impacts described above.

Combined with aging infrastructure this will increase the demand for these types of repairs and improvements. For the short term (perhaps 5 years or so), increasing demands for climate change projects can be met from this small capital budget without significantly impacting other services. However, at some point, the need for regular system repairs (that would occur regardless of climate change) will become noticeable – and possibly result in a reduction of service levels for some segment. Overall it should be expected that small capital budgets are going to have to start increasing in the next several years.

- **Large Capital and “Partner Capital” Projects:** Large capital projects (up to \$50 million) and partner capital projects (typically >\$50 million) are special projects, requiring many years to develop and fund. Most of these projects are not expected to be pursued solely to address direct climate change issues. Projects moving forward should include addressing indirect pressures to increase transport network capacities, and resilience to address industrial development. It is strongly recommended that climate change considerations are formally scoped into these projects – recognizing that expanding project scope will pose additional project costs. The need for assessment of industrial growth and climate change impacts is important to respond to the heightened interest by industry as climate change “opens up” the north.

10.3.2 Sources of Funding

Funding for the actions will arise from a number of sources including:

- Base staff allotment. Budget for DOT staff
- Operations funding: Includes staff overtime, increased contractor effort, more consumables. Typically this would be addressed through progressive increases in base operational funding. However, annual budgeting can be challenging and is subject to variation with the priorities of other departments. There may be opportunities to access or create new funding mechanisms such as a separate contingency or reserve fund for transport related emergencies; or cost recovery arrangements with commercial/industrial users to offset damages incurred by substantial additional road wear.

- Research funding: such as the Building Canada Plan funding, the former Regional Adaptation Collaborative (RAC), and Transport Canada’s Adaptation Initiative funding. These may be most appropriate for the research related activities.
- DOT small capital budgeting as described above;
- Large Capital funding as described above.

10.4 Implementation Considerations

10.4.1 Roles and Responsibilities

DOT is expected to be the lead agent in addressing these issues for the roads, airports, and ferry crossings. “Ownership” of the plan will be by DOT, with cooperation from other GNWT departments.

For river transport and arctic marine operation DOT has a lesser role. These actions fall primarily to other players to implement. The expectation of the plan is that DOT would take a role in encouraging those parties to implement actions and to support these actions through in-kind resources.

10.4.2 Communication and Engagement

Any changes to departmental objectives, mandate, or service levels should be communicated to staff and stakeholders early in the planning stages, as early as possible. Communications plans will need to be put in place for several audiences including:

- **Public:** General public consultation will be required if any changes are made in transport policy that is perceived by the public to reduce or restrict levels of service. Pro-active engagement is also required to ensure the public understands the costs and trade-offs DOT must make to provide its services. Information from the proposed database would be valuable in providing facts and figures. DOT already uses its website effectively to display road conditions and service disruptions but otherwise the website could be made more dynamic, possibly providing a vehicle to make the trend data publicly available. Some of this engagement would be several years into the future, as it is not clear in all cases what trade-offs might be required.

A number of DOT staff identified key messages that they hoped would highlight these issues better to the public including:

- The cost of doing nothing: Taking no action is not a “no cost” option as the future burden and costs increase, and interruptions to service create other costs through delays and impairment of economic activity, etc.).
- The implications of business as usual: whether road openings can be maintained, ferry services times etc.

- The choices for the future: whether services can be maintained, and at what cost? Service levels will have to be adjusted lower unless budgets increase.
- **Stakeholders:** Actions that affect road pricing, or cost for service, or changes in current activity will need to be reviewed with stakeholder groups. Communication and management of the costs and benefits related to different levels of service, particularly of roads and winter roads, will be required. Many of the actions will require engagement on their own (e.g. a service level review for winter roads).
- **Internal communication:** There may be a need for DOT to communicate internally and to other GNWT staff about any actions being taken. As well, communication to management about the urgent need to commence some of these actions is important. Internal messaging to DOT staff regarding the importance of documenting maintenance activity will be useful in designating adequate available resources in the future. Staff needs to buy in to the value of a tracking database. Incentives should be considered. It would also be helpful to make the information from the database accessible to staff so that they can see their efforts being useful and making a difference.

10.4.3 Reporting and Review

Reporting and periodic review is essential. It ensures that actions are being implemented, new knowledge is incorporated, and that DOT can be proactive rather than reactive in their activities.

Reporting would include:

- Documentation of activities performed under the plan
- Incremental expenditures (actual or estimated)
- Compilation of monitoring metrics

Review would include:

- Annual review of the plan prior to the budget setting to define priorities and actions for the next annual budget.
- A more comprehensive review every 5 years to readjust the plan, and to incorporate new conditions.

11 CLOSURE

This report was prepared on behalf of the NWT's Department of Transportation. The report may not be relied upon by any other person or entity without the express written consent of Department of Transportation.

Any use which a third party makes of this report, or any reliance on decisions made based on it, is the responsibility of such third parties. Deton' Cho Stantec Consulting Ltd. accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report.

The information and conclusions contained in this report are based upon work undertaken by trained professional and technical staff in accordance with accepted scientific practices current at the time the work was performed. The conclusions and recommendations presented represent the best judgment of Deton' Cho Stantec based on the data obtained from the work and on the site conditions encountered at the time the work was performed at the specific sampling, testing, and/or observation locations.

APPENDICES

**Climate Change Adaptation Plan for the
Department of Transportation**

FINAL REPORT

Appendices

- A Location Specific Climate Forecasts**
 - B Ferries and Marine Workshop Report**
 - C Notes from Stakeholder Consultations**
 - D Detailed Risk Identification and Adaptation Measures**
 - E Literature Review**
-

APPENDIX A

Location Specific Climate Forecasts

Using the Canadian Climate Scenarios Network (CCCSN)
Localizer Tool



The Canadian Climate Change Scenarios Network (CCCSN) Localizer Tool

Environment Canada has created a web portal called the Canadian Climate Change Scenarios Network (CCCSN - accessible at <http://www.cccsn.ec.gc.ca>). This portal has been established to maintain a network of climate scenarios knowledge. With respect to forecasting of future conditions, the portal contains a number of modeling components including:

- Canadian climate change scenarios derived from GCM (Global Climate Model) simulations, (particularly the Canadian model, available at the Canadian Centre for Climate Modeling and Analysis ([CCCma](#)), those scenarios recommended by the Intergovernmental Panel on Climate Change ([IPCC](#)) and the Program for Climate Model Diagnosis and Intercomparison ([PCMDI](#)) project. In addition, this website will provide regional scale/high resolution output from the Canadian Regional Climate Model (CRCM), through collaboration with the [Ouranos](#) consortium, along with information on other relevant GCM downscaling methods;
- Bioclimate profiles for Canada;
- Scenarios and impact and adaptation research documents from within and outside of Canada;
- Links to IPCC guidelines on scenario use and interpretation;
- On-line instructions for using scenarios and downscaling tools: the Statistical Downscaling Model (SDSM), the Automated Downscaling Tool (ASD) and a weather generator (LARS-WG);
- Links to other tools used in impacts and adaptation research; and
- Scenario Reports and selected scientific publications related to climate scenarios and impacts and adaptation research.

The network also allows the user to:

- Visualize GCM and CRCM experiments, either as maps or through the use of graphical displays of data;
- Facilitate the analysis and comparison of available simulations from GCMs and the CRCM, when comparable simulations are available for the same experiments;
- Develop all relevant derived atmospheric variables based extremes to consider plausible anticipated changes in duration, frequency and intensity of weather extremes; and
- Extract and download all available parameter data for a particular location or region.

A downscaling tool from the portal called the Localizer has been used to generate forecasts of temperature and precipitation for a number of NWT locations. The Localizer uses baseline temperature and precipitation data collected between 1971 -2000 at local Environment Canada climate stations, and uses a range of global and regional climate models to make future projections (2020s, 2050s, 2080s) for the local area of interest.

The CCCSN can provide projections under three different emission scenarios:

- A2-High Emission Scenario (average of 20 models);
- A1B-Medium Emission Scenario (average of 24 models); and
- B1-Low Emission Scenario (average of 21 models).

These emissions scenarios are standardized scenarios of development and energy consumption used by climate change modelers. These are defined by the Intergovernmental Panel on Climate Change (IPCC) (IPCC 2000).

The results presented in Tables A.1 to A-12 are based on the A2 emission scenario, as the global trend appears to be continued high emissions of greenhouse gases. A report by the International Energy Agency (2007) stated that greenhouse gas emissions to 2030 will increase more rapidly than the highest IPCC scenario predicted. All six climate stations show a predicted increase for both temperatures and precipitation.

Table A-1 Projected change in temperature for Fort Simpson

°C	annual	winter	spring	summer	autumn
1971-2000	-3.2	-23.3	-1.6	15.6	-3.3
2020s	-1.9 ± 0.5	-21.4 ± 1.0	-0.6 ± 0.5	16.5 ± 0.4	-2.1 ± 0.7
2050s	-0.5 ± 0.8	-19.4 ± 1.4	0.7 ± 0.7	17.6 ± 0.8	-0.8 ± 0.9
2080s	1.5 ± 1.2	-16.6 ± 1.7	2.5 ± 1.4	18.9 ± 1.2	1.0 ± 1.3

Table A-2 Projected change in precipitation for Fort Simpson

Mm	annual	winter	spring	summer	autumn
1971-2000	365.9	54.2	60.6	163.6	87.6
2020s	383.4 ± 16.3	56.6 ± 4.4	62.6 ± 2.7	171.1 ± 16.8	94.9 ± 7.6
2050s	399.2 ± 23.3	60.6 ± 4.7	66.5 ± 4.6	174.7 ± 16.1	97.8 ± 7.6
2080s	425.4 ± 33.1	65.4 ± 5.1	70.3 ± 5.8	181.4 ± 27.5	108.7 ± 7.5

Table A-3 Projected change in temperature for Fort Smith

°C	annual	winter	spring	summer	autumn
1971-2000	-2.3	-21.6	-1.4	15.1	-1.2
2020s	-1.0 ± 0.4	-19.7 ± 0.9	-0.5 ± 0.5	15.9 ± 0.4	0.1 ± 0.6
2050s	0.4 ± 0.7	-17.7 ± 1.4	0.8 ± 0.6	17.0 ± 0.8	1.4 ± 0.8

2080s	2.3 ± 1.1	-14.9 ± 1.7	2.4 ± 1.2	18.5 ± 1.2	3.2 ± 1.2

Table A-4 Projected change in precipitation for Fort Smith

Mm	annual	winter	spring	summer	autumn
1971-2000	362.6	49.4	54.7	162.4	96.1
2020s	379.9 ± 15.7	51.4 ± 3.3	57.2 ± 3.4	169.7 ± 13.6	102.5 ± 8.6
2050s	400.3 ± 21.7	55.3 ± 3.8	60.6 ± 4.2	177.1 ± 18.7	107.9 ± 7.1
2080s	423.5 ± 33.1	59.7 ± 5.6	64.6 ± 6.2	180.8 ± 27.1	117.4 ± 8.6

Table A-4 Projected change in temperature for Hay River

°C	annual	winter	spring	summer	autumn
1971-2000	-2.9	-21.2	-3.7	14.3	-1.0
2020s	-1.7 ± 0.5	-19.3 ± 1.0	-2.7 ± 0.5	15.1 ± 0.4	0.3 ± 0.6
2050s	-0.3 ± 0.7	-17.4 ± 1.4	-1.6 ± 0.6	16.3 ± 0.8	1.5 ± 0.8
2080s	1.6 ± 1.1	-14.6 ± 1.8	0.1 ± 1.2	17.8 ± 1.1	3.3 ± 1.2

Table A-6 Projected change in precipitation for Hay River

mm	annual	winter	spring	summer	autumn
1971-2000	320.9	45.9	51.1	126.8	97.1
2020s	335.6 ± 15.2	47.7 ± 3.1	53.6 ± 3.2	132.1 ± 11.7	103.4 ± 10.5
2050s	351.1 ± 20.6	51.0 ± 3.7	56.5 ± 4.2	135.7 ± 14.3	108.8 ± 7.2
2080s	371.0 ± 32.7	54.5 ± 5.1	59.9 ± 6.3	139.4 ± 23.6	118.4 ± 9.6

Table A-7 Projected change in temperature for Inuvik

°C	annual	winter	spring	summer	autumn
1971-2000	-8.7	-26.7	-11.9	12.1	-8.5
2020s	-7.2 ± 0.6	-24.4 ± 1.0	-10.6 ± 0.6	13.0 ± 0.5	-6.8 ± 1.0
2050s	-5.7 ± 0.8	-22.1 ± 1.2	-9.3 ± 0.8	13.8 ± 0.8	-5.1 ± 1.2

2080s	-3.4 ± 1.2	-18.7 ± 1.9	-7.0 ± 1.4	15.0 ± 1.3	-2.9 ± 1.6

Table A-8 Projected change in precipitation for Inuvik

mm	annual	winter	spring	summer	autumn
1971-2000	248.4	41.0	38.4	95.4	73.7
2020s	259.3 ± 12.1	43.9 ± 3.0	39.7 ± 1.8	98.1 ± 7.5	78.1 ± 5.3
2050s	278.5 ± 17.2	47.5 ± 3.7	43.3 ± 3.5	103.7 ± 7.5	84.6 ± 7.5
2080s	301.9 ± 23.2	52.2 ± 6.7	46.3 ± 4.0	111.7 ± 9.7	92.4 ± 11.2

Table A-9 Projected change in temperature for Norman Wells

°C	annual	winter	spring	summer	autumn
1971-2000	-5.5	-25.4	-5.9	15.2	-5.8
2020s	-4.2 ± 0.5	-23.5 ± 1.0	-4.9 ± 0.6	16.1 ± 0.4	-4.5 ± 0.8
2050s	-2.9 ± 0.8	-21.7 ± 1.2	-3.6 ± 0.7	17.0 ± 0.8	-3.2 ± 0.9
2080s	-0.9 ± 1.1	-18.9 ± 1.7	-1.7 ± 1.4	18.3 ± 1.2	-1.4 ± 1.3

Table A-10 Projected change in precipitation for Norman Wells

mm	annual	winter	spring	summer	autumn
1971-2000	289.8	48.3	44.4	123.0	74.0
2020s	303.3 ± 10.3	51.3 ± 3.7	45.9 ± 1.6	128.2 ± 7.2	78.6 ± 3.4
2050s	320.3 ± 19.1	56.0 ± 4.7	50.2 ± 3.6	130.9 ± 9.4	84.0 ± 6.5
2080s	344.1 ± 27.0	61.4 ± 6.4	53.3 ± 5.7	139.4 ± 13.6	91.6 ± 8.3

Table A-11 Projected change in temperature for Yellowknife

°C	annual	winter	spring	summer	autumn
1971-2000	-4.6	-24.6	-5.7	14.8	-2.8
2020s	-3.2 ± 0.5	-22.6 ± 1.0	-4.6 ± 0.5	15.6 ± 0.5	-1.4 ± 0.7
2050s	-1.7 ± 0.8	-20.4 ± 1.4	-3.3 ± 0.7	16.8 ± 0.9	-0.0 ± 0.9
2080s	0.3 ± 1.2	-17.4 ± 1.8	-1.4 ± 1.3	18.2 ± 1.3	1.9 ± 1.4

Table A-12 Projected change in precipitation for Yellowknife

mm	annual	winter	spring	summer	autumn
1971-2000	279.6	42.8	43.3	102.8	90.7
2020s	293.6 ± 12.6	44.6 ± 3.5	45.5 ± 1.5	106.4 ± 10.2	98.0 ± 6.2
2050s	308.2 ± 14.5	47.8 ± 3.9	48.2 ± 3.2	110.8 ± 9.4	102.1 ± 6.0
2080s	329.9 ± 22.5	52.3 ± 4.8	51.1 ± 4.7	115.4 ± 15.9	112.5 ± 7.4

Table A-11 Projected change in temperature for Tuktoyaktuk

°C	annual	winter	spring	summer	autumn
1971-2000	-10.2	-25.8	-15.4	8.6	-8.4
2020s	-8.4 ± 0.7	-23.1 ± 1.1	-14.0 ± 0.6	9.5 ± 0.7	-6.0 ± 1.3
2050s	-6.6 ± 1.0	-20.3 ± 1.5	-12.5 ± 0.8	10.1 ± 1.0	-3.7 ± 1.9
2080s	-3.9 ± 1.6	-15.9 ± 2.5	-10.2 ± 1.3	11.4 ± 1.6	-1.0 ± 2.6

Table A-12 Projected change in precipitation for Tuktoyaktuk

mm	annual	winter	spring	summer	autumn
1971-2000	138.6	19.7	16.6	52.3	50.1
2020s	146.6 ± 6.4	21.4 ± 1.7	17.4 ± 1.2	53.6 ± 4.8	54.1 ± 3.3
2050s	161.1 ± 9.6	23.7 ± 2.5	19.0 ± 1.9	60.0 ± 4.9	59.2 ± 5.4
2080s	176.8 ± 13.8	27.4 ± 4.4	20.0 ± 2.1	64.9 ± 6.9	65.7 ± 8.0

APPENDIX B

Ferries and Marine Workshop Report



**Government of the Northwest Territories
Department of Transportation
Climate Change Adaptation Plan Project**

**Ferry and Marine Transportation Workshop
January 25th and 26th, 2012**

Workshop Report

February, 2012

Overview

The NWT Department of Transportation is developing a climate change adaptation plan to respond to the impacts that climate change will have on the transportation network. As part of this process a Marine and Ferry systems workshop was held to address the ferry, river, and marine transportation systems of the NWT. The workshop was held in Yellowknife on January 25th and 26th, 2012. This report represents the compilation of the raw output of that workshop.

The objective of the workshop was to conduct a climate change risk assessment for the marine and ferry systems. Specifically this will help to define:

- The possible changes due to climate change
- The impacts these will have on ferry and marine operations
- The priority areas for action
- Adaptation Actions to address these impacts.

This report is a documentation of the activities of the workshop and a “raw” compilation of the results of the risk assessment process. Further processing of this information will be developed as part of the development of the full adaptation plan.

Activities included a range of presentations, group discussion, and breakout group work. Breakout groups were defined according to activities types and participants were assigned to a group prior to the workshop. The three groups were:

- Ferries and crossings
- River transportation and operations
- Arctic Marine and Coastal re-supply.

For majority of the session comprised breakout groups working through a six step process to identify infrastructure and activities and their interactions with climate and weather variables, assess the likelihood (L) and severity (S) of these risks and to develop a consolidated risk scoring ($R = L * S$). The scoring was used to establish priorities for action. For each priority a screening evaluation was made of the data needs to better understand this risk, and potential actions to adapt to this issue. Ranked tables were developed for each of the three breakout groups to document this information.

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Attachments (separate document)

1 Introduction

The NWT Department of Transportation is developing a climate change adaptation plan to respond to the impacts that climate change will have on the transportation network. The plan will identify risks and management activities for all aspects of the transportation system – road, rail, marine, and air transportation.

As a preliminary activity, in Oct 2010, a risk identification workshop was held with staff from Government of the Northwest Territories (GNWT) – including the Department of Transportation (DoT) and other selected staff. That workshop identified a number of risk areas and was addressed primarily towards roads and air services.¹

To provide more information a workshop was held to address the ferry, river, and marine transportation systems of the NWT. The workshop was held in Yellowknife on January 25th and 26th, 2012. This report represents the compilation of the raw output of that workshop.

1.1 Workshop Purpose

The objective of the workshop is to conduct a climate change risk assessment for the marine and ferry systems. Specifically this will help to define:

1. The possible changes due to climate change
2. The impacts these will have on ferry and marine operations
3. The priority areas for action
4. Actions to address these impacts.

1.2 This Report

This report is a documentation of the activities of the workshop and a compilation of the results of the risk assessment process. Further processing of this information will be developed as part of the development of the full adaptation plan.

¹ Marine services were not included due to the limited role of the GNWT in that area and that suitable participants were not able to attend.

2 Workshop Details

2.1 Logistics

Workshop Dates: January 25th & 26th 2012
Location: Yellowknife, NWT (Commissioner's Room – Chateau Nova)
Services Provided: Lunches and refreshments
Format: Presentations, Group discussion, and Breakout work groups
Workshop Contacts: John McCullum, (Deton' Cho Deton'Cho Stantec) 867-920-2216
Greg Cousineau (Department of Transportation) 867-873-7560

2.2 Summary Agenda

The workshop plan included four main components. An overview is shown below.

Section	Component	Questions to be Explored
Day 1: Morning	Marine Operations	What marine activities are conducted?
	Climate Change in the North	What are the past trends for climate change? What are the forecast for future trends? How will these changes be felt?
Day 1: Afternoon	Impacts to the Marine Transport System	What are the impacts that might occur? How likely are these? How serious are these impacts? First risk assessment.
Day 2: Morning	Refine the Risk Assessment	What are all the things that need to be, or could be done? What is the likelihood and consequences of these events? What are the priorities for action?
Day 2: Afternoon	Planning	What are our options to respond? Who should take the lead? Who else should have input into this?

2.3 Participants

The intent of the workshop was to gather together participants that had knowledge of a range of components of the physical and operational systems in the river, ferry, and marine transportation systems. Invited attendees were identified through conversations with NWT staff as well as other identified by the project team. Invitations were first issued starting in November 2011. Invited attendees included:

- GNWT staff (several ministries including transportation, petroleum products division, energy and natural resources, and environment).
- Researchers & scientists that have experience related to the Mackenzie River
- Federal agency staff (including the Coast Guard, Environment Canada, and the Canadian Ice Service)
- Private sector transportation companies

Not all invited persons or agencies were able to be represented at the workshop. A list of the actual attendees is shown in Table 1.

Table 1: Workshop Attendees

Agency/ Dept. / Company	Name	Role / Position	Attending
Participants			
GNWT DoT	Tom Maher	Assistant Director, Marine Transportation	Both days
GNWT DoT	Greg Whitlock	Regional Superintendent; Ft. Simpson	Both days
GNWT DoT	Greg Cousineau	Senior Transportation Planner	Both days
GNWT – DPW – Petroleum Products Division	Susan Eveleigh	Coordinator, Fuel Operations.	Both days
GNWT – ENR	Brian Sieben	Adaptation Planning Specialist	Both days
GNWT – ITI	Pietro De Bastiani	Associate Director, Oil, Minerals & Gas	Both days
Environment Canada - Canadian Ice Service	Gaetan Langlois	Superintendent; Ice and Marine Satellite Analysis; Meteorological Service of Canada; Environment Canada	Day 2 only
Environment Canada	Bob Reid	Water Survey of Canada	Day 1 only
INAC/AANDC	Steve Kokelj	Environmental Monitoring Specialist	Day 1 only
NTCL	Franklin Lea	Tug Captain	Both days
NTCL	Doug Camsell	Marine Manager, Hay River	Both days
University of Alberta	Faye Hicks	Professor	Day 1 only
University of Alberta	Evan Davies	Assistant Professor	Both
University of Saskatchewan	Chris Spence	Adjunct Professor	Both days
Deton'Cho Stantec	Kevin Hodgins	Senior Principal	Both days
Session Facilitators			
Deton'Cho Stantec	Roger Rempel	Sr. Environmental Engineer	Both days
Deton'Cho Stantec	Ron Macdonald	Sr. Environmental Engineer, Associate	Both days
Deton'Cho Stantec	John McCullum	Team Lead, Environmental Services	Both days

3 Activities

The workshop included a mixture of information presentations, group discussion, and breakout group activity. The information presentations are listed in Table 2 and are provided in Attachment C.

3.1 Workshop Briefing Note

A workshop pre-briefing note was distributed to participants several days in advance of the workshop (provided as Attachment #2). Attendees were not required to bring any advance information. The objective is to obtain input from the attendees and learn from their experience and expertise.

3.2 Information Presentations

Several of the attendees were asked to provide short presentations based on their knowledge and study in the arctic and the NWT in particular (see list in Table 2 below). These had the objectives to:

- Provide some background information so that all participants would have a base level of understanding of the transportation network, recent climate changes, and experiences of others involved with climatic issues in the NWT.
- Provide 'spark information' to start participants thinking about the nature and type of climate changes in the north.

Table 2: Workshop Information Presentations

Agency/ Dept / Company	Organization	Presentation Topic
Greg Cousineau	GNWT Department of Transportation	Department of Transportation: Marine Sector
Roger Rempel	Deton'Cho Stantec: Project Team	Climate Change in the Arctic
Faye Hicks	University of Alberta	River Flow Forecasting: Ice Process Modeling and Ice Flood Forecasting
Chris Spence	Environment Canada	Permafrost and Hydrology Considerations for NWT Marine and Ferry Services in a Changing Climate
Steve Kokelj	Aboriginal and northern Development Canada: Cumulative effects Program	Permafrost issues and marine transportation
Evan Davies	University of Alberta	Systems Approaches and Decision Analysis
Gaetan Langlois	Canadian Ice Service	Canadian Ice Service –Western Arctic ice regime

3.3 Breakout Groups

Breakout groups were defined according to activities types and participants were assigned to a group prior to the workshop. The three groups were:

- Ferries and crossings
- River transportation and operations
- Arctic Marine and Coastal re-supply.

3.4 Risk Identification and Evaluation Process

The Risk evaluation was based on traditional risk estimation techniques that define risk as a combination of both the likelihood that an event will occur and the consequences (or severity) if it does occur.

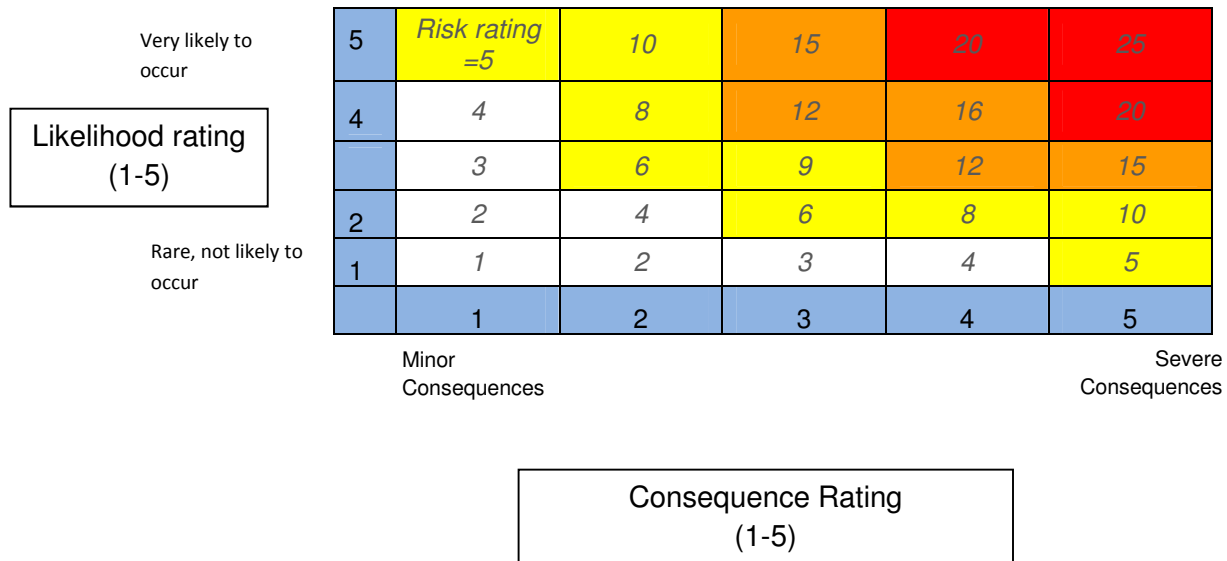
3.5 Risk Identification and Evaluation Process

A six step process was developed specifically for this workshop. This is described in Table 3.

Table 3: Risk Assessment Process

Task	Task Name	Key Activities
1	Identify Risks	• A pre-researched list of infrastructure components, and operational activities was provided to each breakout group. • Review list of identified infrastructure components and operational activities for each breakout group. Revise list as required. • Identify the key environmental factors that affect that component or activity. • Modification of the weather / climate change factors list.
2	Refine the List	• Components were re-written to a new risk matrix form. Components were deleted if: (i) they had been considered not applicable to the NWT system by the group, or (ii) there were no defined climate related factors that affect this component or activity.
3	Event Likelihood Rating	• For each component and environment interaction, a likelihood rating was assigned.
4	Event Severity Rating	• For each component and environment interaction, a severity rating was assigned.
5	Risk Evaluation	• Calculate risks based on the product of likelihood * severity. (See Figure 1)
6	Prioritizing and planning	• Identify top scoring risks and define possible research needs and adaptation measures.

Figure 1: Risk Scoring Matrix



4 Risk Identification and Ranking

4.1 Risk Identification Tables

This section presents the compiled list of components (infrastructure) or activities (operations) and their weather/climate interactions in order of their risk scoring.

Workshop participants also identified potential research and data needs as well as making initial commentary about adaptation actions.

The results for each group are presented in the following table. Note that this presents the raw data compiled at the workshop and that further processing or analysis or some elements may be required in the preparation of the action plan.

4.2 Ferries and River Crossings

Table 4: Prioritized Risks: Ferries and Crossings

Component or Activity	Type I=infrastructure A = activity	Risk Rating Score	Key Climate / weather related driver	Data or research Needs	Adaptation measure (see notes D, and E)
Ferry Landings	I	10	Water level fluctuation	Analyze historical record for trends in operational thresholds being exceeded. = (1)	Permanent landing sites
Riverbank erosion and Debris	I	10	Mean temp	--	Operational prudence = (A)
Ferry cable (Peel River Only)		10	Water level fluctuation	(1)	Maintenance as required = (B)
Ferry maneuverability, operational control		10	Water level fluctuation	(1)	(A)
Ferry maneuverability, operational control		10	fog	(1) + review ferry logs	(A)
MTE: Ramps		10	Water level fluctuation	(1)	(B), increased budget allotment = (C)
Construction: Ramps		10	Water level fluctuation	(1)	(C)
Emergency Construction: Ramps		10	Water level fluctuation	(1)	(C)
Scheduling / Regional Logistics		10	Water level fluctuation	(1)	None
Ferry Landings		9	Drought	(1)	(C)
Ferry Landings		8	Intense rainfall – short term duration	(1) + Q (flow information)	(C)
Ferry Site Drainage		8	Intense rainfall – short term duration	Review operational histories for indications of past occurrences = (2)	(A)

Component or Activity	Type I=infrastructure A = activity	Risk Rating Score	Key Climate / weather related driver	Data or research Needs	Adaptation measure (see notes D, and E)
Ferry Site Drainage		8	Annual Rainfall	--	• (A)
Ferry + River Levels		8	Intense rainfall – short term duration	(2)	• (A)
River levels		8	Annual Rainfall	(1)	• (A)
Riverbanks, debris, obstruction		8	Intense rainfall – short term duration	--	• (A)
Riverbanks, debris, obstruction		8	Annual Rainfall	--	• (A) + (B)
Ferry cable (Peel River Only)		8	Intense rainfall – short term duration	--	• (A) + (B)
Ferry cable (Peel River Only)		8	Annual Rainfall	--	• (B)
Ferry cable (Peel River Only)		8	High Winds – short duration	Possibly Analyze wind records	• (B)
Ferry maneuverability, operational control		8	Intense rainfall – short term duration	--	• (A)
Construction on/off ramps		8	Intense rainfall – short term duration	--	• (C)
Ferry cargo capacity		8	High temperatures	Analysis to correlate capacity limits with water levels. Define frequency of critical water levels	• (A) + analysis on re-assignment of the Merv Harvey
Ferry landings		6	Flooding	Look for historical evidence	• --
Ferry site Drainage		6	Extreme snow	Track?	• (B), (C)
Ferry Water Depths		6	Drought in watershed	Track watershed status	• (A) + more O&M
Ferry Water Depths		6	Extreme snow	Track watershed status	• (A)
Riverbanks, debris, obstruction		6	Ice dynamics	Models Satellite recon?	• Improve understanding of the river dynamics on break-up
Ferry cable (Peel River Only)		6	Sustained high wind	Analysis of wind records for thresholds = (3)	• (B)

Component or Activity	Type I=infrastructure A = activity	Risk Rating Score	Key Climate / weather related driver	Data or research Needs	Adaptation measure (see notes D, and E)
Ferry cable (Peel River Only)		6	Ice dynamics	Models and Sat recon	• (B)
Ferry cargo capacity		6	Drought	(1)	• --
Ferry cargo capacity		6	Sustained high winds	(3)	• (A)
Front end loaders / dozers		5	Water level fluctuations	--	• O&M

Terminology: (1), (2), and (3) for data needs and (A), (B), and (C) for adaptation measures a repeated. A description is provided at the first usage (which is shown in bold font).

4.3 River Transportation and Operations

Table 5: Prioritized Risks: River Transport and Operations

Component or Activity	Type I=infrastructure A = activity	Risk Rating Score	Key Climate / weather related driver	Data or research Needs	Adaptation measure
Barge tie ups	I	15	Break up	--	Move tie-offs further onto shore
Cargo capacity of barges	I	15	Water depth	Monitoring of BC snow pack	Dredging, load management (load lightening),
Cargo relays through the rapids	A	10	Winds	--	Weather is important for Great Slave Lake. Winds create large waves on GSL that may cause slight delays. Wind does not create much wave action on the river.
Other navigable hazards (debris)	I	10	Permafrost (temperatures)	--	
Operational Control	A	10	Wind	--	
Fuel Transfer	A	10	Lightning	--	
Emergency Repair	A	10	Wind	--	
Scheduling	A	10	Wind	--	
Loading / Unloading	A	10	Water level	--	
Unplanned Mooring	A	10	Winds	--	
Mooring	A	10	Fog	--	
Barge facilities	I	9	Flooding / snow	--	Berm around building, stronger structures
Manifolds (bulk fuel)	I	9	Break-up	--	
Navigation systems	I	8	Rain / snow	--	
Docking and Mooring	A	8	Waves / flood / fog	--	- Leak prevention - Possible manifold relocation

4.4 Arctic Marine and Coastal Re-Supply

Table 6: Prioritized Risks: Arctic Marine and Coastal Resupply

Component or Activity	Type I=infrastructure A = activity	Risk Rating Score	Key Climate / weather related driver	Data or research Needs	Adaptation measure (see notes D, and E)
Vessel Propulsion	I	20	Mobile ice	See notes A,B, & C	Route planning, avoidance of ice
"	I	20	Multi-year ice		Pool orders (e.g. future mines etc.) to achieve sufficient cargo demand to justify more ice capable ships
Vessel Maneuverability	A	20	Landfast ice	Charting in many areas is rudimentary, or outdated.	Planning and preparation, improved charting.
"	A	20	Mobile ice		Vessels with advanced maneuvering (e.g. side thrusters etc.),
"	A	20	Multi year ice		
Docking and Mooring	A	20	Landfast ice	Better navigational charts	
"	A	20	Mobile ice		
"	A	20	Multi year ice		
Re-supply and scheduling	A	20	Landfast ice		
"	A	20	Mobile ice		
"	A	20	Multi year ice		
Operational Window	A	20	Landfast ice	Possibly local ice and freeze up forecasts	
"	A	20	Mobile ice		
"	A	20	Multi-year ice		
Completion of Coastal community resupply	A	20	Sustained high wind	Potentially localized ice forecasts	- Ensure to have a backup option (e.g. substantial air lift might require large planes and airstrip upgrades). - Maintain (and increase) the strategic fuel reserves in Tuktoyaktuk.
"	A	20	Landfast ice		
"	A	20	Mobile ice		

Component or Activity	Type I=infrastructure A = activity	Risk Rating Score	Key Climate / weather related driver	Data or research Needs	Adaptation measure (see notes D, and E)
"	A	16	Multi year ice		• Advance planning. • Design the coastal re-supply for more contingency capacity.
Cranes, winches, and conveyors	I	15	Low temperatures	Expertise required more than data- -	
Vessel landing and Mooring	A	15	Wind waves	--	• Permanent landing ramps (e.g. Paulatuk ?)
Bulk fuel shore –based storage	I	12	High temperatures	--	• Ensure that construction standards stay current with new codes – as permafrost changes etc. (NB: Infrastructure mgmt. is currently quite rigorous). • Tank farm inspections (NB events are currently reported – damage leaks etc.)
" "	I	15	Mean temperatures (long term increase)		
" "	I	16	Intense Rain		
" "	I	12	Annual Rain		
" "	I	15	Sustained high wind		
Wharves / Quays / Docks	I	15	Landfast ice	Storm surge predictability for specific locations	• Evaluate structural design. • Evaluate if landfast ice characteristics are changing (e.g. any inter-year movement).
Arctic Passage support operations	A	15	Short-duration high winds	Better understanding of where vessels and community members are going, what activities they are doing, and what support they might require. This could increase as a greater variety of vessels and projects occur.	• Stay current with new activities and in particular with new technologies to assist search and rescue.
" "	A	15	Sustained high winds		
" "	A	15	Wind waves		
" "	A	15	Extreme snow		
" "	A	15	Landfast ice		
" "	A	15	Fog		
" "	A	15	Mobile ice		
" "	A	15	Multi-year ice		

Notes:

- A: Current ice data combined with expertise is reasonable. While users will always desire more data and more local information the current ice data is sufficient.
- B: Overall, there is a limited amount of weather and meteorological data. Wind data is specifically sparse.
- C: RadarSat data is being evaluated to use water surface signature to determine wind speeds and direction.
- D: Commonality of some adaptation measures may result in some risk areas being grouped together.
- E: Comments are presented here as recorded. These may need to be clarified for interpretation.

5 Next Steps

This reporting represents a “raw” echoing of the information collected at the workshop. It has not been post-processed. The objective of this document is to capture the activities that occurred at the workshop swiftly.

The next steps for this project are to:

- Review the data collected and comments received from the groups. This may require some follow-up research or phone calls with participants to reconfirm.
- Consolidate this information with the information derived from the October 2010 workshop for roads and airports.
- Compile a consolidated risk assessment of the transportation systems.
- Execute public consultation with stakeholders on the revised risk assessment.
- Incorporate these comments into the risk assessment and the developing draft adaptation plan.
- Prepare a draft of the adaptation plan for GNWT review.

**Government of the Northwest Territories
Department of Transportation
Climate Change Adaptation Project**

**Marine Transportation Workshop
January 25th and 26th, 2012**

Workshop Report

February 2012

ATTACHMENTS

Attachments

Attachment A:	Invitation Notice
Attachment B:	Workshop Briefing Note
Attachment C:	Workshop Presentations

Attachment A: Invitation Notice

SAVE the DATE: January 24th & 25th

**Climate Change Action Planning in the NWT
Marine and Ferry Services Workshop January 24th & 25th**

The NWT Department of Transportation is developing a climate change action plan to respond to the impacts that climate change will have on the transportation network. The study includes ferry and marine services.

The Department is hosting a workshop to help understand and define:

1. The possible changes due to climate change
2. The impacts these will have on ferry and marine operations
3. The priority areas for action
4. Actions to address these impacts.

Desired Attendees:

Researchers, department of transportation staff, ferry operators, coast guard staff, marine services companies, companies and communities affected by ferry and marine services.

Details:

Workshop Dates: January 24th & 25th

Location: Yellowknife (facility to be determined)

Services: Lunches and refreshments provided

You bring: Your knowledge & your experience

Tentative Agenda:

- What is climate change and what is happening in the North?
- What changes could happen (to river flows, to water levels, ice conditions, storms)
- How could this affect your business and your community?
- What are the priorities for action?

Format: Some presentations and lots of discussion. The Department wants your input!

Cost: Free but we ask that you register

Please RSVP by email

For more info contact: John McCullum, (Stantec) 867-920-2216 or Greg Cousineau
(Department of Transportation) 867-873-7560

Attachment B: Workshop Briefing Note

Marine Workshop Briefing Note

Information for Workshop Attendees

**Government of the Northwest Territories
Department of Transportation**

**Climate change Adaptation Project
Marine Transportation Workshop
January 25th and 26th, 2012**

Yellowknife, NWT



1 Introduction

The NWT Department of Transportation is developing a climate change adaptation plan to respond to the impacts that climate change will have on the transportation network. The final plan will identify risks and management activities for all aspects of the transportation system – road, rail, marine, and air transportation.

As a preliminary activity, on Oct 2010, a risk identification workshop was held with staff from the Department of transportation (DoT) of the Government of the Northwest Territories (GNWT). That workshop identified a number of risk areas but was addressed primarily roads and air services.¹

As part of the development of a full adaptation strategy, the DoT is hosting a two day workshop to conduct a risk assessment on the marine and ferry systems in the NWT.

About the Workshop

Workshop Purpose

The objective of the workshop is to conduct a climate change risk assessment for the marine and ferry systems. Specifically this will help to define:

1. The possible changes due to climate change
2. The impacts these will have on ferry and marine operations
3. The priority areas for action
4. Actions to address these impacts.

Logistics

Workshop Dates: January 25th & 26th 2012
Location: Yellowknife (Commissioner's Room – Chateau Nova)
Services Provided: Lunches and refreshments
Format: Some presentations and lots of discussion.
Workshop Contacts: John McCullum, (Stantec) 867-920-2216
Greg Cousineau (Department of Transportation) 867-873-7560

¹ Marine services were not included due to the limited role of the GNWT in that area and that suitable participants were not able to attend.

Workshop Agenda

The workshop will be structured into four main components. An overview is shown below.

Section	Component	Questions to be Explored
Day 1: Morning	Marine Operations Climate Change in the North	What marine activities are conducted? What are the past trends for climate change? What are the forecast for future trends? How will these changes be felt?
Day 1: Afternoon	Impacts to the Marine Transport System	What are the impacts that might occur? How likely are these? How serious are these impacts? First risk assessment.
Day 2: Morning	Refine the Risk Assessment	What are all the things that need to be, or could be done? What is the likelihood and consequences of these events? What are the priorities for action?
Day 2: Afternoon	Planning	What are our options to respond? Who should take the lead? Who else should have input into this?

Participants

The workshop will benefit from all the players in the marine system being heard. Invitations have been made to scientific researchers, department of transportation staff, ferry operators, coast guard staff, marine services companies, companies and communities affected by ferry and marine services.

The on the ground knowledge and experience is crucial to making the session a success.

Activities

The workshop will include some presentations by Department of transportation staff and a few other participants. Primarily the sessions will be table-top discussions – both as a group or in smaller discussion sessions.

Attendees are not required to bring any advance information. The objective is to obtain input from the attendees and learn from their experience and expertise.

2 Overview of Ferry and Marine Operations in the NWT

River and Marine systems are an important part of the NWT transportation network. While many communities have some road access (all weather or seasonal), a number of communities are accessible only by air or marine transport. For the provision of fuel and commodities, these marine links are crucial lifelines for these communities.

The ferry system provides crucial crossings for the highway network. Operation of these ferries is important for the livelihood of all of the NWT communities.

River and Marine Activities and Operations

The river and marine systems operate through a combination of private sector operations, as well as a number of territorial and Federal agencies. This includes:

Government of the NWT:

- River ferry services (some by GNWT staff, some by private operators)
- Provision of petroleum products to selected communities (by contract with private agents)
- Maintenance of some shoreline facilities – including Federally owned facilities.
- Transportation planning

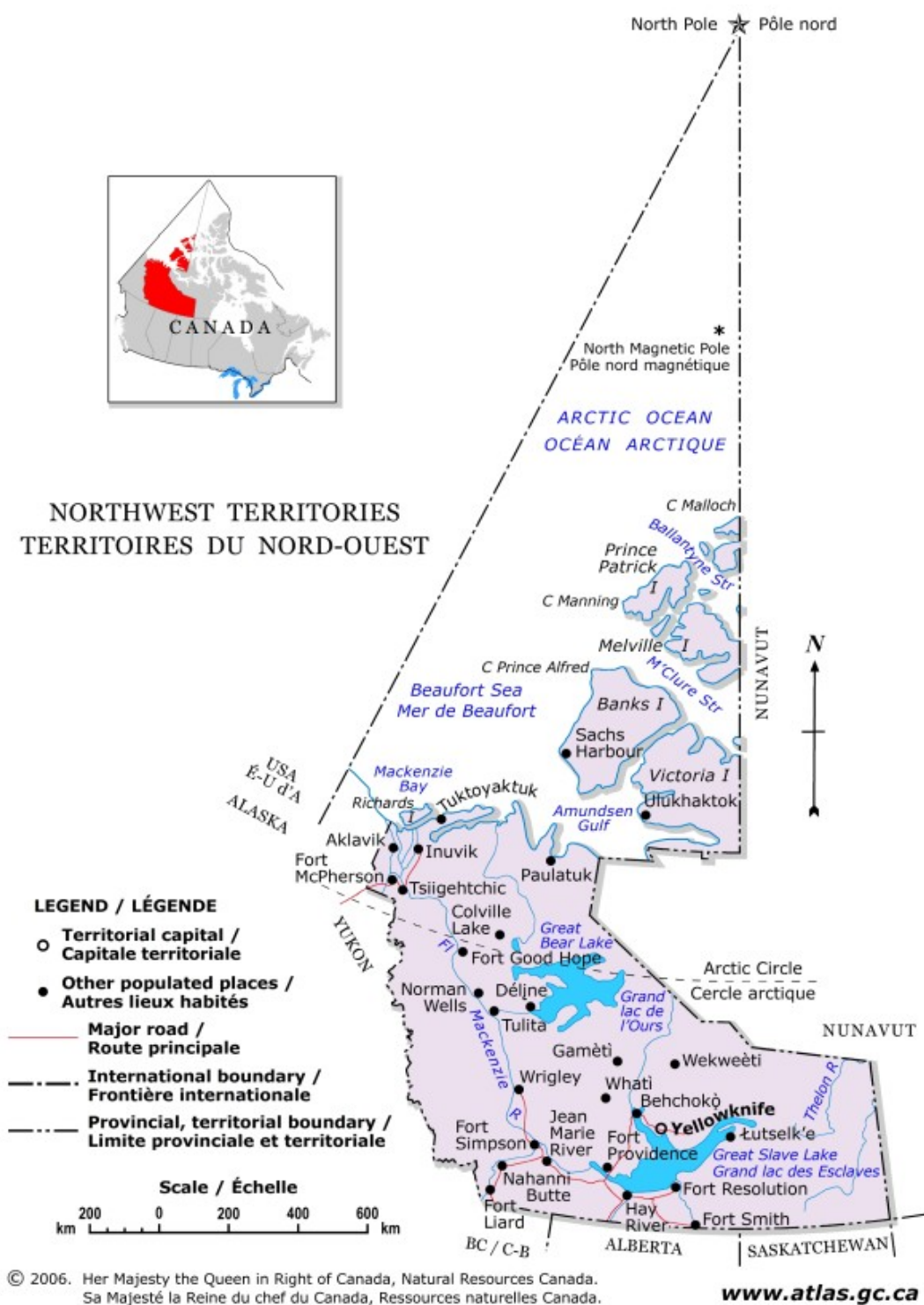
Coast Guard:

- Aids to Navigational aids for the Mackenzie River shipping route including annual setting and recovery of buoys and markers
- Aids to navigation for the arctic waters
- Icebreaking services

Private Operations

- Provision of delivery and re-supply services petroleum products and dry goods to Mackenzie R. communities and marine locations.
- Contracted services for delivery (e.g. petroleum products, some ferry services).

Figure 1: Location Map of the NWT



Source: Atlas of Canada

Note: Not all communities may be represented here

3 Climate Change

For many years, there has been increasing evidence that global climate change resulting from emissions of carbon dioxide and other greenhouse gases (GHGs) is causing, or will soon cause, significant environmental impact on the ecology of the planet. These GHGs are primarily from the combustion of fossil fuel carbon such as coal, gasoline, diesel, and natural gas.

Recent conclusions of the 2007 Intergovernmental Panel on Climate Change (IPCC) state that:

- Trend changes observed to date are “more likely than not” caused by human-sourced GHG contributions; and
- The expectation is that the human-caused climate change in the future is “virtually certain.”

Mitigation and Adaptation

Taking action on climate change can be made in two ways – through mitigation or adaptation.

- MITIGATION is the reduction of GHG emissions – or reducing our ‘carbon footprint’. Making these reductions will reduce the severity of future climate change. Currently there is not international agreement on a path forward to achieve substantive reductions.
- ADAPTATION is preparing and developing strategies that will cope with the changes already incurred – or those that we are committed to over the coming decades due to our past emissions. It is important to note that the emissions that have occurred to the present will create climate change into the future

Climate Changes in the North:

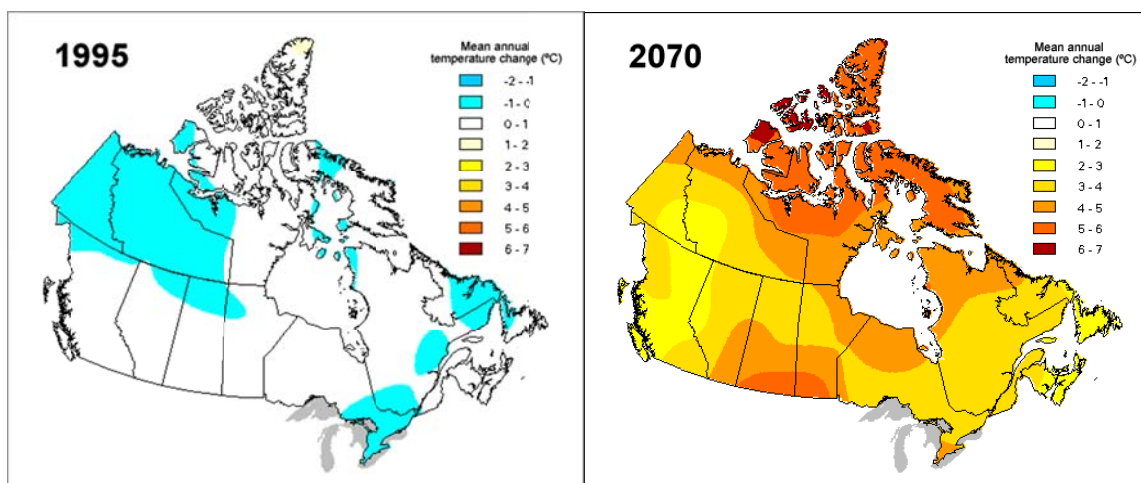
The impacts of climate change are expected to be felt in two ways. First – there are long term trends that show that conditions are changing. These trends are becoming more and more evident even though each year is unique and conditions vary greatly. Secondly, it is expected that “extreme events” will become more frequent as these trends continue. An extreme event is a storm, or a heat wave, or a drought. Extreme events that used to occur only rarely, are now expected to occur more and more often.

Trend Changes: Past and Forecasted for the Future

Climate scientists have examined historical trends and have made forecasts of future climate conditions. As an example Figure 2 shows the change of the average annual temperature. This figure shows the entire country and highlights some key issues.

- Changes of several degrees of annual average temperature are expected. This does not seem like a lot but the difference between our current climate and the last ice age is only a few degrees of annual temperature.
- Canada's north is expected to experience greater changes than many other parts of Canada

Figure 2: Change in Average Temperature from the 1961-1990 Average



Source: Atlas of Canada

Analysis has been made specifically for the north and the historical data show that the climate has already been changing and is forecast to continue to change (see Table 1).

Table 1: Climate changes and Environmental Responses in the Arctic – Past and Forecasted

Climate Parameter	What we've seen so far. (Recent History)	What we should expect (Forecast)
Mean Air Temperature	1.6°C increase (1964-2004)	3.7°C ±25% by 2071-2090
Seasonal Mean Air Temperatures	Greater warming in winter & spring	Greater warming in winter
Precipitation	14% increase last century (1900-2003)	12.3% increase by 2071-2090
Sea Level Rise	Global mean sea level rise of 0.1 - 0.2m last century	0.65m rise in the Arctic Ocean by 2100
Sea Ice Cover	Reduced by 4% per decade for winter & 8% for summer (1979-2005)	Increased speed of reduction anticipated due to feedback affect
Permafrost Extent	Northward retreat and thawing	Northward retreat by several hundred km's. 50% of the top 3m of permafrost could thaw by 2050
Snow Cover	Reduced by 5% -10% since 1972	Further reduction of 13% by 2071-2090

Extreme Events and Variability

As well as long term trends and changes, most climate estimates predict that extreme and highly variable events are likely to be more common.

- Extreme events are those that in the past have only occurred rarely. Examples are extreme storms, droughts, floods etc. Climate science is indicating that these events are likely to occur more often in the future. Planning will have to account for these as more than rarities – but as part of the “new normal”.
- Variability is the range of possible conditions. In the past conditions may have been more stable from year to year, or through a season. (e.g. ice conditions or temperatures). In the future there is an expectation that conditions will be more variable (from year to year, or even month to month and week to week), As well this variability may become harder to predict.

New Weather Patterns

There is a concern that new weather patterns are, or will emerge. Examples might be tornados in place that never experienced them previously, changes to rainfall, changes from snow to rain patterns etc.

Translating Climate changes to Land, Sea, and Water Impacts

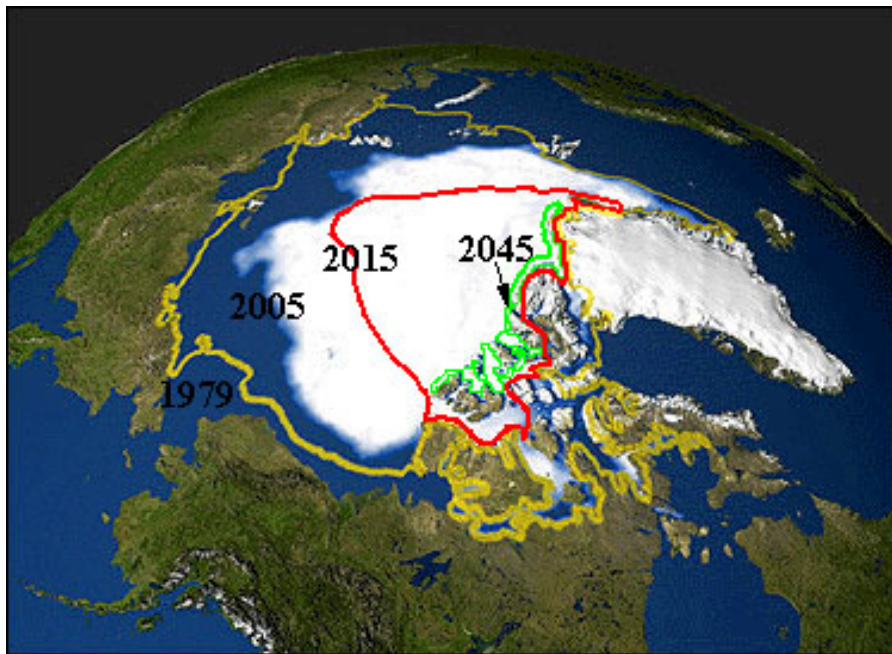
Climate scientists try to understand conditions that have changed and they use computer models to predict the future trends. But the important factor is how those changes in temperature and precipitation will affect the other parts of the environment – and out human systems. Based on past trends and future predictions, some expected changes that the changing climate will create include:

Permafrost degradation	• A reduction of permafrost and a northward movement of the permafrost boundary by several hundred kilometers towards the end of the century; • Potential for 50% of the top 3 meters of permafrost will thaw by 2050. • Disruption of permafrost – affecting structure, shoreline stability
Sea Level Rise	• Mean sea level rise of several tens of cm's due to glacier and ice cap melt, and thermal expansion (which may be amplified or reduced depending on local land subsidence). • An estimated global sea level rise of 20 - 70cm by the end of the century (2-7mm per year).
Storm Surges	• Increased storm surges will reduce sea ice along northern Canadian coastlines will increase the risk of erosion.

Changes to sea ice,	• Later freeze up and earlier breakup of sea ice • Reduction in the amount of multiyear ice • A quicker melting of shore-fast ice
Changes to precipitation and freshwater systems, such as	• Snow melt earlier in the season of spring. • Less cover in autumn. Snow cover extent is projected to decrease by 13% by 2071-2090, which will be correlated with an increase in mean annual temperatures. • River discharge increases of 5 - 25% towards the end of the century • Earlier ice break up and later freeze up of lakes and rivers.
Impacts to terrestrial, freshwater, and marine ecosystems,	• A loss and / or displacement of arctic species from their present locations. • A northward shift of the existing tree line.

As an example – predictions indicate that the ice cover will continue to retreat through this century (Figure 3).

Figure 3: Sea Ice Cover Retreat (1979-2005, and predicted to 2045)



Source: Atlas of Canada

4 Risk Assessment

What is Risk Assessment?

Risk assessment is a thinking process designed to highlight the priorities for action. The first step is to identify the possible risks for operations. In this work we will be focused on weather and climate related risks.

Once the possible risks have been identified, they are reviewed and categorized according to:

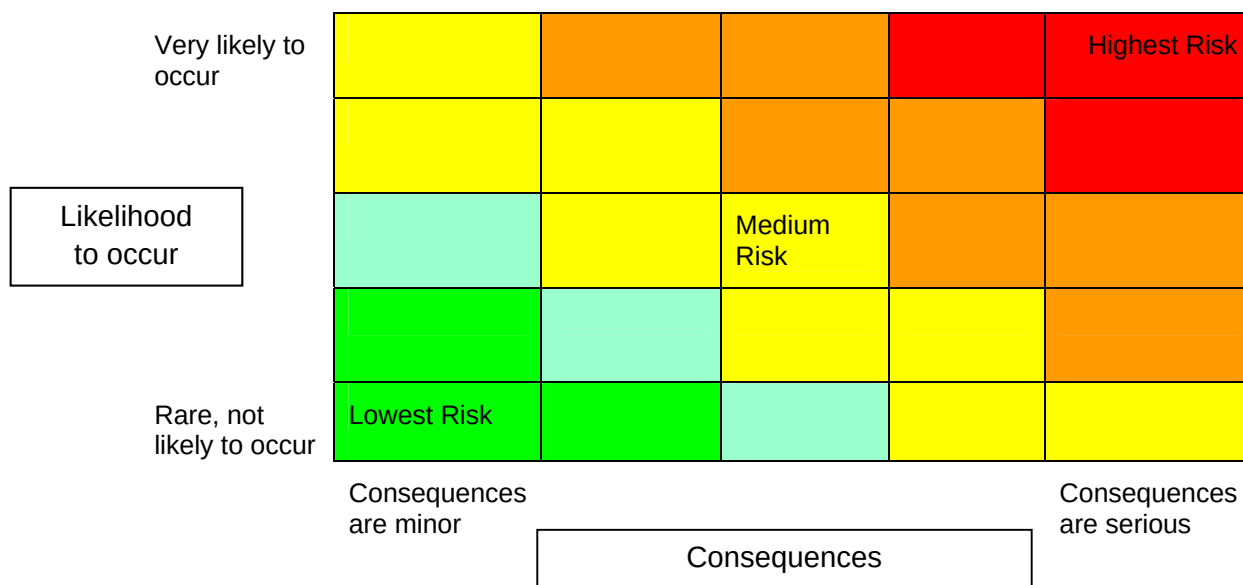
- How likely is it that something could happen?
- What are the consequences if it does happen?

The actual risk is based on an assessment of BOTH of these factors.

- The highest risk is for impacts that have a serious consequence and that will occur often (top right corner).
- The lowest risk is for minor impacts that occur rarely (bottom left corner).

Even if the impact of an event is high, if it is extremely unlikely to occur then the total risk might be low.

Figure 4: A Risk Assessment Matrix



Attachment C: Workshop Presentations

Department of Transportation



Marine Sector

January 2012



Marine Sector



NTOL Vio Ingham in Hay River Harbour

Photo Copyright © 2004 Flying Colours Design

NWT Marine Resupply



Traffic and Useage



- 519 200 Tonnes of freight came into the NWT in 2009
 - 194,000 - community re-supply
 - 54,000 - resource projects
 - 273,000 - bulk fuel
 - 241,000 - by truck
 - 212,000 - by rail
 - 20,000 - by air



On Track - Department of Transportation 2011

Western Arctic Re-Supply Forecast



- Indicative Petroleum Product Volumes - 2020 in m³

Region	Diesel	Gasoline	Jet A1
NWT Coastal	13000	1600	1600
NWT Delta	13500	6000	5000
NWT River	15600	2800	2800
Nunavut	22600	3300	8100
Mining	15000	Drums Only	1000
Alaska	10000	2600	3299
Total	89700	16300	21800

Western Arctic Re-Supply Forecast



- Indicative dry cargo quantities for 2020

Region	Tonnes	Cubic Metres
NWT Coastal	3000	10500
NWT Delta	12000	40000
NWT River	16000	56000
Nunavut	8000	16000
Total	50000	161000

Remote Site Resupply Program



- Annual funding of ~\$500,000, used for O&M and capital works
- Recent major projects
 - construction of a breakwater at Lutselk'e
 - expansion of the Inuvik facilities
 - finalization of the complete marine system inventory
- DFO wants to devolve ownership to GNWT or others



Northern Marine Voyages - 2009



- Northwest Passage transits:
 - 3 Coast Guard sailings
 - 2 commercial sailings
 - 8 pleasure craft sailings
 - 4 cruise ship sailings (592 Passengers)
- Eastern Sealift:
 - 7 Woodward's tanker sailings to Iqaluit
 - 4 Woodward's tanker sailings to Rankin Inlet
 - 3 Woodward's tanker sailings to Cape Dorset & Baker Lake
 - 1 or 2 Woodward's tanker sailings to all other Kivalliq and Qigitaalik communities
 - 1 or 2 NSSI and NEAS dry cargo resupply ship sailings to all Nunavut communities

Northern Marine Voyages - 2009



- Western Sealift:
 - 2 NTCL charter tanker sailings from West Coast to Western Arctic communities
 - 3 NTCL bulk/deck cargo barge sailings from Hay River to Western Arctic communities
- Mackenzie River Sailings:
 - 14 NTCL bulk/deck cargo barge sailings from Hay River to Mackenzie River communities
 - 9 Cooper's barge sailings from Fort Nelson to Tulitù and Norman Wells

Northern Marine Voyages - 2009



➤ Inside Passage Sailings:

- 52 scheduled container barge sailings to Skagway and Haines
- 12 scheduled fuel barge sailings to Skagway and Haines
- 424 cruise ship sailings to Skagway and Haines (779,043 passengers)

➤ Hudson Bay Sailings:

- 18 bulk ships loading grain for export
- 1 NTCL barge sailing to Kivalliq



Marine Summary Reports



➤ Marine summary reports developed in partnership with the Department of Public Works

- Community Re-Supply Options and Costs
- Deep Draft Access to the Western Arctic
- Delivery Costs for Dry Cargo to Western Arctic Communities
- Hay River Water Depths
- Fuel Specification Issues to Western Arctic Petroleum Product Deliveries
- Petroleum Products Delivery to Service Western Arctic Communities
- Reorganization of Pipelines, Manifolds, & Lay down Areas for Paulatuk, Sachs Harbour and Ulukhaktok
- Re-Supply Forecasts for the Western Arctic
- Western Arctic Access Routes
- Tuktoyaktuk Channel Dredging
- Western Arctic Re-Supply Study – Summary Report

Ferries and Marine



On Track - Department of Transportation 2011

Deh Cho Bridge



On Track - Department of Transportation 2011

Producing Mines 2011



Mineral Exploration 2011



Oil and Gas Exploration 2011



Resource Development Challenges



- Uncertain and unpredictable regulatory process
- Land use issues
 - Unsettled claims
 - Land use plans not finalized
 - Protected areas
- Global influences such as commodity prices and demand
- Lack of supporting infrastructure

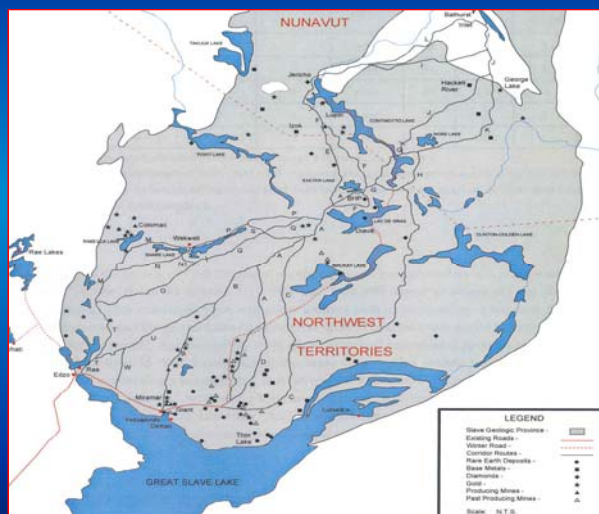
McGraw-Hill
Higher Education



Inuvik to Tuktoyaktuk Highway



Slave Geologic Province Potential



Seasonal Overland Road



Over the Top - Marine Route



Major Challenges & Issues



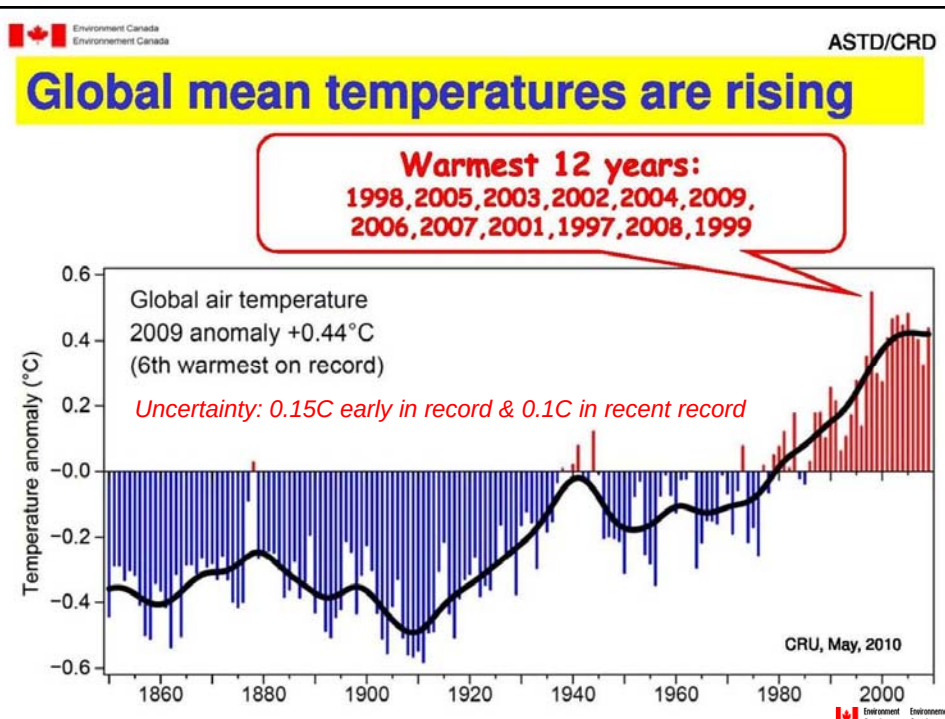
- Increased pressure on river system as the Mackenzie Gas Project and other resource developments proceed (+ 450 barges/ year)
- Over the Top route could increase usage/provide economic opportunities
- PPD bringing in fuel from Over the Top
 - Potential shifts in community fuel resupply mechanisms
- No capacity issues envisioned
- Mitigation measures could include traffic zone reporting, designated passing zones, and others
- Climate Change
- Networks of Expertise: Marine & Permafrost

Questions?



Climate Change and Northern Transportation

Heather Auld, S. Cheng, N. Comer
Environment Canada

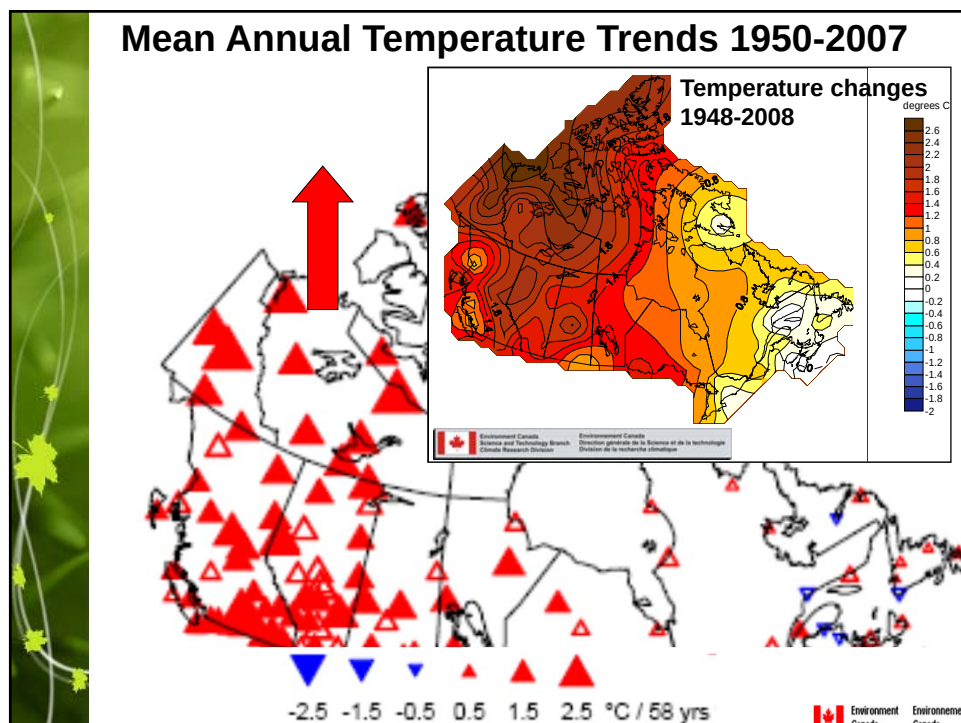


WHAT WE DO KNOW ABOUT CHANGING EXTREMES in the NORTH?

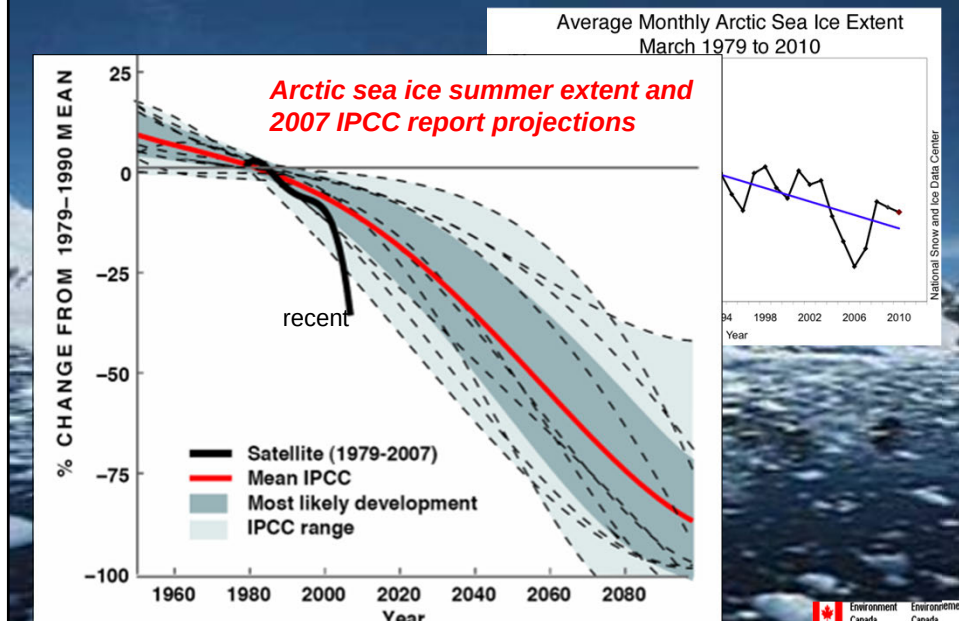
- Canada warmed at almost twice the rate of global average.
- Permafrost and ice melting in North is occurring faster than climate model projections indicated.

- Arctic, like many regions of Canada, tending towards wetter conditions (45% increase in precipitation in high Arctic)
- Extreme snowfalls likely increasing in western Arctic

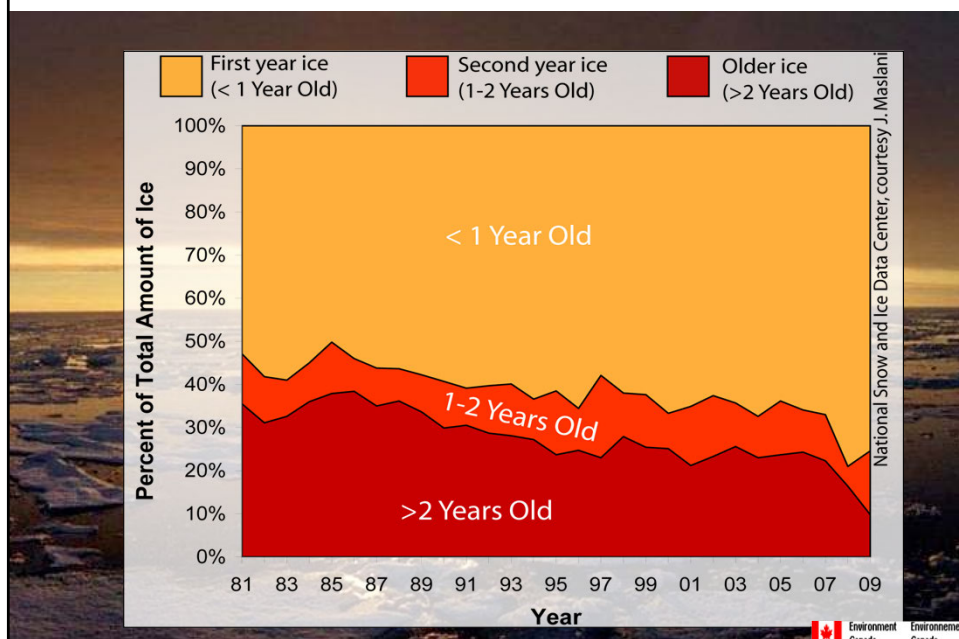
Impacts from precipitation extremes appear to be increasing



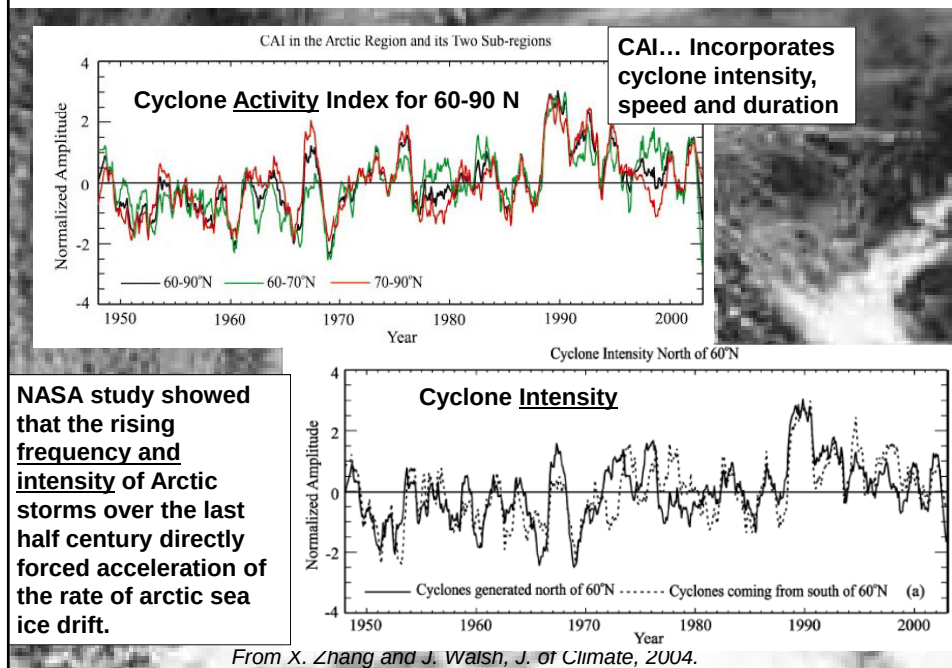
Arctic ice is melting much faster (by some 35 years) than projected by most climate models...



Multi-Year Arctic Ice is Thinning... Transportation implications



Shifting Storm Tracks ... Increasing Storm Intensities

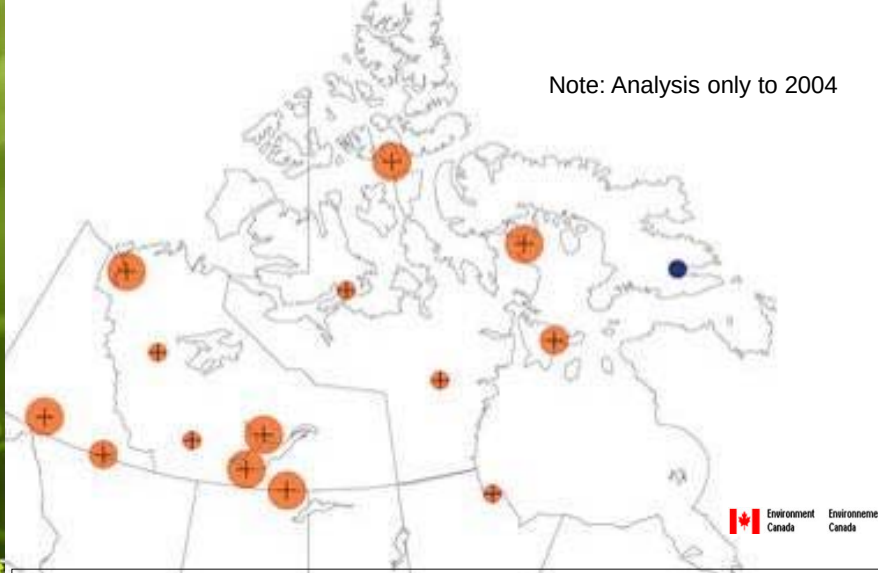


Storm Surges, Flooding... More Hazardous Weather, Disaster Management and Community Planning



More Freezing Rain Events... Statistically Significant Trends for Period 1953-2004

Note: Analysis only to 2004

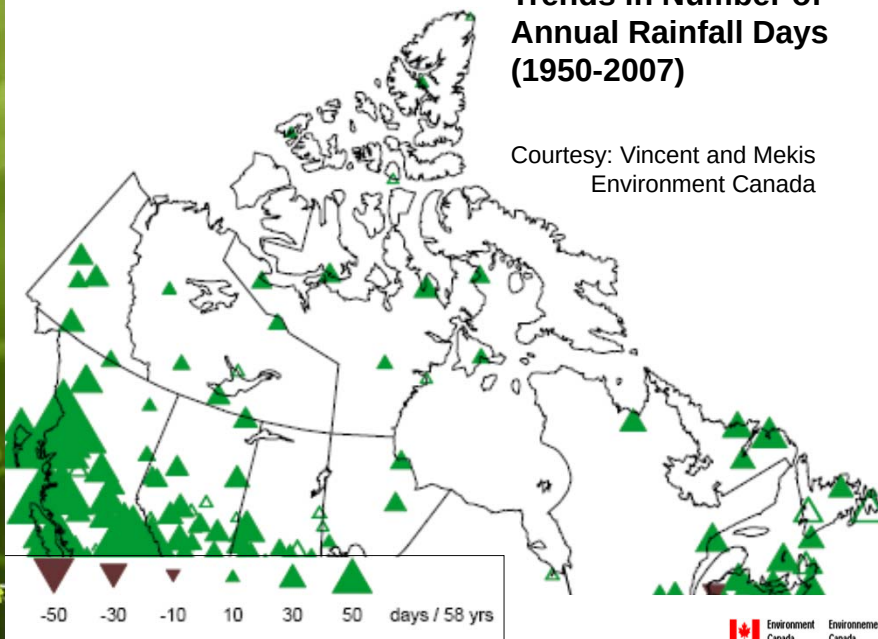


Hanesiak & Wang, Adverse Weather Trends in the Canadian Arctic. J. Climate, 2005

Rainfall Trends

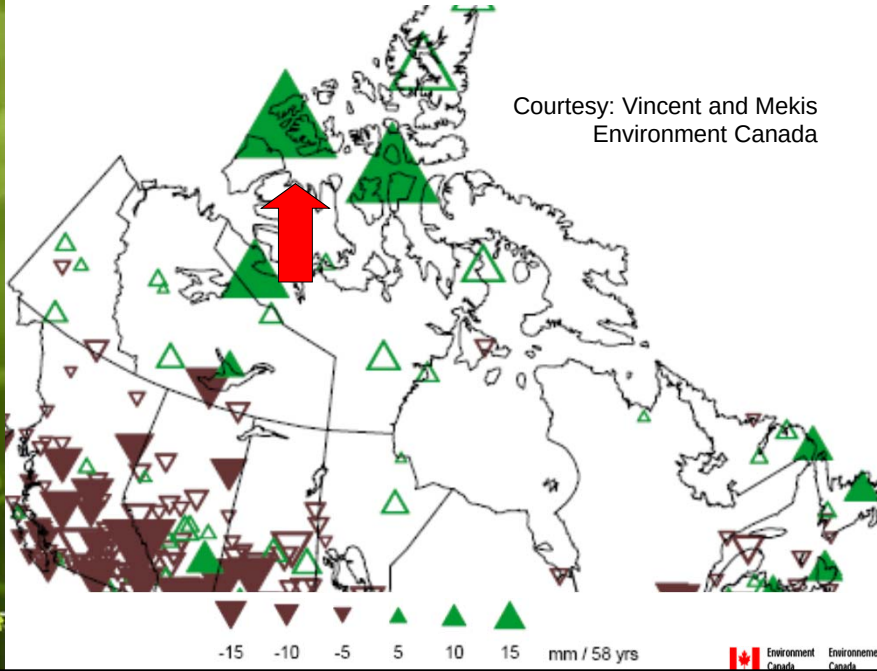
Trends in Number of Annual Rainfall Days (1950-2007)

Courtesy: Vincent and Mekis
Environment Canada



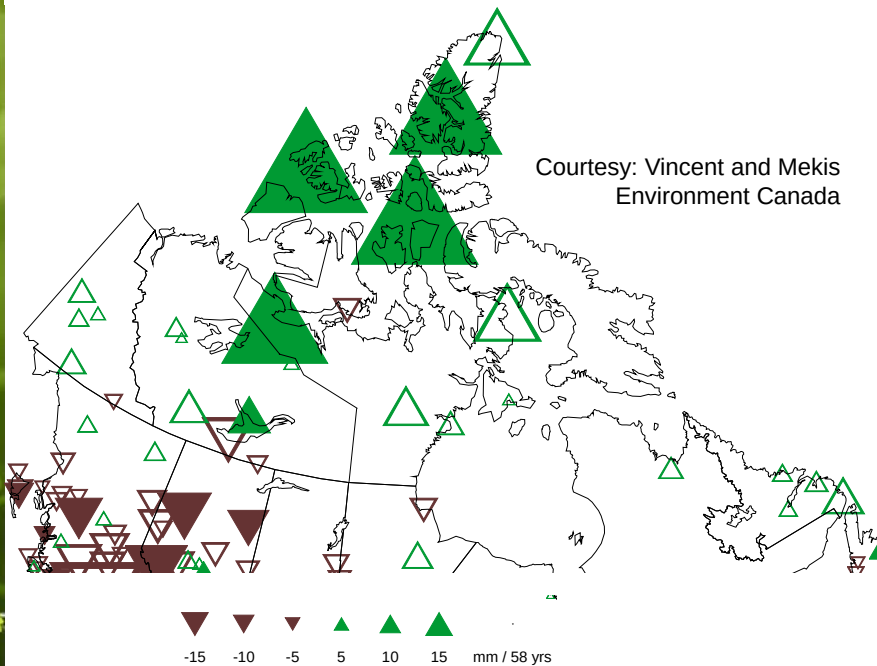
Trends in Highest One-Day Snowfalls: 1950-2007

Courtesy: Vincent and Mekis
Environment Canada

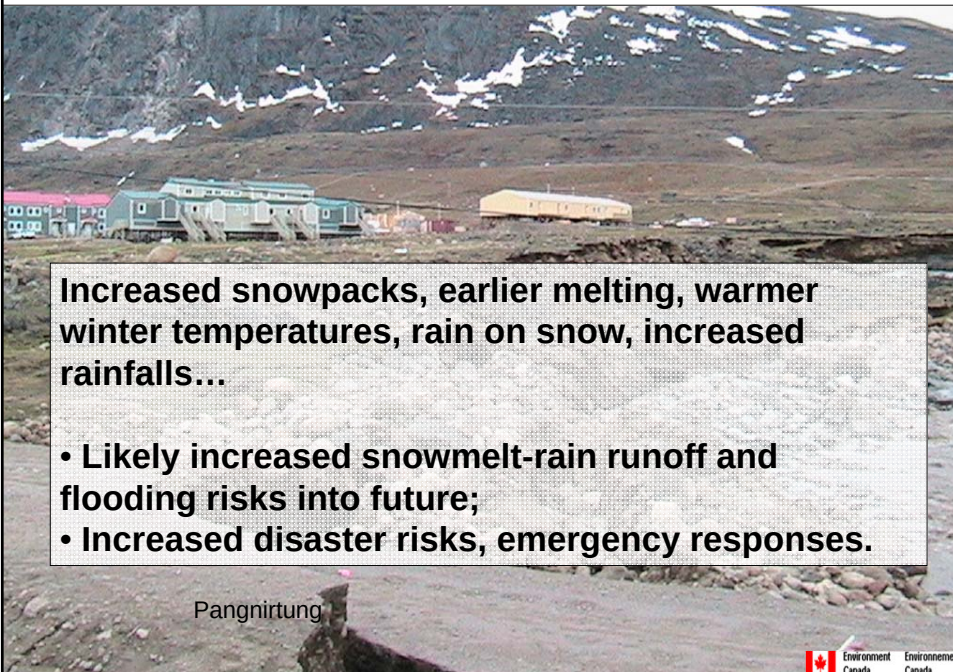


Trends in Highest Three-Day Snowfalls: 1950-2007

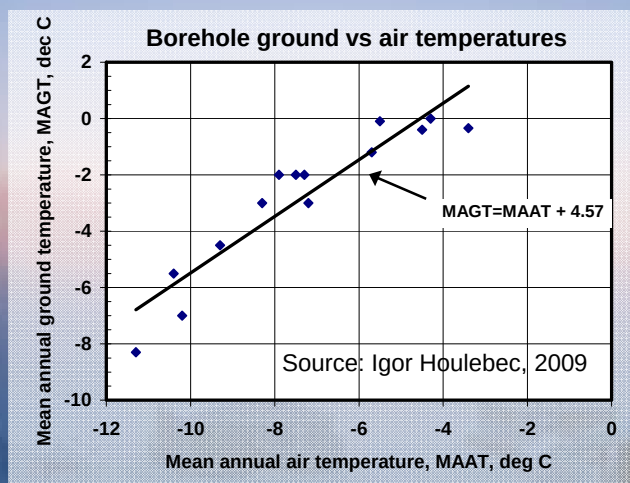
Courtesy: Vincent and Mekis
Environment Canada



Changing Snowmelt Conditions & Increased Flooding Risks



Ground Temperatures Related to Air Temperatures



Ground temperatures near surface will warm with air temperature increases ... with melting permafrost and decreasing stability of natural slopes and infrastructure in permafrost regions...

Now lets look at specific changes projected by Climate Models

- For the North...

CLIMATE MODEL PROJECTIONS: Probability
of daily extreme precipitation events to
increase by **AT LEAST** a factor of 2 before end
of 21st century

Climate Models and Projected Changes: Inuvik Temperatures

Table 17 Projected annual and seasonal average **daily temperature change increments** for Inuvik compared to the 1970-2000 **normals** recorded

°C	annual	winter	spring	summer	autumn
2020s	+1.5	+2.3	+1.3	+0.9	+1.7
2050s	+3.0	+4.6	+2.6	+1.7	+3.4
2080s	+5.3	+8.0	+4.9	+2.9	+5.6

Table 18 Projected annual and seasonal average **daily temperatures ranges** for Inuvik compared to the 1971 -2000 **normals** recorded

°C	annual	winter	spring	summer	autumn
1971-2000	-8.7	-26.7	-11.9	12.1	-8.5
2020s	-7.2 ± 0.6	-24.4 ± 1.0	-10.6 ± 0.6	13.0 ± 0.5	-6.8 ± 1.0
2050s	-5.7 ± 0.8	-22.1 ± 1.2	-9.3 ± 0.8	13.8 ± 0.8	-5.1 ± 1.2
2080s	-3.4 ± 1.2	-18.7 ± 1.9	-7.0 ± 1.4	15.0 ± 1.3	-2.9 ± 1.6

Climate Models and Projected Changes: Inuvik Precipitation

Table 19 Projected annual and seasonal **precipitation change increments** for Inuvik

mm	annual	winter	spring	summer	autumn
2020s	+10.9	+2.9	+1.3	+2.7	+4.4
2050s	+30.1	+6.5	+4.9	+8.3	+10.9
2080s	+53.5	+11.2	+7.9	+16.3	+18.7

Table 20 Projected annual and seasonal **precipitation ranges** for Inuvik compared to the 1971 -2000 **normals** recorded

mm	annual	winter	spring	summer	autumn
1971-2000	248.4	41.0	38.4	95.4	73.7
2020s	259.3 ± 12.1	43.9 ± 3.0	39.7 ± 1.8	98.1 ± 7.5	78.1 ± 5.3
2050s	278.5 ± 17.2	47.5 ± 3.7	43.3 ± 3.5	103.7 ± 7.5	84.6 ± 7.5
2080s	301.9 ± 23.2	52.2 ± 6.7	46.3 ± 4.0	111.7 ± 9.7	92.4 ± 11.2

Climate Models and Projected Changes: Hay River Temperatures

Table 13 Projected annual and seasonal average **daily temperature change increments** for Hay River compared to the 1970-2000 **normals** recorded

°C	annual	winter	spring	summer	autumn
2020s	+1.2	+1.9	+1.0	+0.8	+1.3
2050s	+2.6	+3.8	+2.1	+2.0	+2.5
2080s	+4.5	+6.6	+3.8	+3.5	+4.3

Table 14 Projected annual and seasonal average **daily temperatures ranges** for Hay River compared to the 1971 -2000 **normals** recorded

°C	annual	winter	spring	summer	autumn
1971-2000	-2.9	-21.2	-3.7	14.3	-1.0
2020s	-1.7 ± 0.5	-19.3 ± 1.0	-2.7 ± 0.5	15.1 ± 0.4	0.3 ± 0.6
2050s	-0.3 ± 0.7	-17.4 ± 1.4	-1.6 ± 0.6	16.3 ± 0.8	1.5 ± 0.8
2080s	1.6 ± 1.1	-14.6 ± 1.8	0.1 ± 1.2	17.8 ± 1.1	3.3 ± 1.2

Climate Models and Projected Changes: Hay River Precipitation

Table 15 Projected annual and seasonal **precipitation change increments** for Hay River

mm	annual	winter	spring	summer	autumn
2020s	+14.7	+1.8	+2.5	+5.3	+6.3
2050s	+30.2	+5.1	+5.4	+8.9	+11.7
2080s	+50.1	+8.6	+8.8	+12.6	+21.3

Table 16 Projected annual and seasonal **precipitation ranges** for Hay River compared to the 1971 -2000 normals recorded

mm	annual	winter	spring	summer	autumn
1971-2000	320.9	45.9	51.1	126.8	97.1
2020s	335.6 ± 15.2	47.7 ± 3.1	53.6 ± 3.2	132.1 ± 11.7	103.4 ± 10.5
2050s	351.1 ± 20.6	51.0 ± 3.7	56.5 ± 4.2	135.7 ± 14.3	108.8 ± 7.2
2080s	371.0 ± 32.7	54.5 ± 5.1	59.9 ± 6.3	139.4 ± 23.6	118.4 ± 9.6

Now lets look at specific changes projected by Climate Models

Table 19 Projected annual and seasonal **precipitation change increments** for Inuvik

mm	annual	winter	spring	summer	autumn
2020s	+10.9	+2.9	+1.3	+2.7	+4.4
2050s	+30.1	+6.5	+4.9	+8.3	+10.9
2080s	+53.5	+11.2	+7.9	+16.3	+18.7

Table 20 Projected annual and seasonal **precipitation ranges** for Inuvik compared to the 1971 -2000 normals recorded

mm	annual	winter	spring	summer	autumn
1971-2000	248.4	41.0	38.4	95.4	73.7
2020s	259.3 ± 12.1	43.9 ± 3.0	39.7 ± 1.8	98.1 ± 7.5	78.1 ± 5.3
2050s	278.5 ± 17.2	47.5 ± 3.7	43.3 ± 3.5	103.7 ± 7.5	84.6 ± 7.5
2080s	301.9 ± 23.2	52.2 ± 6.7	46.3 ± 4.0	111.7 ± 9.7	92.4 ± 11.2

Faye Hicks

faye.hicks@ualberta.ca

River Flow Forecasting Ice Process Modeling and Ice Flood Forecasting

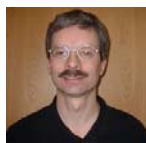


Prepared for:



Northwest Territories Transportation

Collaborations



Dr. Mark Loewen, University of Alberta

- *River freeze-up studies and ice effects on aquatic habitat*



Robyn Andrishak, AMEC Earth and Environmental

- *Hydraulic and ice process model development and custom applications*

Additional Collaborations:

- *Lance Lesack (SFU) and Phil Marsh (Env. Canada): Mackenzie Delta hydrology and ecology*
- *Shawne Kokelj and Meg McCluskie (AANDC): Hay River ice jam flood forecasting*
- *Joost van der Sanden (CCRS): Satellite remote sensing of river ice*
- *Rick Cunjak (Canadian Rivers Institute): ice effects on fish productivity*

Mackenzie Basin Routing Model - MRBB

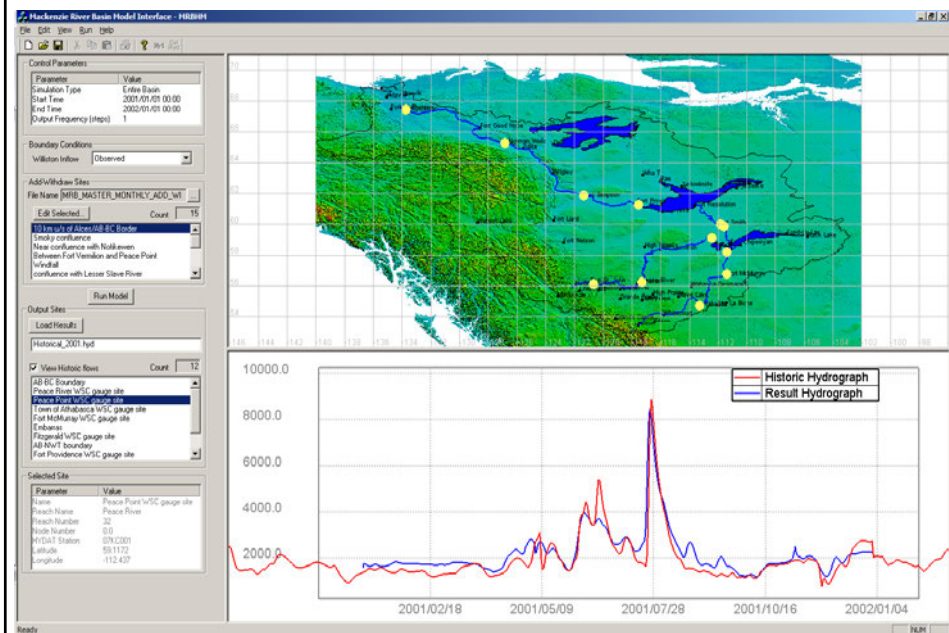
- Employs the *River1D* flow routing model
- Includes all major water courses and storage elements:

- ✓ Athabasca River
- ✓ Peace River
- ✓ Peace Athabasca Delta
- ✓ Slave River
- ✓ GSL
- ✓ Mackenzie River

- Capable of examining the effects of various hypothetical water management strategies

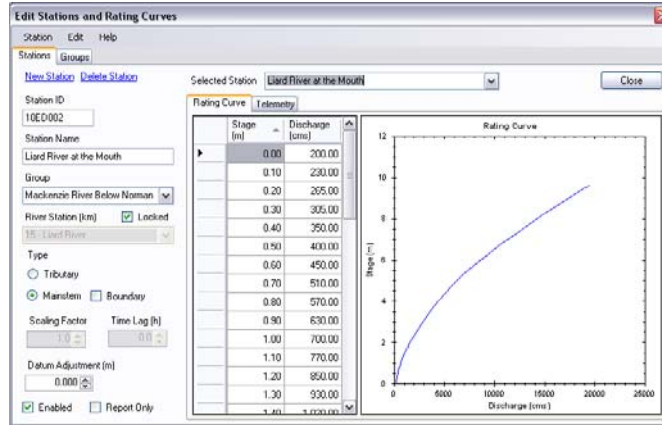


Mackenzie Basin Routing Model - MRBB

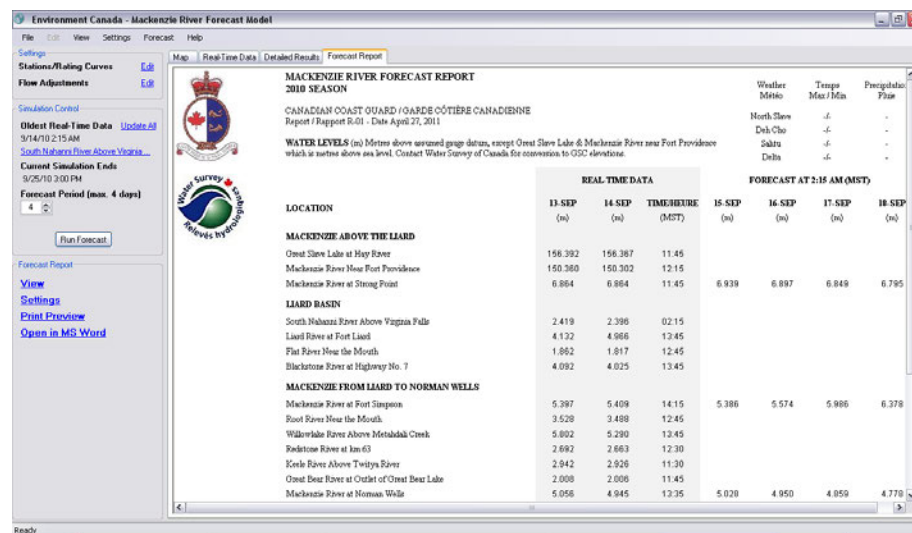


Environment Canada – Mackenzie River Forecast Model

- Employs the [River1D](#) flow routing model
- Operational forecasting model – predicts flows at key sites
 - these are converted to water levels using site specific rating curves



Environment Canada – Mackenzie River Forecast Model



Mackenzie Delta Routing Model



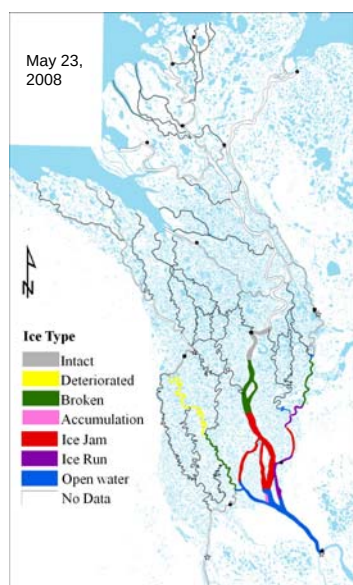
Model Channels

- █ Primary Importance
- █ Secondary Importance
- █ Tertiary Importance

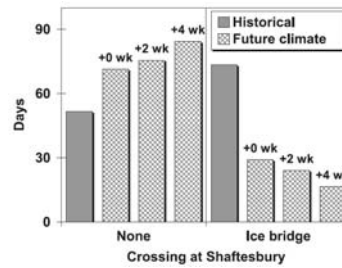
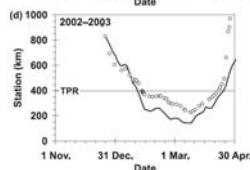
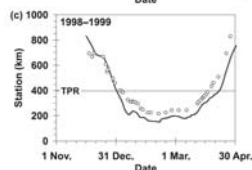
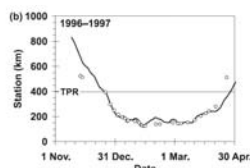
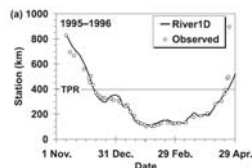
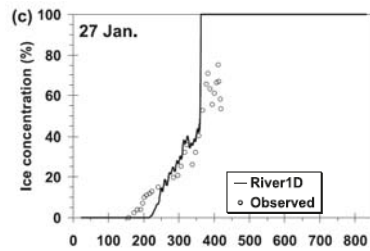
Hydrometric Stations

- Only Water Level Available
- Flow Data Available
- ▲ Inflow Boundary Condition

Mackenzie Delta Routing Model

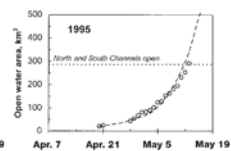
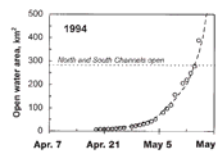
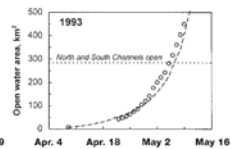
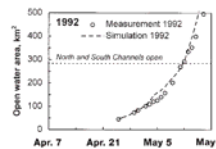


Peace River Ice Process Modelling



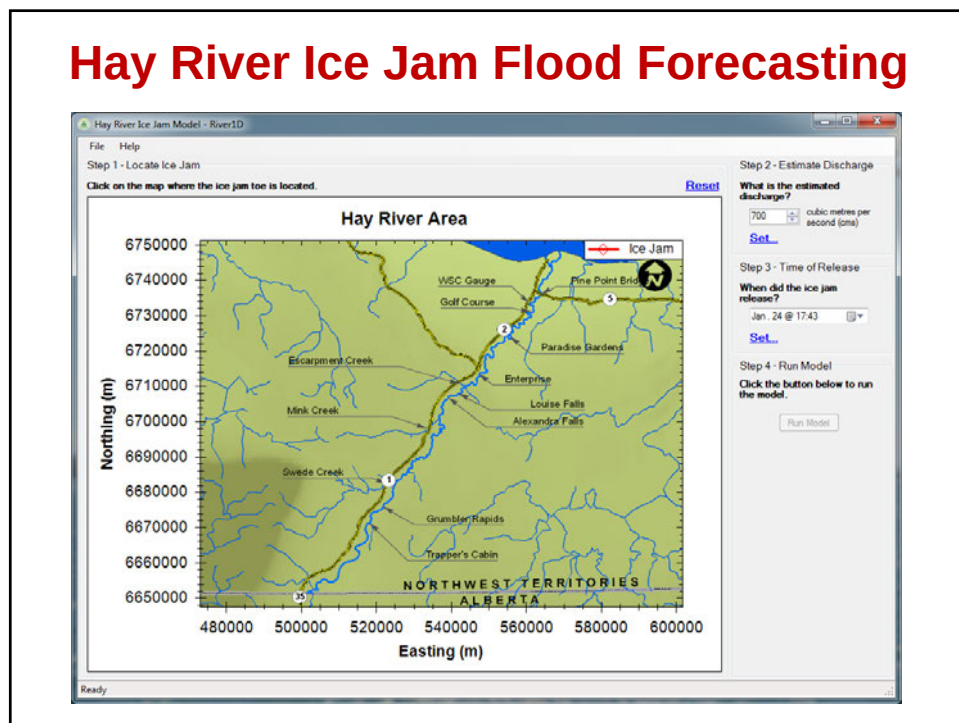
Mackenzie River Breakup Forecasting

Photo courtesy of GNWT





Hay River Ice Jam Flood Forecasting







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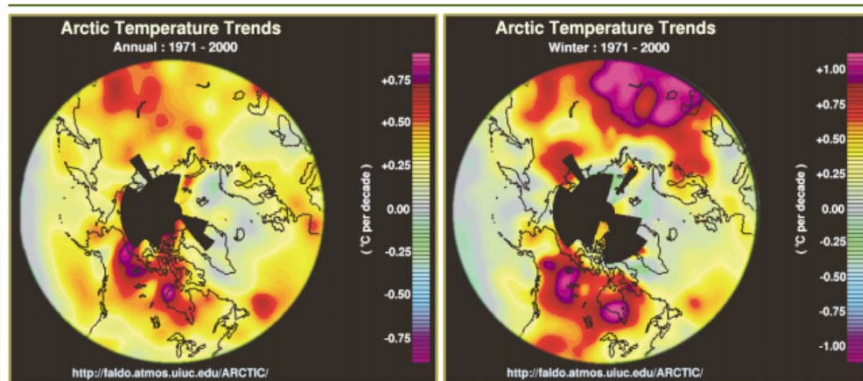
Environnement
Canada

Canada

Permafrost and Hydrology Considerations for NWT Marine and Ferry Services in a Changing Climate

Christopher Spence
National Hydrology Research Centre
Saskatoon, Saskatchewan

Recent warming

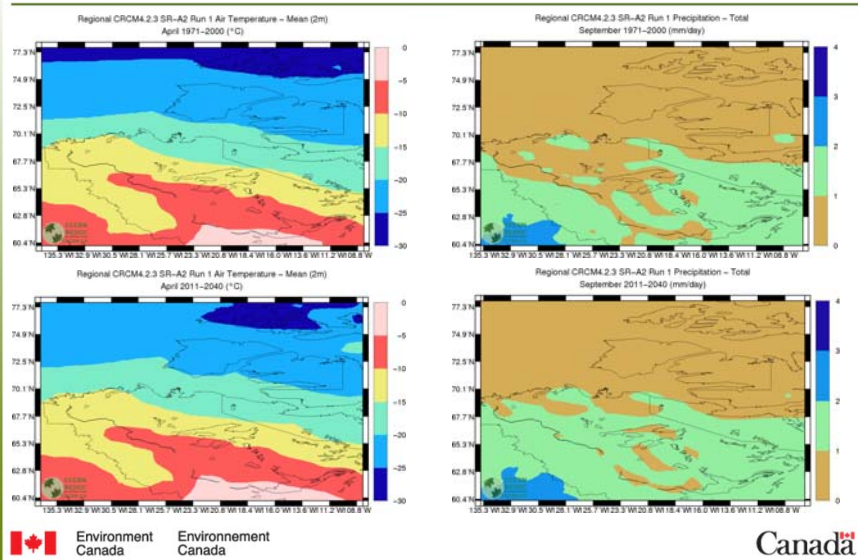


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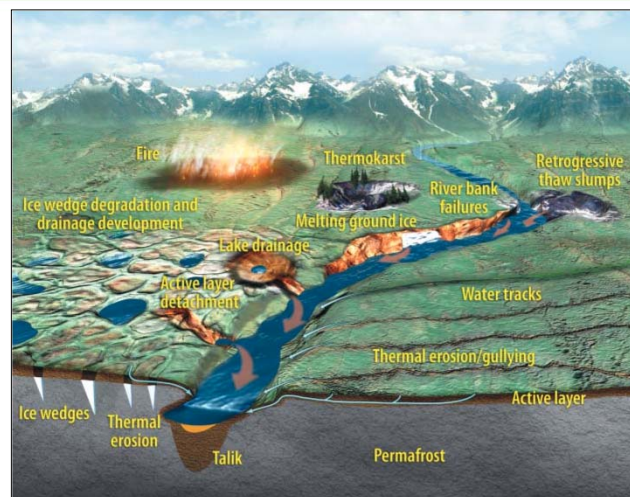
Environnement
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Projected climate change

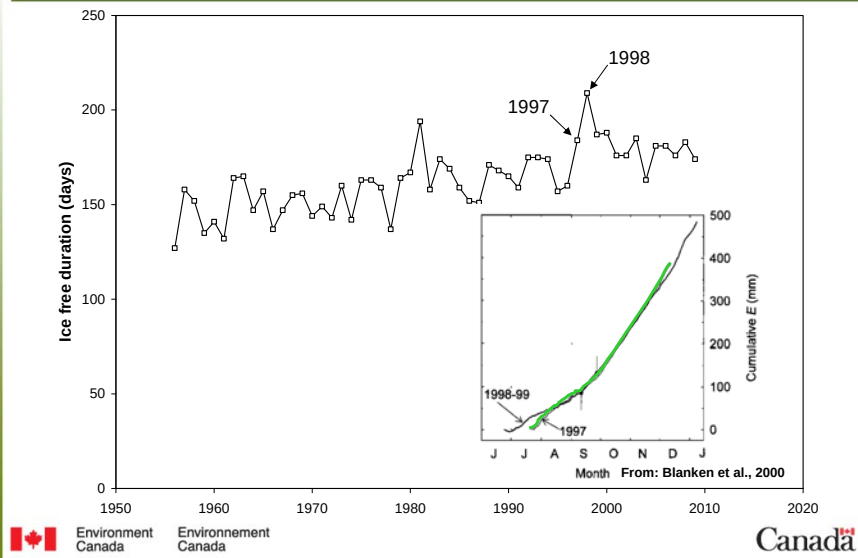


Impacts on hydrology

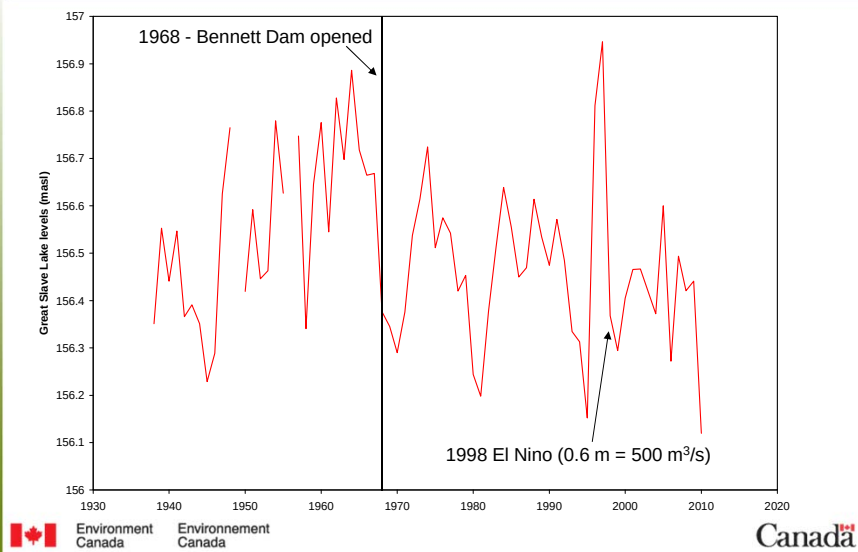


From: Rowland et al., 2010

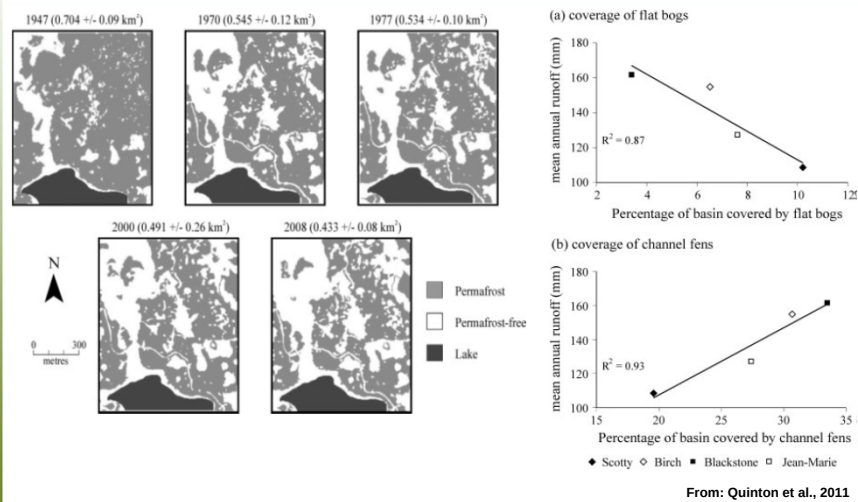
Great Slave Lake



Great Slave Lake



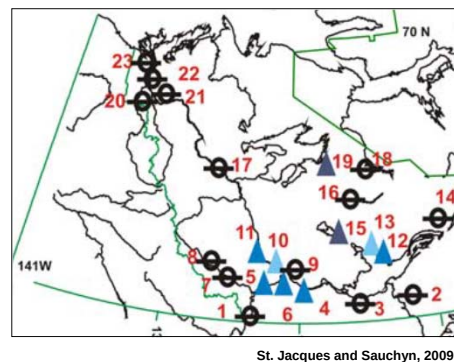
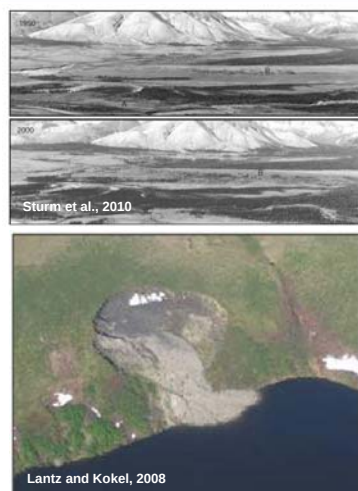
Permafrost degradation



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Landscape change



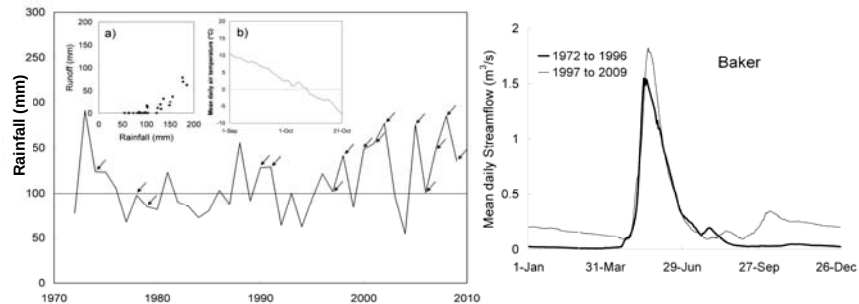
St. Jacques and Sauchyn, 2009

Environment Canada / Environnement Canada

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Changes to precipitation regimes

- Any changes around 0°C have profound effects on hydrology



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Impacts on ferry and marine operations

- There are no shortage of documented climate induced changes to the permafrost and hydrological regimes in the NWT.
- Impacts need to be framed by the season and scales in which ferry and marine operations occur.
- There is a risk of an increase in evaporation from Great Slave Lake due to longer ice free periods and this may result in more common low flows to the Mackenzie River.
- Tributary streamflow is increasing, but largely in winter, and these have not manifested into trends in Mackenzie or Liard River flow.
- There have been few attempts to connect small scale physical with large scale trend studies.



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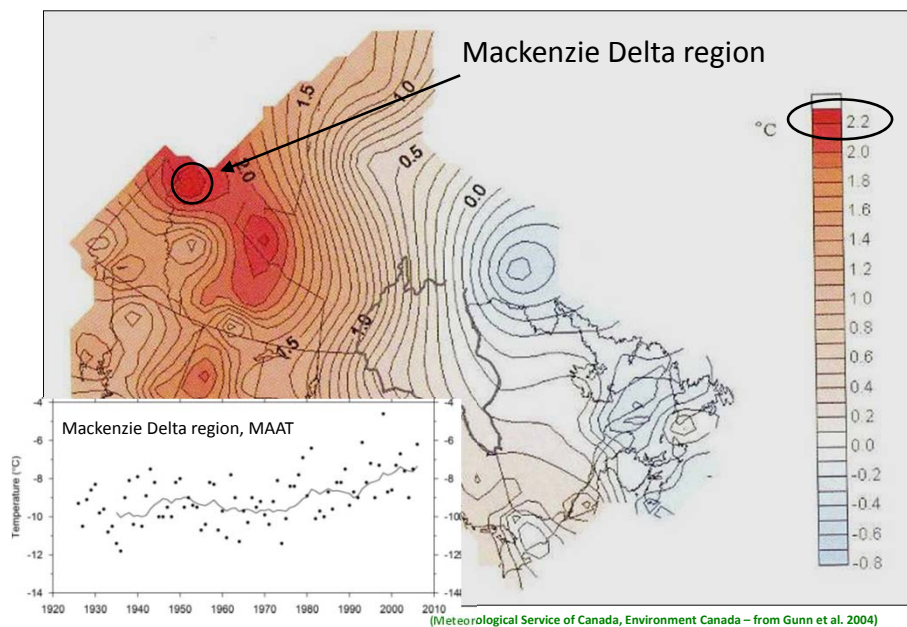
Environnement
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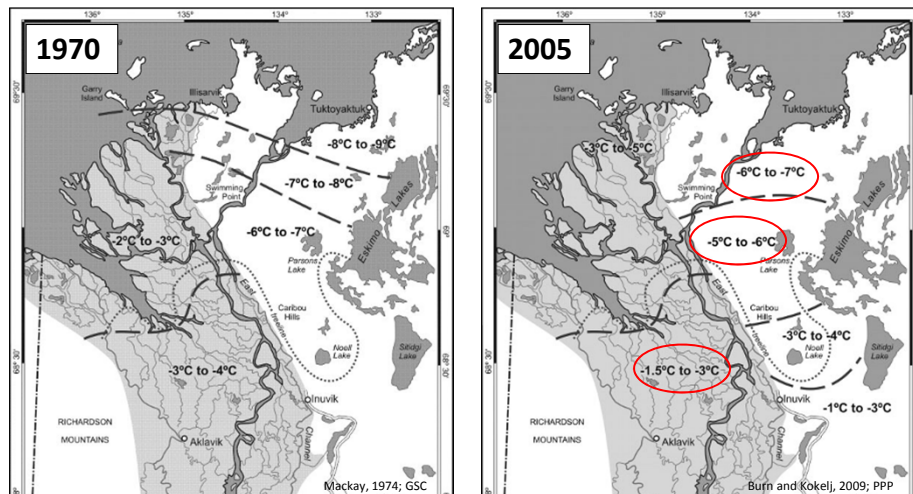
Permafrost issues and marine transportation

Steve Kokelj

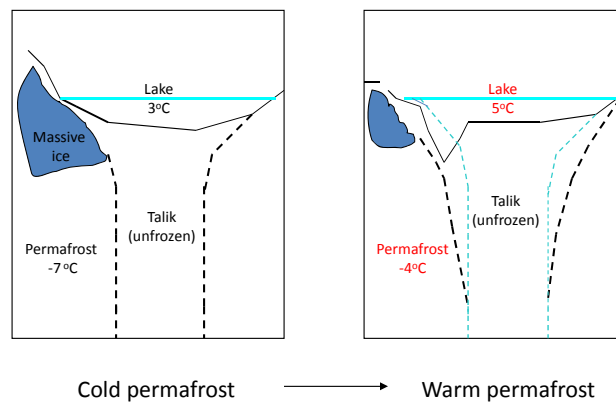
Observed changes in mean annual air temperature – 1948 to 2000



Climate warming and permafrost



Talik adjustment due to warming

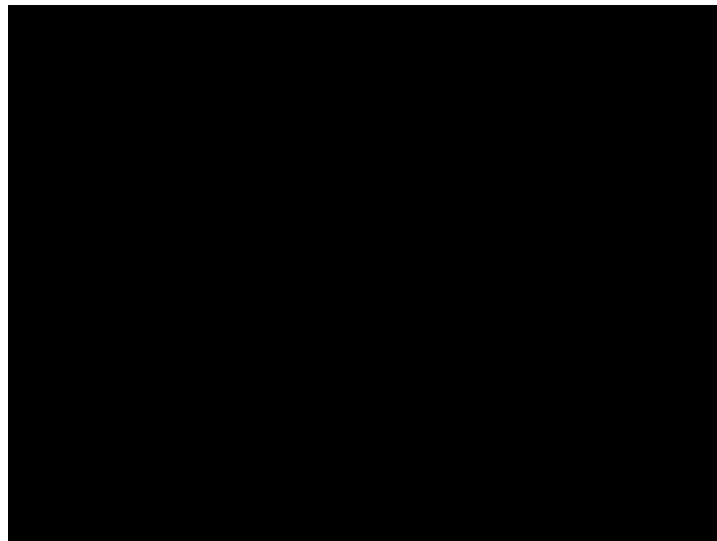




Hundreds of disturbances in Peel Plateau and
Mackenzie Mountains foothills may impact
sediment regimes in large rivers



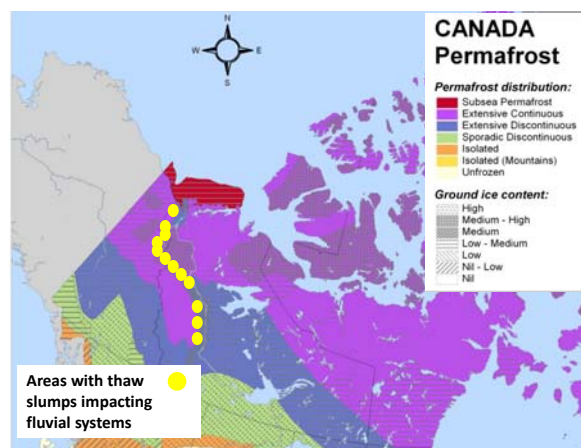
Conveyor belt of sediment transport from slopes
to streams



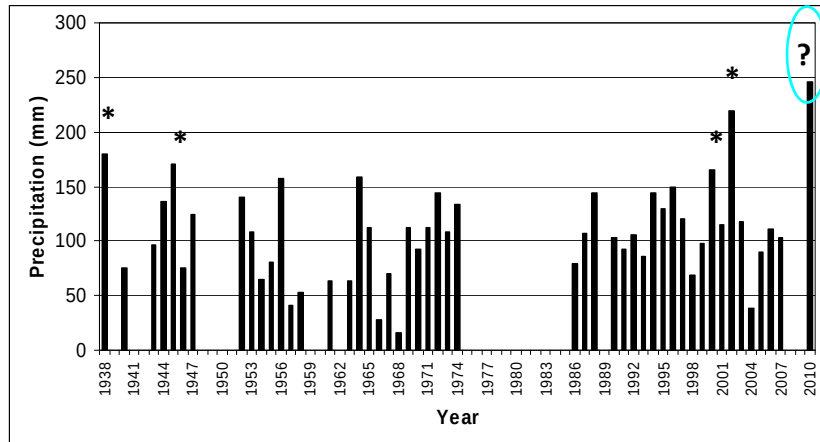
Slumps cause sediment in the river to increase
This impacts what lives in the streams



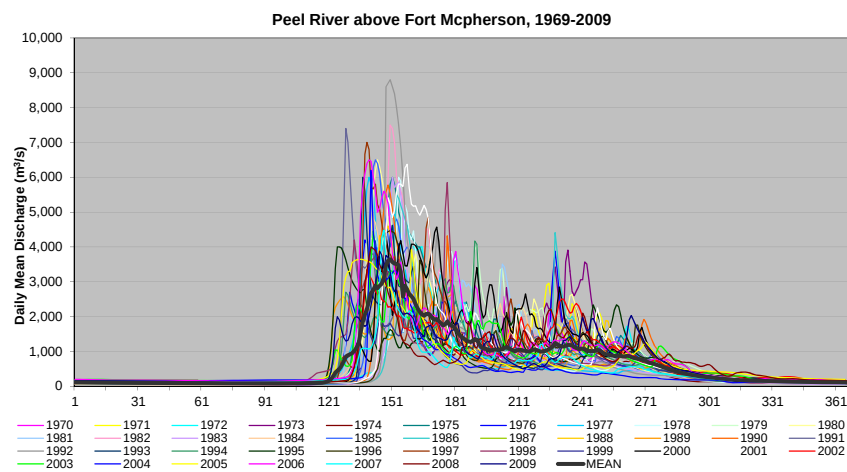
Rivers draining Mackenzie and Richardson
Mountains most impacted



Fort McPherson summer rain (mm)

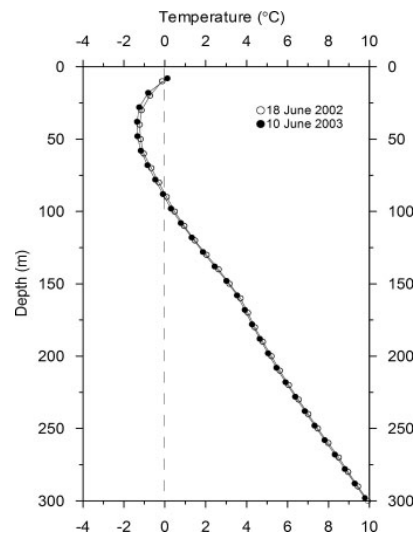


Variability in water levels



Inuvik quarry – thermal regime

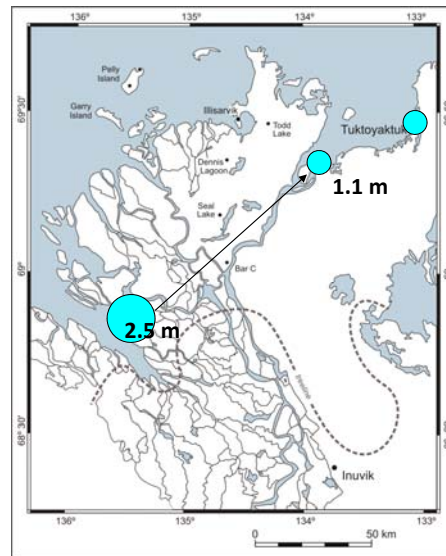
- Disturbance leads to degradation of permafrost
- Effects are also seen at burns and sumps



Quarries



Storm surge in 1999 yielded peak water levels in the central outer Delta



Summary

- Permafrost warming – shoreline stability
- Increased stream sediment loads – thaw slumping
- Increased variability in water levels – ferry approaches
- Managing quarries – to support ferry operations
- Intensity of storms is likely to increase – issues related to marine travel, stability of ports

Pre Workshop Interviews

Ron Macdonald, Stantec
Marine Transportation Workshop
January 25 & 26, 2012
Yellowknife

Interviewed

- GNWT DoT staff – Marine ops, Petroleum Products Division, ENR – climate change adaptation, Oil & gas division
- Canadian Hydrographic Service (ecosystems science section)
- Coast Guard (Wilfred Laurier, Mackenzie R)
- Canadian Ice Service
- Private Shipping Company Captain

Key Interview Questions

- Q1: Describe your job, your role, etc.
- Q2: What components of climate and weather affect your operation?
- Q3: Have you noted any changes in climate / weather – related to your work?

Q2: Weather & Climate Issues

- Visibility (fog, heavy rains)
- Wind (lesser concern on the river than ocean)
- Water levels (too high or too low)
- Debris from the Liard R. (freshet and storms)
- Breakup – ice on shores
- Freeze up timing (river and marine)
- Loss of navigation aids (debris, ice, shoreline erosion)
- Break up timing

Q3: Observed changes...

Weather

- Winters more moderate
- More snow in winter
- Summer rains “seem to be stronger”

Rivers

- Increasing operational period – longer fall
- Some rivers less flashy with precipitation
- Shoreline erosion – river and coastal
- More landslides on the shore
- Heavy mist seems more common (river)

Marine / Ocean

- Less ice, less old ice, less ice thickness
- Less ice breaking time
- Less “bad years”

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Prepared for:



Marine and Ferry Services Workshop

Evan Davies
Civil and Environmental Engineering
University of Alberta

Yellowknife, NWT, January 26, 2012



Research Interests

- * Water resources planning and management
- * Climate- and global change adaptation
- * Connections – “feedbacks” – between
 - * Climate, water, natural resources and energy, and socio-economic development



Decision Support Tools

- * Simulation models that answer “what if” questions
- * Identify effects (short- or long-term) of operations or policy options
- * Identify “surprises”, understand connections
- * Make mistakes in virtual world → avoid problems in real world
- * Combine many connected sub-systems into one

General Approach: Systems

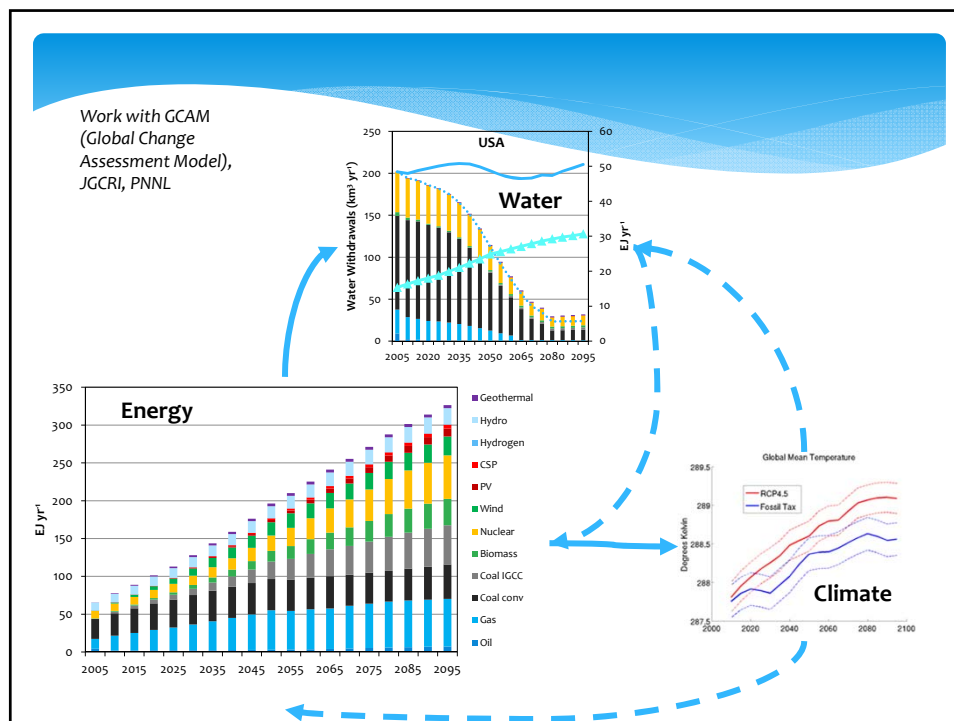
- * General approach to solving problems:

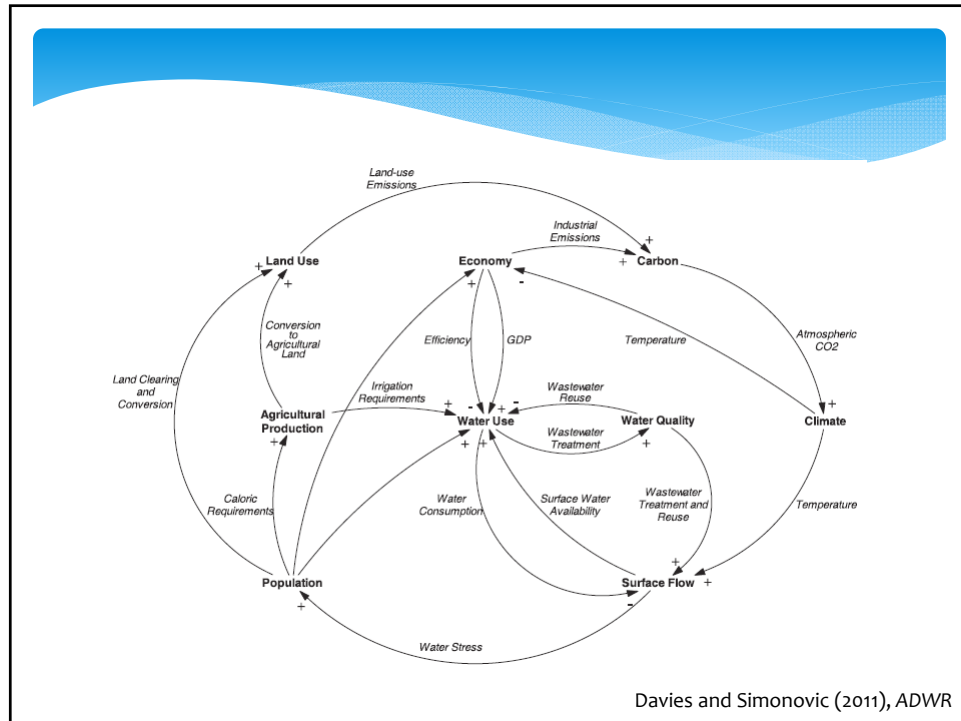
Systems thinking is “a general problem-solving technique that brings more objectivity to the planning/design process.

It is, in essence, good design: a logical and systematic approach to problem solution in which assumptions, goals, objectives, and criteria are clearly defined and specified” (Simonovic 2009)

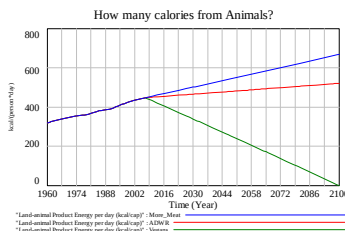
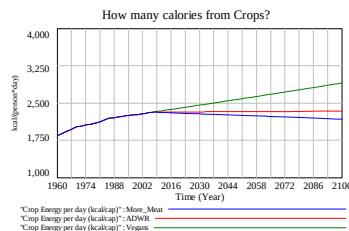
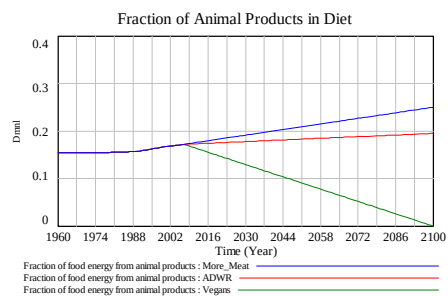
Example: Integrated Assessment

- * Integrated assessment models
 - * Evaluate consequences of and responses to climate and global change
 - * Structure knowledge, characterize uncertainty
 - * Connect climate change with other ongoing environmental and socio-economic changes
- * Key components:
 - * Policy relevance
 - * Stakeholder participation

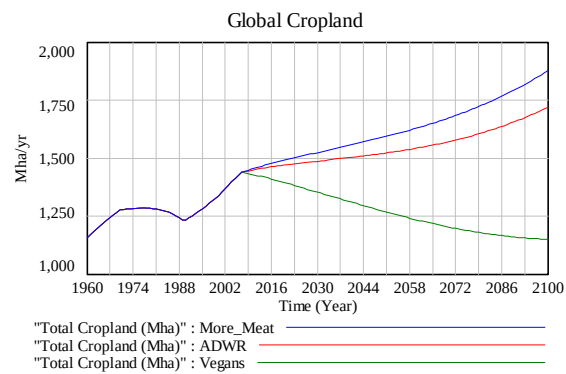




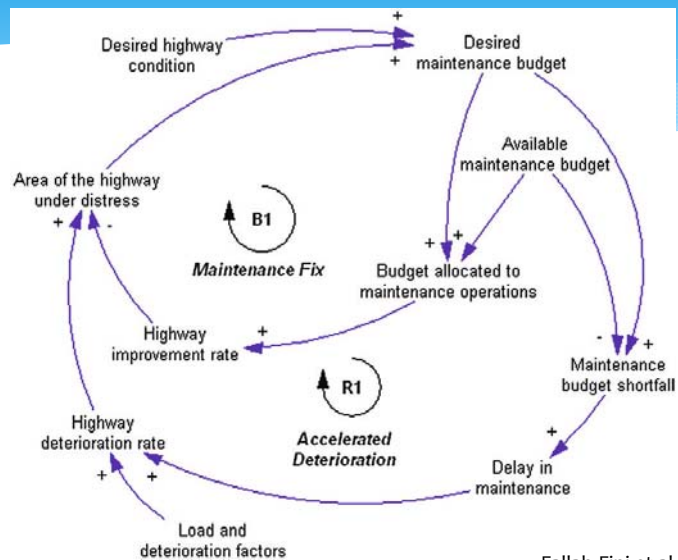
Model Use: Develop Scenarios



Effects...

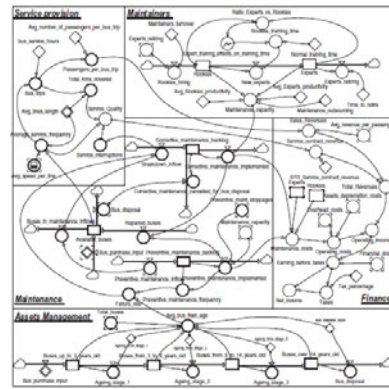
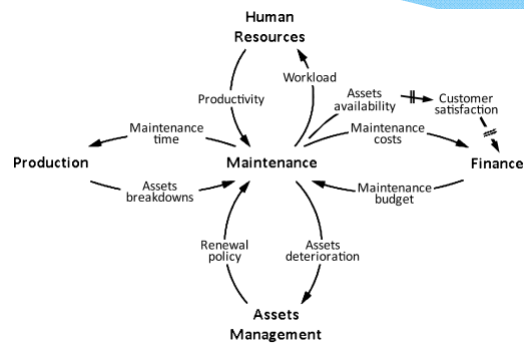


Road Maintenance



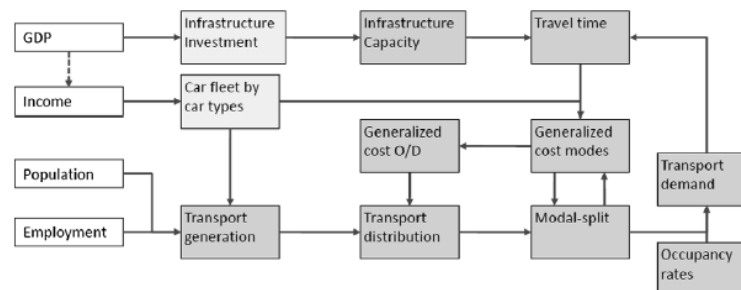
Fallah-Fini et al. (2010), SDR

Bus Fleet Management



Bivona et al. (2010), SDR

Generation of Traffic



Fiorello et al. (2010), SDR

Experience

evan.davies@ualberta.ca

- * Integrated assessment modelling
 - * NSERC-funded climate-economy-water-society model
 - * GCAM work with Pacific Northwest Nat'l Lab
 - * AAFC-funded Invitational Drought Tournament
 - * Climate change, energy production and infrastructure (NU)
- * Water resources
 - * AWRI-funded efficient water use for irrigation
 - * Water quality on Samson Cree Nation
 - * Municipal water use and GIS



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Canadian Ice Service – Western Arctic ice regime



GNWT DOT Marine / Ferry Workshop
Yellowknife, NWT
Gaetan Langlois
Canadian Ice Service
Jan 25-26, 2012

Canadian Ice Service (CIS) www.ec.gc.ca/glaces-ice

What we do

- Provide ice information in support of:
 - Ship routing
 - Icebreaking ops
 - Climate monitoring
 - Weather forecasting
- Monitoring for oil spills
- Ice Reconnaissance
- Ice Analysis and Forecasts
- Product Distribution and Archive
- Applied Science



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Monitoring

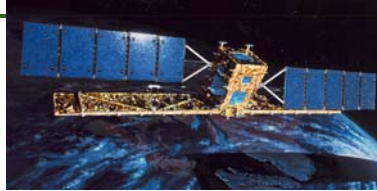
Satellites

- RADARSAT
- Envisat
- NOAA AVHRR
- Modis



Aircraft reconnaissance

- Fixed wing
- Helicopter



Ship reports

- CCG ice breakers
- Commercial ship reports



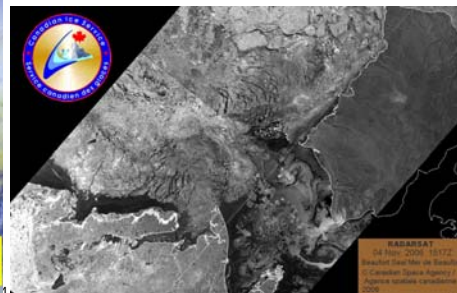
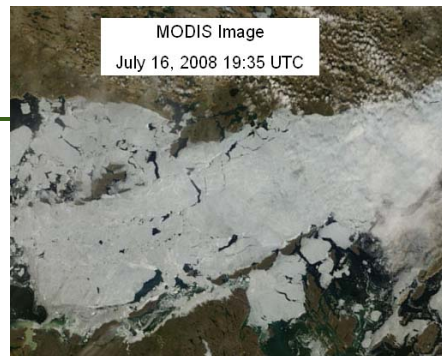
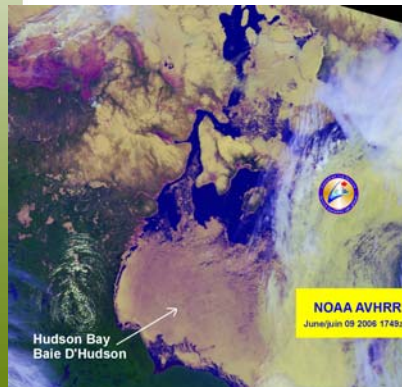
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Satellites

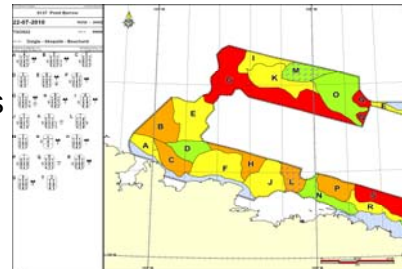
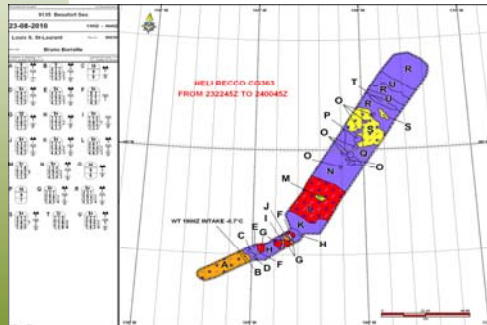
- RADARSAT-1, 2
- Envisat
- Modis
- NOAA AVHRR



Canada

Visual Observations

- Ship reports
- Aircraft reconnaissance reports



CFR Maritime Surveillance DASH-7

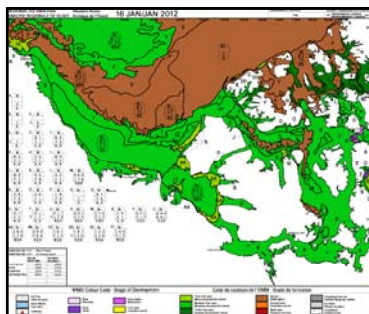


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Page 5 – February 3, 2012

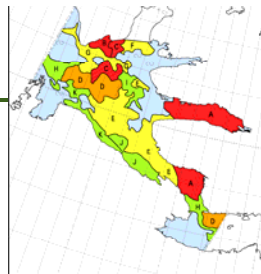
Canada



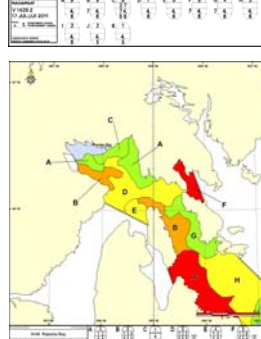
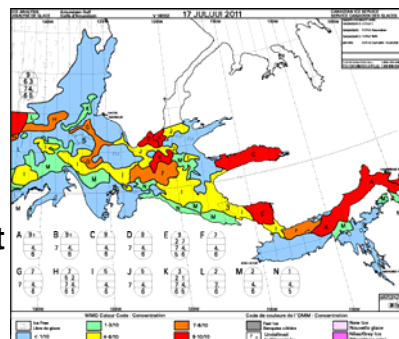
Ice Charts

Weekly –
Available
Wednesdays

Satellite image analysis



Strategic - short
term – daily



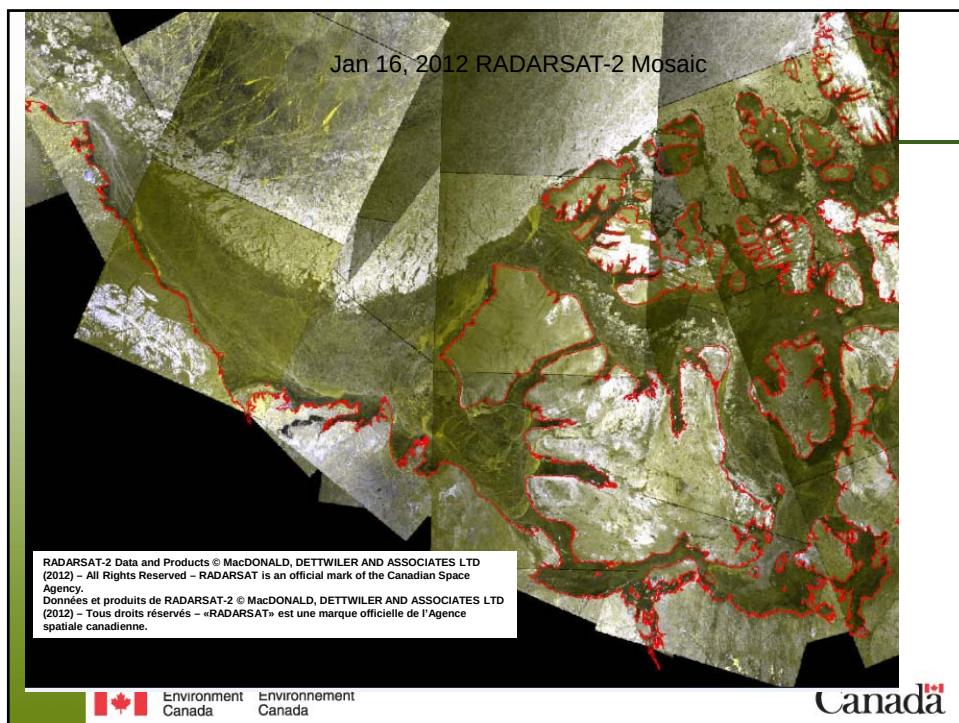
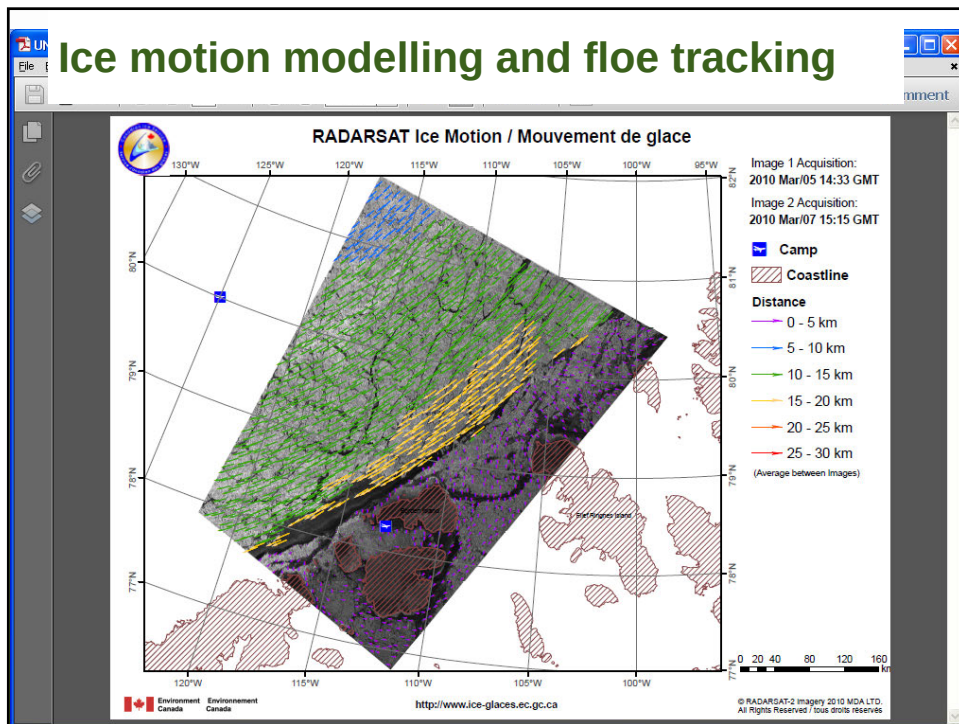
Aircraft chart

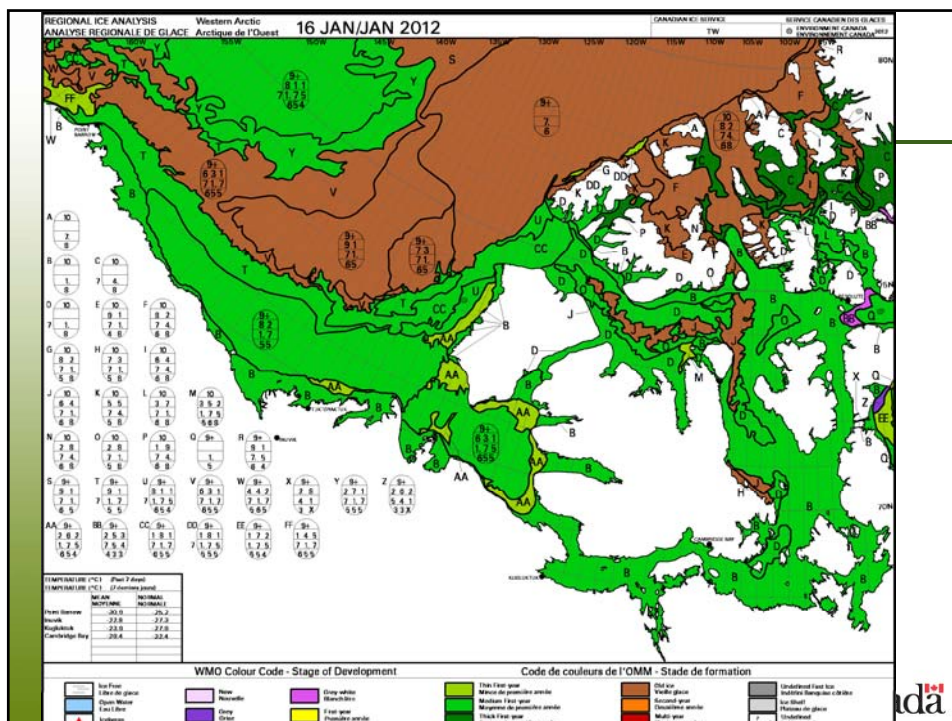
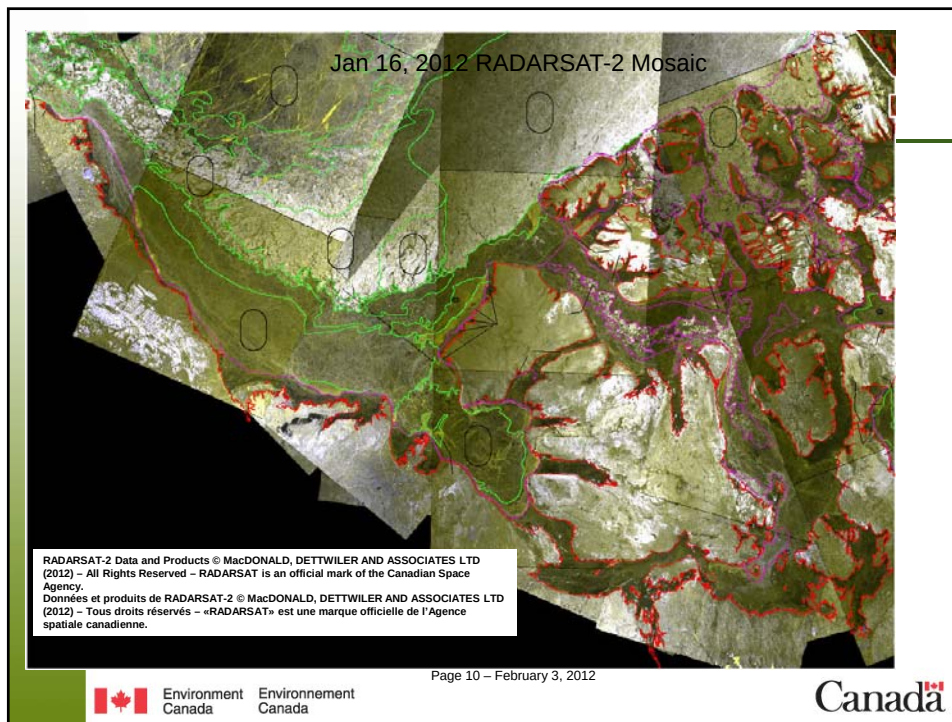


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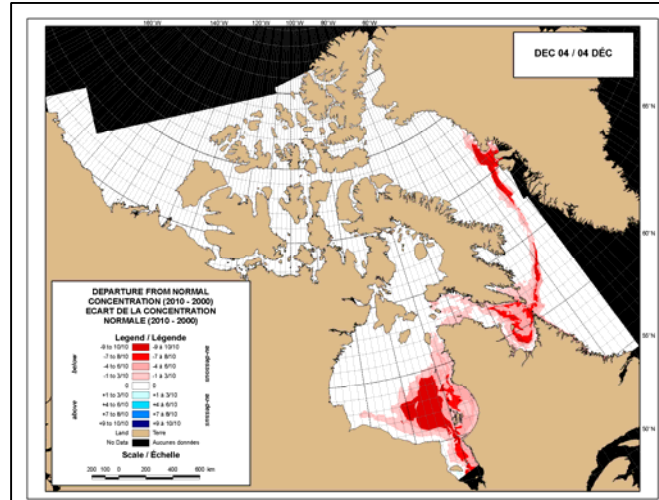
Page 6 – February 3, 2012





Comparing 30 yr climatic periods

Differences between the current (1981 – 2010) climate period with the 1971- 2000 period.

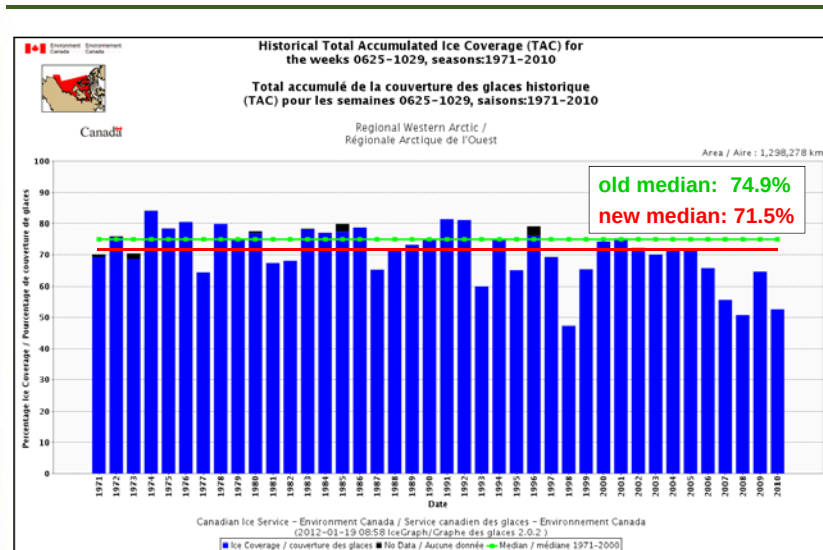


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Comparison with Previous Climatology

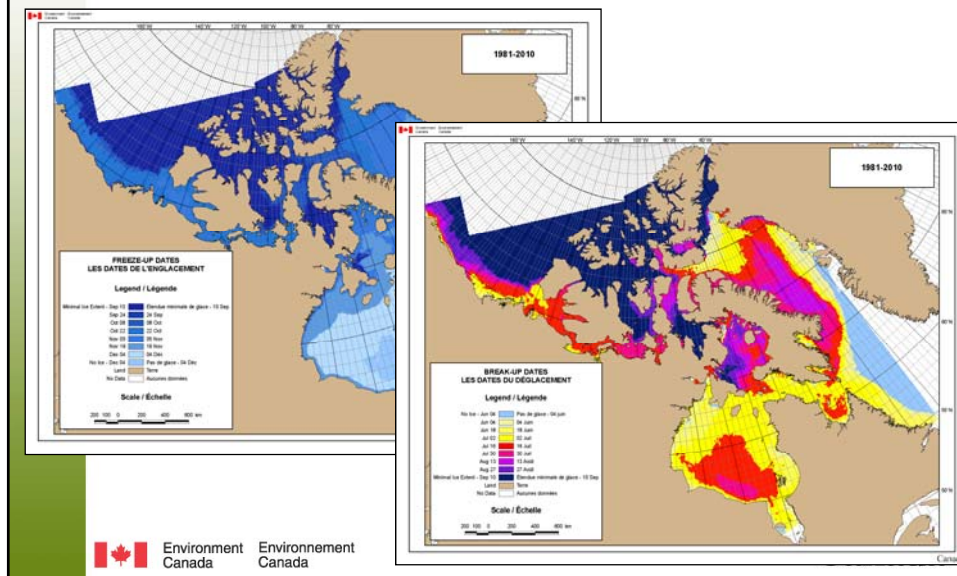


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Freeze-up and Break-up dates



Climate change and sea ice impacts

- Longer shipping season (ice clearing earlier and forming later)
 - more opportunities for re-supply
- first year ice melting earlier in the season
 - Old ice more mobile and could be encountered in unusual areas
 - ice harder early in the season so more hazardous if ships contact ice
 - Inexperienced mariners think NWP is open and that they don't need ice information or ice experience
 - Less ice makes transits more efficient

Climate change and sea ice impacts

- Ice not forming as early in the fall
 - Increased risk of encountering storms (waves, freezing spray, dark, cold)
 - Storms causing coastal erosion since fast ice not protecting coastline
 - Freezing spray causing ice accretion on communities
 - Fast ice too thin or weak to support transportation
 - Effect of wildlife sea mammals / polar bears
 - Late season rapid freeze up can be more dramatic and can trap ships



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Climate change and sea ice impacts

- Traditional knowledge not necessarily appropriate
- Extreme inter-annual variability so mariner experience or operational plans may not capture “normal” events if based on particular years
- Navigation into previously inaccessible areas expands area that information and search and rescue may be required.



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APPENDIX C

Community Consultations and Stakeholder Interviews

Stakeholder Engagement: Climate Change Adaptation Plan

Deton'Cho Stantec (DCS) prepared a stakeholder engagement plan in consultation with Department of Transportation, that included consultation with communities, experts and users of the NWT transportation network. DCS engaged with a number of key stakeholders to review the risk assessment results resulting from the 2010 workshop on roads and air transport, and the ferries and marine workshop held in January 2012. Our engagement process included:

- community engagement sessions in select communities;
- interviews with experts on climate change trends in the north, and effects on permafrost, infrastructure, ice, and hydrology; and
- interviews with select service users/providers.

Results of those meetings and interviews are presented below. In general the results of the consultations reflect the results of the other sources for the risk assessment. The main concerns mentioned were about opening and closing dates for winter roads and ice crossings; and concern about the condition of highways, particular Highway 7, Highway 8 and the portion of Highway 3 from Behchoko to Yellowknife. Concerns were also raised about runway stability where permafrost is degrading, as well as specific airport situations, notably lack of friction in Inuvik, fog at Norman Wells and a general concern about the effect of airport closures in communities not served by permanent roads.

Community Engagement

A DCS team accompanied by DOT officials visited representative communities holding public engagement sessions and opportunistically interviewing local officials and businesses. Community organizations were formally invited to the sessions in advance, posters were provided to local organizations to advertise the meetings and public service announcements were made on CBC radio. Sessions were arranged in Inuvik, Paulatuk, Norman Wells, Tulita and Yellowknife and useful input was received and has been incorporated into this report. However turnout was lower than expected and meetings in Hay River and Whati were postponed and eventually cancelled.

The format for the engagement was that a presentation was given to the participants summarizing the results of the risk assessment to date. Participants were given the opportunity to ask questions or comment during the presentation and after.

The results are summarized below:

Community	Participants	Comments/Issues
Inuvik	0	n/a
Paulatuk	6	• Mining companies exploring in the area are concerned about transportation costs in winter • Noticing that spring is coming earlier now • Barge came late in season last year – usually mid-August, but last year in September

		- Experiencing strong winds that stay for longer periods; strongest winds ever within last two weeks 110-120 km/hr. - Can't reach permafrost layer for caches in summer even after digging down to six feet - Seeing more shoreline erosion now; concern about erosion along the airstrip (which runs along a strip of land between the ocean and the bay) - A lot more rain in summer last year; more heavy fog in spring, starting earlier in the season. Have not noticed any more cancelled flights as a result, though. - Freeze-up happens later - Noticed a cruise ship offshore last summer - They do not see icebreakers in the area - Noted that the air link is critical, so any erosion around airstrip would be bad. - DOT will return to check the runway in future; they can also monitor erosion using air photos
Tulita	0	n/a
Norman Wells	3	1) Winter road - Winter road season has been reduced from about 8 weeks to 6 weeks in the last few years - Last year the road closed on very short notice; this left some trailers stuck in Norman Wells for the summer when the company should have been deploying them elsewhere - Winter road conditions this year are already bad: exposed muskeg; drivers are spinning out on some hills. - Once the March sun hits the exposed muskeg the road will deteriorate quickly under use - Noted the town is trying to stimulate development: there are 5 companies that want to drill for oil and gas, and they need road transport - DOT rep notes that the problems on the winter road used to be at ice bridges; these have been replaced with permanent structures - Lack of snow has been the main issue; the road can't open until there is enough snow, and once the ground surface is exposed the road can deteriorate quickly - Snow season has changed: very little in October/November, lots in December - Had rain in January – unheard of in the past - Was +6 degrees in February - Ice crossings on the Mackenzie River are getting harder to put in; ice is not forming fast enough - DOT had to bring in snow-making machines - Break-up has also changed RECOMMENDATION: restrict road travel to night only

		when temperatures rise to zero, to protect road ○ RECOMMENDATION: build an all-weather Mackenzie Valley Highway • Businesses seeing increasing freight damage claims due to winter road being so rough. For example in a pallet of canned beer, the bottom layer will get crushed. 2) Airport • Airport – fog has been causing flight cancellations; recently had a two-week stretch of cancellations. This happens in both spring and fall. ○ Noted that GPS system at airports allow planes to land with a lower ceiling, reducing cancellations due to fog ○ Spending more to clear snow • Note runway had grooves cut into it recently to shed rain better. This may have also eliminated friction issues, that have been experienced in Inuvik (see interview with Inuvik mayor). 3) Energy for Norman Wells • Norman Wells' energy supply is natural gas from the Esso refinery. This will be turned off ins 2014 ○ Town was leaning towards the option of propane as a replacement fuel ○ Propane companies will not transport propane on a winter road, so would require more storage if propane is used 4) Barge traffic • Fewer barges now • Any new fuel barges are required to be double-hulled ○ NTCL considers double-hulls to be too expensive so fuel may have to be trucked in ○ This also applies to aviation fuel • Noted barges getting stuck at Ramparts and sand bars due to low water 5) Other • Fuel has had to be flown into Fort Good Hope, Paulatuk and Colville Lake due to shortages • Noted that some items can't be airlifted • Very late road on Great Bear Lake to Deline last year; almost didn't get in. This would have meant airlifting fuel. • Pilings under buildings are sinking as permafrost melts • RESEARCH NEEDS ○ Changes in snowfall patterns vis-à-vis winter road
Yellowknife	7	• Does clearing the edge of highways create a heated strip that

		affects the permafrost adjacent to and under the road • Need for compiling/quantifying costs due to climate change such as additional repairs and maintenance, as well as costs of risks such as re-supply costs if the winter road is less reliable or non-functional ○ Look into results of increasing numbers of freeze-thaw cycles on asphalt – runways and some highways • Need for integration of climate change responses within GNWT, government and with communities

Expert Consultation

Expert input was received from Kevin Hodgins, Jim Oswell and Dr. Daniel Fortier on the DCS team; Dr. Faye Hicks and Dr. Evan Davies from University of Alberta; Dr. Chris Spence from Environment Canada; Gaetan Langlois from the Canadian Ice Service and Dr. Steve Kokelj from AANDC. DCS team input has been received over time in an unstructured form and is reflected throughout the CCAP report. Other expert input was received prior to and during workshops and has been documented in those reports.

Stakeholders

In addition to the workshops, several stakeholders were interviewed from chambers of commerce, road transport users, air transport industry, local authorities, and the resources extraction industry. The results of these interviews have been incorporated in the report and are presented below.

Stakeholder engagement results – users

Organization and contact	Effects/Adaptations	Concerns/Comments
Aklak Air – Operations manager, Ken Dalton	• Not seeing any climate or weather factors affecting operations • Aklak flies small planes so not affected by friction issues on Inuvik runway	
Town of Inuvik – Mayor Denny Rogers; Manager of Public Works – Rick Campbell	• Main concern is flights by large carriers being scrubbed due to lack of friction on the runway – earlier warmth seems to be causing frost ○ 19 flights scrubbed in January (check this?) ○ Affects other communities and local business/industry ○ This is a particular concern during periods when the highway is out ○ Mentioned that grooves cut in Norman Wells runway seem to be preventing friction issues there • Dempster highway has been closed more	Scrubbed flights due to lack of friction on runway at certain times of year. Increased maintenance costs for sand/gravel and staff

	often due to high winds, which affect visibility ○ Shipping delays affect local businesses • Ice crossings/ferry season generally result in road being out for about 9 weeks per year; timing has moved but amount of time is consistent. ○ Noted that it is not always clear what prevents ferries from going in earlier • Roads around the town are more slippery so more gravel is needed – used to need a small pile of gravel for the entire winter; now use 1200 cu. M. • Seeing more and stronger wind; and more snow; increasing costs for snow clearing • Winter road season (to Tuk) seems to be shortened by a couple of weeks – used to open late November, but took until mid-December this year ○ This is an economic effect since people come from Tuk to shop in Inuvik • Slumpage has affected local infrastructure – sewage outfall. Used to have to repair this area once every 10 years; in the last 10 years it had to be repaired four times. • RECOMMENDATION: extend runway • RECOMMENDATION: better sanding equipment	
DOT Sahtu Region – Airport Manager – Danny Michaud	• Grooves cut in runway were used to shed water to avoid ponding on the airstrip • Seem to be preventing friction issues • Noted that prior to 2000 they needed 30T of sand for 2-3 years of runway sanding ○ Now use 150T/yr.	Increased cost for sanding runways
Matco Transportation Systems – Norman Wells Branch Manager – Bob Greek	• Main concern is shortening of winter road season ○ Winters are shortening ○ Had rain in February • Noted that river levels are dropping earlier so barges have trouble getting into the docks • In 2011 they had 5 Coopers barge loads, an Esso charter barge and 2 or 3 NTCL barges delivering fuel only	Shorter winter road season

North-Wright Airways – Co-owner – Warren Wright	• Noticing holes developing in airstrips, particularly in Deline and Tulita. These grow big quickly and would be very hazardous if landing gear went into them. • Seeing more frost: humidity is higher. There is more and stronger wind. • Longer blizzard periods • More fog delays in last five years • Airstrips are starting to sink • RECOMMENDATION: more frequent inspections of runways; daily	Holes in gravel airstrips
NWT Association of Communities – Sara Brown		Policy paper on permafrost and climate change that addresses transportation including a motion. Survey of members shows concerns about climate change effects on: difficulty of travel on roads; delays and cancellations of travel and shortened seasons for winter roads and ice bridges. NWTAC resolution to work cooperatively with DOT on effects on airports, marine, roads and winter roads.
NWT Chamber of Commerce – Hughie Graham, President	• main concern is roads, especially winter roads – late openings and early closures • around Norman Wells in April the increased heavy traffic by Husky Energy led to a lot of degradation. DOT did not allocate sufficient funds to address this • deterioration of Dempster and Liard highways exacerbated by climate change. Again DOT has not allocated sufficient maintenance budget. • Lack of DOT maintenance budget for highways is seen across the board, with resulting deterioration in condition • Not a high level of concern about airports: some site-specific issues such as lack of friction in Inuvik in January or flights not being able to land in Norman Wells due to	• Infrastructure is an increasing concern • NWTCoc has taken a position on the need to complete the MV Highway. This would address climate change concerns regarding that winter road. • There is also concern about the state of the Liard Highway

	fog.	
Yellowknife Chamber of Commerce – Tim Doyle, Executive Director	• Highway 3 from Behchoko to Yellowknife is deteriorating • Concerns about length of winter road season	Length of winter road season
Joint Venture Winter Road, Diavik Diamond Mines – Ron Near, Director Winter Road Operations	Conditions for 2012 were a lot like 2006 for most of the season but they had no problems (last time quite a bit of fuel didn't get in). This is pretty much entirely due to their improved management. He stressed that the critical path is portages, not ice. Once the ice is in its fine – although there are a few places they need to monitor carefully. For portages - In 2012 they had a couple of portages that experience overflow and running water for almost the entire winter - One discovery they made after 2006 was that there were specific lakes that were the bottlenecks for a number of reasons: warmer, currents near the portage approaches and patterns of shoals/shallows near the portage approaches. This last was new to me – not only is there the pressure wave issue to contend with (slowing trucks down and spacing them out), but the shallow areas and bathymetry can cause the under-ice water to wash fairly forcefully across the bottom of the ice, eroding it just as surely as running water over the top would. - Adaptations ○ More flooding ○ Normal speed on the ice road is 25K; on problem lakes it's 10K; spacing between trucks is also managed differently (not sure how this would work) ○ More information collected more frequently on problem areas: profiling of ice and to identify areas where the wave might be deflected, eroding the ice from underneath ○ Building multiple road configurations so traffic can be re-directed without	No current concerns

	having to wait for an additional approach to be built ○ Longer term they are looking at re-directing the road to portages on higher ground or building them up with aggregate and channeling runoff away from the road They require 41" of ice for full loads. This generally takes a month, so the earlier they can get on the ice the better. They are continually looking for ways to improve through monitoring and finding better (lighter) equipment). Ron says based on their visits this is probably the most advanced winter road in the world in terms of monitoring and techniques for building the road and managing traffic/loads.	
DOT Inuvik Regional Superintendent – Gurdev Jagpal	Permanent Roads – <u>Dempster Hwy</u> – km 94: heavy cracking; deep, wide recurring cracks due to settlement from thawing permafrost; similar problems at km 27 due to thawing of permafrost under embankments. This settlement tends to recur in specific areas. DOT has responded by lowering the embankment to reduce the weight of it, or digging out the road and re-building. Similar issue on Inuvik Airport Rd. Culverts are also distorting/cracking. This is monitored visually only. Once it gets bad enough they replace the culvert. EBA did some work in '92 using radar and photography to determine culvert condition <u>Source 177 Gravel Access</u> Road, which is south of Tuk, is four years old and DOT is already seeing settlement. Currently monitoring is just visual, but they are planning a more formal program <u>General</u> Seeing sloughing of side slopes and eventual collapse every 2-3 years in some areas due to thawing permafrost. They do temporary repairs as needed. <u>Inuvik-Tuk Highway</u> Final design is not complete but will include adaptations including use of geotextiles,	Higher maintenance costs for roads, winter roads and ferry landings.

	increased number of culverts and more bridges instead of culverts <u>Community Access Roads</u> These are hard to construct to the load specifications due to thawing permafrost Winter Roads Not seeing delays in construction due to warming. There is more snow now, so higher maintenance costs Experiencing early thawing leading to weak areas of ice (trucks went through last winter). This is due to warmer water temperatures especially at sand bars. It's not affordable to try to fix this problem. Runways Seeing some settlement due to permafrost thawing on Inuvik runway; also on service roads and culverts. Gravel runways are not a problem – they do sometimes see some cracking, but not sure this is related to climate change. Has been some flooding of airstrips etc. Aklavik. Ferries High water events where water comes up, carrying lots of trees, creates problems for the ferries and they have to be shut down until the water drops and the trees are gone. This happens on the Mackenzie and Arctic Red River ferries. DOT is seeing more of these events, with higher water than in the past. These events also damage the ferry landings so they have to be re-shaped. This is a significant cost especially since they have to use clean gravel which must be accessed from further away. Ferry opening dates have not changed much, but closing dates are later. Marine Hasn't really heard much about any problems.	
RTL/Westcan – Vice-President, Operations – Larry Wheaton	RTL/Westcan does shipping as well as construction of all-weather and winter roads. They believe there are changes in annual	No current concerns

	climate, although they feel the data is not adequate. They are not seeing any effects on shipping or on all-weather road construction. He noted that the area they do construction on is largely in rock (John's note – they built the Hwy 3 upgrade which has a lot of problems). With respect to winter roads, they work on the JV road, and the construction techniques have changed a great deal, especially since the 2006 season when the road had to close before all the loads were delivered. In particular they use radar a lot more and they use lighter equipment so they can get out earlier. They are not seeing effects of climate change, but that is very likely due to adaptations. He noted that if the road opened later it would cause problems. The radar they use is dragged behind a vehicle and they use this information to decide when they can get on the ice to start clearing snow, as well as to monitor the road to see when it is thick enough to handle loads. The radar is dragged using amphibious equipment. The lighter vehicles allow them to get out earlier. The biggest problem is portages. They used to drag the portages to pack the snow. Now they put down a 4inch layer of frozen cover (this is both best practice and a permitting requirement). They also use night travel restrictions later in the season, so trucks don't start until the portages have re-frozen after the daily thaw – usually between 10- 12 pm, and run until 8-10am. This extends the season by 10-14 days A positive effect of climate change is that equipment breaks down less because of less exposure to extreme cold.	
Northern Air Transport Association – Executive Director – Steven Norris	NATA represents 36 commercial carriers across Canada, including NWT. They range from major carriers using jets and large turbo-props to very small operations using bush planes. NATA's main concern is runways and stability of runways north of 60 and this is largely a	Runways and stability of runways. Erosion of low-lying coastal runways.

	concern of the large carriers. Many are built on permafrost and as this deteriorates there are problems. • Paved runways, which are required for the larger aircraft, are more complicated and expensive to fix. Some are developing humps and dips: there are regulations about size of dips/humps and if they get too big some aircraft can't use the runway. • Gravel runways just get re-graded. Some develop soft spots especially during thaw and these can damage an aircraft. It is possible that certain runways might not be usable during these periods. Weather is also a problem, particularly fog, which is increasing due to a longer open water season. He also noted friction problems due to freezing fog. It is a concern at Inuvik, and was a concern at Norman Wells until the runway was grooved. It leads to much higher runway de-icing/maintenance costs. Upgrading of navigation systems to improve instrument approaches helps adapt to fog. There is also concern about erosion at low-lying runways in coastal communities such as Tuk and Paulatuk. With less sea ice and shorter periods where there is land-fast ice, the runway area is subject to more wave action and larger waves.	
Husky Energy – Canol Shale Project Manager – NWT - Ken Hansen – 403-298-6655	Husky has been operating in the NW area for 10 years, so they have a good understanding of how things work. Typical drilling overview to have a well drilled within five years of the licence (a requirement) • Year 1: ground truth, LIDAR, gravity surveys • Year 2: 2-D seismic • Year 3: 3-D seismic • Year 4: choose location: do regulatory permitting work • Year 5: Drill Takes 10 times the effort and 5 times the cost to do this in the NWT compared to Alberta	When the test is done the season following the drilling it is not ideal for planning, since the information from the test helps to identify locations for additional holes.

	Husky needs to be able to mobilize in heavy loads (60,000 lbs.), drill the well, test it and mobilize equipment out in a season. This typically takes about 90 days. This is not possible in the current winter road season, but they are able to drill a well (two months), then come back the following season to test it (one month). Even getting the well drilled can be very difficult in years when the road is not ready for heavy loads until February and starts to deteriorate by end of March. Husky is able to start construction for the drill site December 1. They have a barge staging area constructed on the west side of the Mackenzie (where the drilling occurs), so can mobilize some equipment by barge. They can have the ice bridge across the Mackenzie built before Christmas. Then they wait for the road to open. Husky recognizes the winter road is not built for its loads so contributes \$500K to DOT each year to assist in getting the road opened early. They try to work collaboratively with DOT. Husky has made a number of adaptations: • Do seismic in summer (usually done in winter) • Barge staging area • Have applied to build an all-weather road from the barge staging area of the project site (~\$40M) • Husky is supportive of daytime road closures to maintain road condition. The only way Husky could do a full 3-month program would be if there was an all-weather Mackenzie Highway.	
Tlicho Landtran – contact made by phone but unable to arrange interview		

Appendix D: Detailed Compilation of Climate Change Risks and Adaptations:

Overview of the Compiled Risks and Adaptations

The compiled risks and adaptation measures are based on a consolidation of a number of inputs including two separate adaptation workshops, previously commissioned DoT studies, selected literature review, staff and stakeholder interviews, community consultation, and a staff review workshop. Each of these captured different components of the transportation system and provided input from a different perspective.

The information below serves as a consolidation of these information sources. The objectives of this compilation are to:

- Document the identified issues, risks, and adaptation measures in a consistent format;
- Capture the variety of input obtained and identification of site specific features; and
- Retain (where ever possible) the ranking of issues that occurred through the risk assessment discussions of the two workshops.

List of Identified Risks and Adaptation Measures

Note that within each sector, the risks are presented according to the risk rating for that risk.

Sector: Roads

R- 1: Changes to Winter Road Season and Operations

Immediate Term (1 – 5 years)

- Action - 1: Pre-emptive snow removal
- Action - 2: Advanced ice profiling equipment
- Action - 3: Increased manpower and equipment
- Action - 4: „Hybrid“ Winter Road
- Action - 5: Explore new practices and technologies.
- Action - 6: Snow caches
- Action - 7: Equipment Caching and altered construction plans
- Action - 8: Review of design and construction protocol
- Action - 9: Selected replacement of winter roads
- Action - 10: Information sharing
- Action - 11: Proactively reduce overflow onto road beds
- Action - 12: Winter roads “resiliency” research and workshop.
- Action - 13: Define winter road levels or „service commitments“

Medium Term (5 - 20 years)

- Action - 14: Update/ revise route planning
- Action - 15: Route change for JV road
- Action - 16: More permanent structures
- Action - 17: Winter Road Alternatives

Long Term (20 – 40 years)

- Action - 18: Replace winter road with an all season road

R- 2: Problems with ice crossings (winter roads)

Immediate Term (1 – 5 years)

- Action - 19: Permanent crossings
- Action - 20: Crossing Design Changes
- Action - 21: Use more permanent culvert crossings
- Action - 22: Raise grade level to reduce overflowing
- Action - 23: Ft Providence equipment redeployment

R- 3: Road Integrity and Quality

Immediate Term (1 – 5 years)

- Action - 24: Time of day travel restrictions

R- 4: Drainage Issues

Immediate Term (1 – 5 years)

- Action - 25: Increased Maintenance

Medium Term (5 - 20 years)

- Action - 26: New technologies.

R- 5: Culvert collapse, road slumping due to changing permafrost conditions

Immediate Term (1 – 5 years)

- Action - 27: Planning and data collection (culverts)
- Action - 28: Culvert Replacement.
- Action - 29: Updated Facility Condition assessments
- Action - 30: Preliminary data collection -
- Action - 31: Research and development
- Action - 32: Activity Guidelines

Medium Term (5 - 20 years)

- Action - 33: New technologies and designs

R- 6: Changing demands on staff, equipment, and costs

Immediate Term (1 – 5 years)

- Action - 34: Define Service baselines
- Action - 35: Increase equipment capabilities and utilization
- Action - 36: Increase budget for consumables
- Action - 37: Vegetation Management

R- 7: Changing window for construction and maintenance of the roads and winter roads

Medium Term (5 - 20 years)

- Action - 38: Equipment and staff scheduling

R- 8: Degradation of Embankments and Structures

Immediate Term (1 – 5 years)

- Action - 39: Snow clearing and management
- Action - 40: Road Restrictions
- Action - 41: Monitoring and reporting
- Action - 42: Innovative financing
- Action - 43: Review road construction and design criteria

Medium Term (5 - 20 years)

- Action - 44: Evaluate new construction practices
- Action - 45: Mapping and Remote sensing

R- 9: Travel delays: Weather / Fires

Immediate Term (1 – 5 years)

- Action - 46: Review design criteria
- Action - 47: Reporting and Public information

Sector: Airports

A- 1: Runways buckling due to changing runoff soil/ permafrost conditions

Immediate Term (1 – 5 years)

- Action - 48: Complete airstrip risk assessments
- Action - 49: Strategic snow clearing

- Medium Term (5 - 20 years)
 - Action - 50: Runway rebuild
 - Action - 51: Periodic regarding (gravel strips)
- A- 2: Runways / taxiways flooded
 - Immediate Term (1 – 5 years)
 - Action - 52: Grooving of runways (paved)
 - Medium Term (5 - 20 years)
 - Action - 53: Drainage assessments
- A- 3: Loss of Friction
 - Immediate Term (1 – 5 years)
 - Action - 54: Increased chemicals use
 - Action - 55: Runway Grooving
 - Medium Term (5 - 20 years)
 - Action - 56: Runway extensions
- A- 4: Increasing Maintenance burden
 - Immediate Term (1 – 5 years)
 - Action - 57: increase budgets for staff and materials
 - Action - 58: Increased glycol management.
- A- 5: Travel delays: Weather / Fires
 - Immediate Term (1 – 5 years)
 - Action - 59: Notification system
 - Medium Term (5 - 20 years)
 - Action - 60: Improved instrument landing systems
- A- 6: Shoreline Erosion of airstrip
 - Medium Term (5 - 20 years)
 - Action - 61: Monitoring

Sector: Ferries and Crossings

- F- 1: Infrastructure damage or travel disruptions
 - Medium Term (5 - 20 years)
 - Action - 62: Permanent landing structures
- F- 2: Weather Related Ferry Service disruption
 - Immediate Term (1 – 5 years)
 - Action - 63: Operational prudence
 - Action - 64: Notifications and Public Information
- F- 3: Loading Ramp Activities Disruption
 - Immediate Term (1 – 5 years)
 - Action - 65: Increased ferry operations resources.
- F- 4: Changes to bank stability and location
 - Medium Term (5 - 20 years)
 - Action - 66: Improve understanding of what future break-up conditions will be (more ice, less ice, more jams)
- F- 5: Cable ferry damage or disruption
 - Immediate Term (1 – 5 years)
 - Action - 67: More Maintenance as required
- F- 6: Drainage Impacts to Ferry Facilities
 - Immediate Term (1 – 5 years)
 - Action - 68: Review and upgrade vehicle areas for drainage
- F- 7: Reduction of ferry load capacity
 - Immediate Term (1 – 5 years)
 - Action - 69: Longer operational hours if required.

Action - 70: Re-assign the Merv Hardie

F- 8: Changing operational season

Immediate Term (1 – 5 years)

Action - 71: Prepare for longer ferry operations

Sector: River Transportation

B- 1: Damage or loss of facilities

Immediate Term (1 – 5 years)

Action - 72: Reconstruction of structures

Action - 73: Relocation of mooring anchor points

B- 2: Disruptions to capacity or utility of barges

Immediate Term (1 – 5 years)

Action - 74: Facilities Assessments

B- 3: Service Interruptions

Immediate Term (1 – 5 years)

Action - 75: Load and trip planning.

Sector: Arctic Marine / Community Resupply

M- 1: Damage to props and rudders

Immediate Term (1 – 5 years)

Action - 76: Route Planning and Charting

Medium Term (5 - 20 years)

Action - 77: Larger Vessels

M- 2: Challenges to vessel maneuverability, docking and mooring

Immediate Term (1 – 5 years)

Action - 78: Planning and prudence – improved harbor charting

Medium Term (5 - 20 years)

Action - 79: New vessel types

Action - 80: Upgraded shoreside facilities

M- 3: Disruptions to re-supply activities

Immediate Term (1 – 5 years)

Action - 81: Planning

Medium Term (5 - 20 years)

Action - 82: Develop greater reserve supplies and capacity

M- 4: Damage to support infrastructure

Immediate Term (1 – 5 years)

Action - 83: Infrastructure monitoring

Medium Term (5 - 20 years)

Action - 84: Standards and design

Action - 85: Ice monitoring

M- 5: Impairment of Arctic Passage support operations

Medium Term (5 - 20 years)

Action - 86: User activities and requirements

Sector: Roads

Impact Area:

R- 1: Changes to Winter Road Season and Operations

Transport Element:

Winter Roads

Description:

Changing conditions are affecting the construction, and operational duration of the winter roads. Observed environmental factors have included delayed freezing of water crossings, new challenges with winter road construction, and a shorter operational season.

Workshop rated assessment

High (Risk score = 20)

Expectation of the impact of climate change:

Frequency: **more often**, less often, unknown

Impact: **more severe**, less severe, unknown

Specific Locations / Incidents

- JV Road
 - Changes in temp and weather patterns noted
 - Portages are becoming a problem area. Water level changes and increased vegetation growth at transition from lake to portage create problems for road construction. In shallow and swamp areas at the southern end; this tends to make opening date later and require more effort to build as well as affecting type of equipment needed.
 - Deterioration of portages at end of season due to increased temps)
 - Conditions for 2012 were a lot like 2006 for most of the season but they had no problems in 2012 (compared to 2006 when quite a bit of fuel didn't get in). This is pretty much entirely due to the JV road improved management. Critical issue is portages, not ice!. Once the ice is in, it's fine – although there are a few places they need to monitor carefully.
 - For portages: In 2012 they (JV road) had a couple of portages that experience overflow and running water for almost the entire winter.
 - One discovery they made after 2006 was that there were specific lakes that were the bottlenecks for a number of reasons: warmer, currents near the portage approaches and patterns of shoals/shallows near the portage approaches. Not only is there the pressure wave issue to contend with (slowing trucks down and spacing them out), but the shallow areas and bathymetry can cause the under-ice water to wash fairly forcefully across the bottom of the ice, eroding it just as surely as running water over the top would.
- Mackenzie Valley
 - Overflow anywhere is a problem
 - Drainage issues - melting that forms ponds, creeks that flowed thru winter, created issues with flooding sections
 - Deline road – a creek continued to flow much later than usual. Couldn't build road until creek was frozen.
 - Land crossings are the challenge here.

- Gravel Access Road (Aklavik).
- Trout Lake – now in sporadic permafrost zone due to northern migration of permafrost boundary. Permafrost is degrading or disappearing all together. Over time this may lead to a more stable (melted) subgrade that in the long term (depending on the routing) could actually perform better. If the winter road route was chosen to maximize ponds, fens etc., then performance problems will be enhanced. If the route maximizes mineral soil, long term stability as the permafrost disappears may improve the performance after a period of settling and adjustment.
- Tlicho Road: Behchoko to Gameti – problematic due to lakes not freezing sufficiently. DoT examining changing the RoW.
 - Water level changes and increased vegetation at approaches (similar to JV road above)
 - Also overflow is much more common than in the past
 - Water level changes results from higher temperatures, leading to ongoing drainage and overflow – some sites usually experience this, but it is becoming more widespread. This affects the opening and early part of season
 - Early season affect. Greater snow in early season. Insulates and prevents ice formation on water bodies. Storms & wind blow newly-forming ice around so it has to re-form, creates delays and greater effort to build; sometimes breakthroughs early in season in shallow areas.
 - Changes to expected snow cover on portages can also cause delays in opening (Note: not clear if this is an historical challenge or a new /increasing challenge)
 - A recent adaptation has been to stage winter road building equipment in Whati, Gameti and Wekweeti, so that the equipment can start in these communities and work south – better road establishment this method.
 - In fall, biggest issue limiting construction is consistent outside air temps, 2nd factor is increased snowfalls, 3rd factor is increased storms - partial freezing, then high winds, and creates ice consistency issues
- Tlicho and MVR: Winter overflows and runoff associated with higher snow levels and warmer temps has created drainage issues that flood sections
 - Last 3 of 5 years, DOT had to shut down roads in areas. This is a growing problem, they had historically troublesome sites, but now there are locations seeing this that never did before.
 - Occurrences are logged and tracked but this data is in a box and not distributed.
 - Had to do some realignment to respond to these impacts (e.g. Baker Creek Region - a trouble spot)

Are noted impacts climate change related?

- Likely. All anecdotes tend to indicate that these changes are new, or of increasing frequency and burden. Winter roads are rebuilt every year so operational challenges cannot be attributed to decaying infrastructure etc.).

Adaptation Actions Identified

Number and Title	Description	Locations / areas	Time Frame	Status
Immediate Term (1 – 5 years)				
Action - 1: Pre-emptive snow removal	Removal of snow from water crossings as early as possible can enhance ice thickness formation and reduce the insulating effect of snow cover. This requires lighter snow removal equipment, and sometimes floating equipment in order to ensure	Tlicho / JV Roads	1 – 5	Lighter equipment is being deployed. JV road is using floating

Number and Title	Description	Locations / areas	Time Frame	Status
	operator safety.			equipment. DoT has not yet deployed
Action - 2: Advanced ice profiling equipment	Increase use of ice profile technology allows for more sophisticated condition assessment.	Tlicho / JV Roads	1 - 5	In place in some areas. Radar profiling is done routinely.
Action - 3: Increased manpower and equipment	Construction window could be shortened by deploying more equipment simultaneously during the construction window. This would allow the road to be opened as early as possible, given a later start to the construction window.	Tlicho / JV Roads	1 - 5	
Action - 4: „Hybrid“ Winter Road	Place a shallow embankment on the winter road route on selected sections of the road (e.g. the portages) Normally for an all-weather road, embankments are 1.5 m thick and more. Anecdotal evidence suggests that on the Trans-Alaska pipeline (TAP) the „workpad“ / service road (about 2 ft. thick) has in some locations evolved to be suitable as an all-weather road work, and in other locations has at least extended the operational window of the winter road. The described mechanism is that the thin layer of gravel will settle (melt) into the permafrost until the top of the gravel is even with the adjacent ground and becomes quite stable. The objective is to provide a more stable winter road. However, there are areas where this platform may provide all season access for light duty vehicles. JV road operators have indicated that they are evaluating this technique for some of their problematic portages.	All,	1 - 5	
Action - 5: Explore new practices and technologies.	Staff keep current on new practices and have deployed new technologies to increase efficiency. Efforts should be made to implement measures that have shown promise elsewhere.	Tlicho / JV Roads	1 - 5	Some implementation. (e.g. using “blankets” to reduce heat transfer from new material to existing ground)
Action - 6: Snow caches	Snow caches could be built at troublesome land crossing areas to allow for swift rebuild of overland sections. An option may be to augment fallen snow by “mining” ice and/or snow from lakes and ponds and hauling to overland sections needing supplemental materials.	Tlicho / JV Roads	1 - 5	
Action - 7: Equipment Caching and altered construction plans	Positioning equipment can allow for swifter construction. E.g. on the Tlicho Road, the bottleneck was waiting for southern end to freeze to allow construction north. Recently the DOT has placed equipment in Whati and Gameti and Wekweeti so road can be constructed in a number of locations at once (in Whati for last 7 years with last 3 being done “seriously”, Gameti and Wekweeti for last 2 years)	Tlicho	1 - 5	Under way on Tlicho

Number and Title	Description	Locations / areas	Time Frame	Status
	This approach could also be used to allow early construction of the water portions, and later construct the portages.			
Action - 8: Review of design and construction protocol	Suggested that the TAC guidelines may have components that are too conservative for the NWT situation. The question is whether under a controlled construction environment, could a safe road be opened sooner. Is DOT's ice factor too high/rigid (noted that JV road has a lower factor than DOT – learning opportunity??) This would require specialized engineering input.		1 – 5	
Action - 9: Selected replacement of winter roads	The Source 177 access road is being constructed to provide all season road access to a gravel supply from Tuktoyaktuk The access road from Aklavik to a gravel source at Willow River is being evaluated to be replaced with an all season road (about 27 km) that is currently a winter road.	ITH	1 - 5	Source 177 is built Aklavik is being planned.
Action - 10: Information sharing	More information sharing activities to improve everyone's knowledge base. Possible examples include: - Ice radar data is used for day to day operations but may not be archived for any analysis - Documenting and sharing the types of service disruptions. - Connection with broader jurisdictions (e.g. Alaska, US military)	All winter roads	1 – 5	Some activity underway (e.g. the DOT meets with JV operator regularly during construction and operating ice road season)
Action - 11: Proactively reduce overflow onto road beds	Water Overflow could be reduced through better knowledge, tracking, and intervention. Activities would include: - Incident tracking - Temporary culverts - Adding snow to absorb water - Level roads - Re-align around susceptible areas Obviously this requires more effort but could reduce the operational challenges when overflow does occur.	MVH	1 – 5	Initiating this on the MVH
Action - 12: Winter roads "resiliency" research and workshop.	A fundamental unknown that remains is: "When is a winter road no longer viable? This activity would develop a better understanding of the future prospects for the winter roads. Activities would include: - A winter road "resiliency" workshop with experts to identify the key research questions. - Research or data analysis to better understand if thresholds or correlations exist for specific roads (e.g. 2006, when the JV road failed, was the warmest winter – but not by very much. What caused that year to be a problem when other similar years were not?) - Meteorological data analysis of relevant stations (examples include Ft Simpson and Ft Nelson where different climatic changes appear to be occurring)	All winter roads	1 - 5	Planned for 2012 / 2013

Number and Title	Description	Locations / areas	Time Frame	Status
	- The overall approach to the winter roads may need review. Are there fundamental things that could be changed to thought/changed for level of service to be maintained? - Guidance on winter “tundra” access on Alaska North Slope is available. For example BLM/ADNR specify specific criteria (e.g. minimum ground temperature of -5°C at specified depth) for travel on tundra. This might be applied to south of the treeline.			
Action - 13: Define winter road levels or „service commitments“	Currently roads are constructed and managed to maximize the operational window. Initially, these roads were developed to provide basic community re-supply (diesel generators, bulk supplies, etc.). Over time the use has increased, and by greater stakeholders. Public expectation has become a driver for increased length of season and quality of road surface. A service review would define the key objectives and purpose of each winter road segment. Questions to be posed might include: - What are the purposes of the winter road? - What are the desired operational windows? (different users have different minimum requirements) - For whom is the road built and who provides the funding? - What are the community expectations of the road? - Are resupply, travel, or resource industry users expected to increase or not? - Are there safety issue? - Is a winter road the best way to deliver the services? - What are the different expectations for different roads (e.g. the Wekweeti portion of the Tlicho road is identified as only for re-supply, while the rest of the road is public – expectations are increasing that the Wekweeti portion will also become public – requiring a better quality road. - What are the cost trade-offs?	All	1 - 5	Not initiated.
Medium Term (5 - 20 years)				
Action - 14: Update/ revise route planning	Route review may allow for better planning of road construction at scales ranging from individual water bodies to larger scale re-alignment. Potential activities include: - Bathymetry (lake bottom profiling) to choose where to come off lake - Moving the roads onto land (NB a Tlicho road re-alignment study is being undertaken)	Tlicho / JV Roads	5 - 20	
Action - 15: Route change for JV road	Suggestion that if the JV road becomes untenable, then a seasonal overland route could be built north from Yellowknife, or a road south from Bathurst inlet. Most likely this would be viable only is accompanied by mining activity between the diamond mines and Bathurst.	Tlicho / JV Roads	5 – 20	

Number and Title	Description	Locations / areas	Time Frame	Status
Action - 16: More permanent structures	Permanent structures on crossings will allow swifter construction (do not have to wait until creek freeze) Construction of embankments on the south side of winter road portages. These would act to reduce exposure to the sun on the road bed (JV road already doing this) Note on the MVH more permanent structures are being built at Prohibition Ck. and 4-Mile.	Tlicho / JV Roads	5 - 20	
Action - 17: Winter Road Alternatives	Given the uncertainty with the future of winter road viability it is likely that some roads may become chronically difficult to construct and maintain. Over the next few years, better information may become available to indicate the climate features that may affect winter road viability. As more information is obtained the DoT may have to develop and assess alternatives for each winter road.	All	5 - 20	Future
Long Term (20 – 40 years)				
Action - 18: Replace winter road with an all season road	Plans are currently underway to expand the all season road network. EA and engineering has been started for the ITH and funding is being secured. The GNWT is committed to building an all-weather MVH to connect to the Dempster Other roads may have to become all season as winter road viability declines. – (e.g. Tlicho)	All	5 – 20 20-40	Future

Gaps

- Understanding of broader climate variables that can be used to correlate to winter road metrics. Could be used to link climate change forecasts to forecast future winter road expectations.
 - Not clear if permitting issues and expectations could hinder opportunities for road changes.
 - Scientists (Kokelj) are studying overflow onto winter roads at Baker Creek (Yellowknife). Results may be applicable to roads
 - Note: annual Highways Div. meeting to discuss issues held – usually in November – minutes are produced (see I-drive). Possible source of information. Pertains to Roads and winter roads, This is not pulled together into an accessible form – eg. Database to help ID trends etc.
 - Winter Roads – meetings with contractors at kickoff and end of season includes a discussion of lessons learned – also not in widely accessible form.
 - Institutional memory needs to be kept more systematically
 - Public Education may be required to communicate the trade-offs and costs of maintaining a road service beyond a basic community re-supply.
 - As well – public education on safe travel requirements might need enhancement.
-
- Need to better understand where we are going with WRs in the future, define our long term goals. If we believe, say 5 years from now, that season will be much shorter, then how do we respond to that?
 - Need to identify the minimum service needs and expectations for each winter road. Once established, you can keep building roads until min service needs cannot be met feasibly
 - eg. Wekweeti winter road is a RESUPPLY only road, but public is now using it also.
- One Adaptation could be to remove the social service aspect of winter roads and convert their purpose to RESUPPLY only.

Comments

- Stakeholders expressed concerns about the length of winter road season allowing all required shipping to pass in time.
 - Some stakeholders did support the idea of daytime travel bans
 - Maintenance management system theoretically tracks grader hours etc. but is not used consistently throughout NWT. Garry Snider has raw radar data but it has not been processed or analyzed.
 - The JV has the same kind of information and uses it. There may be a learning opportunity or information sharing activity.
 - Noted that Wekweeti road is different than others: it was originally put in by the users whenever it was cheaper to put in a road than ship by air. In the „80’s it was a cat train trail and is still mostly single-lane. It expanded when exploration companies put in a road that went part way, making it easier to build a road to the community – now expectations are building – some residents may be expecting a full service road.
 - JV road was always private – originally to supply Echo Bay Mine (on Contwoyto Lake, north and east of Ekati and Diavik)
 - Noted that DOT used to pack snow on winter road portages, but now they remove it and spray water. Rationale was that snow removal was done to speed up freezing of ground, then put back once freezing has occurred.
 - Northern Roads (Gurdev Jagpal) Not seeing delays in construction due to warming. There is more snow now, so higher maintenance costs. Experiencing early thawing leading to weak areas of ice (trucks went through last winter). This is due to warmer water temperatures especially at sand bars. Not sure that there is an affordable way to fix this problem.
 - Community Access Roads: These are hard to construct to the load specifications due to thawing permafrost (Gurdev)
 - Adaptations on the JV road:
 - More flooding
 - Normal speed on the ice road is 25K; on problem lakes it’s 10K; spacing between trucks is also managed differently (not completely specified).
 - More information collected more frequently on problem areas: profiling of ice and to identify areas where the wave might be deflected, eroding the ice from underneath
 - Building multiple road configurations so traffic can be re-directed without having to wait for an additional approach to be built
 - Longer term: looking at re-directing the road to portages on higher ground or building them up with aggregate and channeling runoff away from the road
 - JV operators feel that based on their visits this is probably the most advanced winter road in the world in terms of monitoring and techniques for building the road and managing traffic/loads.
 - JV road requires 41” of ice for full loads. This generally takes a month, so the earlier they can get on the ice the better. Operators are continually looking for ways to improve through monitoring and finding better (lighter) equipment).
 - Overflow is worse on Mackenzie Valley Road. If we want to avoid this, we need to raise elevation on roads and structures, so adding to the natural ground, (including geotextile blankets if effective).
- On permanent crossings, DOT is shifting from metal structures to more driven pile foundations for fixed crossing, more protection against scour, more wider openings. Also including better permanent crossings (better construction techniques, pile foundations, scour protections, and wider openings)
- Tuktoyaktuk Ice road: Almost all is over water. No problem with enough cold to establish the road.
 - Information Compilation: The DOT has season-end summary meetings (debriefs) with notes that can be available from DoT (should be on DOT’s “I-DRIVE”). No real system in place to track or feedback results – mostly just data collection.
- Nighttime travel is a good technique to minimize damage to portage sections on winter roads. Nighttime travel USED TO be a temporary measure, but now DOT considers using more because it extends WR season significantly.

Impact Area:

R- 2: Problems with ice crossings (winter roads)

Transport Element:

Winter Roads

Description:

Winter roads experience difficulties with ice crossings of water courses (streams, rivers, and lakes). Issues noted to date include crossings being less stable and less predictable in terms of development (e.g. streams freezing later, or unpredictably); areas of ice crossings that have been moved to land.

Workshop rated assessment

High (risk score = 20)

Expectation of the impact of climate change to the Risk Rating:

Frequency: **more often,** less often, unknown
Impact: **more severe,** less severe, unknown

Specific Locations / Incidents

Mackenzie Valley Road: Problems with overflow and streams flowing later into the year. Overflow affects crossings by delaying the construction. This seems to happen where cuts are made – need to avoid disturbing the surface

Are observed issues climate change related?

Likely.

Adaptation Actions Identified:

Action Number	Action	Locations / areas	Time Frame	Status
Immediate Term (1 – 5 years)				
Action - 19: Permanent crossings	Create permanent stream crossings along the MV winter road route	Mackenzie Valley (MV) road	1 – 5	36 crossings installed to date. 4 more required over the next 5 years
Action - 20: Crossing Design Changes	Review design of permanent crossings may provide for improved service with uncertain future conditions. Examples include: Avoiding disturbance to the surface topography at crossings (prevents overflow). - Increasing the heights and spans of permanent crossings. Has greater cost but avoids scour - Changing the structural systems such as moving from	Mackenzie Valley (MV) road	1 – 5	Being implemented.

Action Number	Action	Locations / areas	Time Frame	Status
	footings to piles			
Action - 21: Use more permanent culvert crossings	Convert temporary culvert crossings to permanent. One options might be to install multiple levels of culverts (stacked culverts) so that when the lower culvert ices up, a culvert at a higher elevation through the road embankment will remain open and allow spring flows to pass	MVH	1 - 5	Already being done on an as needed basis
Action - 22: Raise grade level to reduce overflowing	Higher grade level will reduce the amount of stream flow that overflows the road bed. This has benefit of reducing disruptions to natural stream course flows.	MV	1 -5	??
Action - 23: Ft Providence equipment redeployment	Move ice bridge equipment that has been used for Ft. Providence ice crossing to be used on MV road crossings	MV	1 – 5	Planned

Gaps

- Record culvert failures
- Needed for mgmt. plans required by regulatory boards

Comments

- Regulatory changes have also affected availability of solutions. Some former practices are restricted in time or location (e.g. in-stream work windows, permitting requirements, stream disruption limitations).
- Climate change effects must now be considered in EA's. This may affect road or resource development so that future projects will need to be cognizant of potential future climate scenarios.

Impact Area:

R- 3: Road Integrity and Quality

Transport Element:

Winter Roads

Description:

Winter road integrity and track quality can be damaged by transit during warm conditions (soft road bed). This has been identified on exposed and sunnier areas – particularly in the later winter.

Workshop rated assessment

Medium (Note: unrated at workshops. Introduced at staff review)

Expectation of the impact of climate change:

Frequency: **more often**, less often, unknown
Impact: **more severe**, less severe, unknown

Specific Locations / Incidents

- All

Are noted impacts climate change related?

Definitely climate related. Expected to be climate change related as conditions become warmer and more variable.

Adaptation Actions Identified

Action Number	Action	Locations	Time Frame	Status
Immediate Term (1 – 5 years)				
Action - 24: Time of day travel restrictions	Winter road travel is controlled (typically limited to nighttime travel) on selected road sections to preserve road quality.	Primarily the MV road, but also others as required.	1 - 5	Currently implemented as required.

Gaps

- Need to review road segments to determine if this requires localized, or generalized implementation.
- Criteria for restrictions might need to be formalized: observation of degradation, current temps; predicted temps

Comments

- Road closures may not be popular. Public expectation is that roads are available at all times. May require public education that the benefit of daytime restrictions (e.g. longer operational season) would be worthwhile.
- Noted that the road ROW from Wrigley to Fort Good Hope has been in place for decades. So over those portions of the route that was originally in permafrost, the clearing of the trees etc. has likely induced significant deepening of the active layer and even created a permanent talik between the base of the active layer and the top of the permafrost. So, now the upper say 4 m or 6 m might now be thawed and no longer ice rich and no different from non-permafrost terrain in High Level or Hay River. This suggests to me that with time the overall subgrade of the road should become more stable. Can this be leveraged to create a better winter road?

Impact Area:

R- 4: Drainage Issues

Transport Element:

All Season Roads

Description:

Drainage issues can undermine roads. Current examples include fine grain soils which hold water, summer rainfall washouts, and delays in road openings due to wet roadbed conditions.

Workshop rated assessment

Medium (Risk score = 16)

Expectation of the impact of climate change:

Frequency: more often, less often, **unknown**
Impact: **more severe**, less severe, unknown

Specific Locations / Incidents

- Fine grains Soils (highway 7, 1, & 2)
- Liard: Two week closure in 2011, one month closure during 2012 due to wet conditions that make the road bed unsuitable for travel.
- Dempster highway maintenance has increased and concern over culvert failures. Cause is uncertain – could be due to ground/permafrost changes or simply aging infrastructure.
- Summer rainfall – leading to washouts and mud
- Spring runoff occurs before culverts are clear (Dempster)
- Overflow has also become a problem in last 5 years– noted for Hwy 4

Adaptation Actions Identified

Action Number	Action	Locations / areas	Time Frame	Status
Immediate Term (1 – 5 years)				
Action - 25: Increased Maintenance	Increased maintenance can overcome some of the smaller impacts. Example would include more frequent road grading and increased surveillance of infrastructure		1 - 5	Likely occurring informally, though budgets may not have increased
Medium Term (5 - 20 years)				
Action - 26: New technologies.	Repairs and replacements should consider new practices and road bed technologies.		1 – 5 5 – 20	DoT has started. Also applies to other impact areas.

Gaps

- Causes of failure are not always certain. Failure could be due to climate, and climate –change related factors, or simply old infrastructure requiring replacement. For example the failure of the culvert at Caribou Creek on the Dempster, which was due to age. It is not known whether aging culverts are system-wide and that cc may accelerate “aging” by increasing moisture and freeze-thaw cycles.
- Would be valuable to access maintenance logs and track trends of many years to identify problematic locations
- Review maintenance logging procedure.

Comments

None identified

Impact Area:

R- 5: Culvert collapse, road slumping due to changing permafrost conditions

Transport Element:

All Season Roads

Description:

Degradation of permafrost results in slumping and settlement of road surfaces.

Workshop rated assessment

Medium (Risk score = 16)

Expectation of the impact of climate change:

Frequency: **more often**, less often, unknown
Impact: **more severe**, less severe, unknown

Specific Locations / Incidents

- All components on permafrost
- e.g. Culvert collapse on Behchoko access road (2009?) – Behchoko cut off for some days.
- Sinkholes in Hwy 5 (2008 and 2010).
- Hwy3: Sagging in soil covered areas, 2007 sinkhole at km 258, general deterioration.
- Dempster Hwy: km 94: heavy cracking; deep, wide recurring cracks due to settlement from thawing permafrost; similar problems at km 27 due to thawing of permafrost under embankments. This settlement tends to recur in specific areas. DOT has responded by lowering the embankment to reduce the weight of it, or digging out the road and re-building. Similar issue on Inuvik Airport Rd.
- Culverts are also distorting/cracking. This is monitored visually only. Once it gets bad enough they replace the culvert. EBA did some work in '92 using radar and photography to determine culvert condition
- Source 177 Gravel Access Road: South of Tuktoyaktuk is four years old and DOT is already seeing settlement. Currently monitoring is just visual, but they are planning a more formal program
- General: Seeing sloughing of side slopes and eventual collapse every 2-3 years in some areas due to thawing permafrost. Implement temporary repairs as needed.
- Inuvik-Tuk Highway: Final design is not complete but will include adaptations including use of geotextiles, increased number of culverts and more bridges instead of culverts
- Liard Hwy (Hwy 7), destruction by ground water changes (km 5.9). Groundwater is an unidentified impact (i.e. staff not sure how big, or what the impacts will be)

Are noted impacts climate change related?

Most likely. Permafrost regimes are changing.

Adaptation Actions Identified

Action Number	Action	Locations / areas	Time Frame	Status
Immediate Term (1 – 5 years)				

Action Number	Action	Locations / areas	Time Frame	Status
Action - 27: Planning and data collection (culverts)	Updating of infrastructure inventories and condition assessments will help to identify problematic areas. As an example culvert inspection frequency has been increased on the Dempster Hwy. A more robust inspection method is needed that can identify changing profiles over time.	Dempster (Hwy 8)	1 - 5	Being done informally or at the regional level
Action - 28: Culvert Replacement.	Replace culverts upon failure (or near failure)	All	1 – 5 5 - 20	Currently done as needed
Action - 29: Updated Facility Condition assessments	Regular or ongoing facility condition assessments will identify long term infrastructure requirements	All	1 - 5	Currently done as needed
Action - 30: Preliminary data collection -	Review of the appropriate data collection of soil and ground conditions prior to maintenance and construction activities may better identify site-specific features that need to be addressed.	Dempster Liard	1 - 5	
Action - 31: Research and development	R & D on NWT roads could be incorporated more into operations (e.g. Source 177 initiative, Beaver Creek YK		1 - 5	
Action - 32: Activity Guidelines	Some informal activities might need more formal procedures guidelines. An example cited is that some gravel pits have resulted in degrading surrounding lands. DoT might need to establish some guidelines to decommission these sources after use		1 - 5	
Medium Term (5 - 20 years)				
Action - 33: New technologies and designs	Working with engineering experts and research specialists, new technologies and designs could be tested for the mitigation and control of permafrost degradation		5 - 20	

Gaps

- Explore causes of Highway 1 sub grade failure
- Permafrost context description and conditions in various regions
- Further permafrost research in Mackenzie area and high arctic and begin research on highways and the North Slave areas
- Permafrost design R&D
- Risks of new approaches or technologies may not be understood
- Not always clear if every site is unique or can approaches be generalized?

Comments

- Hwy3 PIEVC Risk assessment identified high risk for ice-rich sections (>20%). Still remains limited information and mapping of these conditions.
- Stakeholder comments (Chamber of Commerce): deterioration of Dempster and Liard highways is felt to be exacerbated by climate change. Members are concerned that the DoT does not allocate sufficient maintenance budget. In general: felt that DOT maintenance budget for highways is insufficient across the board, with resulting deterioration in condition of roadways
- Highway 7 Liard Hwy (workshop comments)
- Greg C – precipitation is increasing in last 40 years especially in spring
- Road bans are imposed earlier in recent years. Bans occur when road is too wet to use without damaging it extensively. Bans cease when roadbed dries sufficiently
- Highway 7 was closed for one month last year, road was too soft to be passable, and would not dry out
- Major culvert failure during a large rain event (one year of rain in one day)
- Ziaur (DOT) confirms data indicates much higher precipitation trend in recent years
- Liard Hwy has always had potential to be problematic, but last 3 years it has been completely impassable for some periods.
- Hwy needs to be rebuilt - road is essentially reduced to silty subgrade in many sections
- Major rehab of this road is needed. Have spent \$12m over last 4 years. Estimates indicate that they need \$3m/year to make it passable
- To build a new Hwy 7, estimate is about \$1m/km.
- Possibility of entering into a MOU with Mine industry to get contributions from industry to help maintain road.
- Short term option is to use road bans & restrict large loads etc.
- Alternate option would be to allow heavy vehicle users but require some contribution to assist with extra maintenance burden".
- Some unexpected users. E.G. good frac sand source for shale gas drilling has been identified along Liard Hwy, so DOT anticipating large increase in truck hauling down along Liard Hwy to AB.
- General:
- Challenge – existing regulations applying to species and plants that never used to be prevalent in NWT, but have migrated in with CC
- Challenge – how to enforce regulatory requirements in the environment of reduced Federal environmental/regulatory enforcement staff
- Inuvik-Tuk Proposed Hwy (AWR)
- Terrain Assessment undertaken on Inuvik-Tuk Hwy. Very distinct terrain segments along route – need to be addressed distinctly in design.
- For example, before tree line, different characteristics. Sections where ice wedges are very prominent. Sections further north towards Tuktoyaktuk, more surface water accumulation, ice

Impact Area:

R- 6: Changing demands on staff, equipment, and costs

Transport Element:

Equipment & Work Practices (roads)

Description:

Changing conditions are changing the demands on DoT staff and equipment for operational activities. Examples include longer operational hours, more material requirements (salt, sand, etc.).

Workshop rated assessment

Medium (Risk score = 12)

Expectation of the impact of climate change:

Frequency: **more often**, less often, unknown
Impact: more severe, less severe, **unknown**

Specific Locations / Incidents

- Gravel and sanding materials can be hard to source locally. Expenses for hauling can be substantial.
- Longer “summer season” has resulted in longer maintenance period.
- Climate change is changing the windows when wildlife and especially fish are present – this affects regulatory aspects where construction must avoid certain seasons, or mitigate. If fish-bearing streams don’t freeze the operating window is reduced or eliminated.
- Potential arrival of new species or changing migratory patterns could affect regulatory restrictions on some operations.
- Increasing precipitation has led to stricter mitigation on culverts and bridges; and a greater need for access to materials such as rock for rip-wrap

Are noted impacts climate change related?

Likely. The nature of the extra effort is consistent with the changes that climate change is expected to bring.

Adaptation Actions Identified

Action Number	Action	Locations / areas	Time Frame	Status
Immediate Term (1 – 5 years)				
Action - 34: Define Service baselines	Establishing service level baselines or minimum needs can help to define and communicate acceptable condition to users.	All	1 - 5	??
Action - 35: Increase equipment capabilities and utilization	Meeting increasing servicing effort may require additional machinery. Future needs and operational windows might require an expansion of the DOT (or contracted) equipment fleets.	All	1 -5	

Action Number	Action	Locations / areas	Time Frame	Status
	As well, or alternatively, increased utilization of existing equipment can be implemented. More operational hours requires more budget for staff, consumables, and equipment replacement. However, it is a highly responsive activity that can allow for the extension of current services, while other planning decisions are made (e.g. finding and developing new routes, funding major initiatives, etc.). Most operations groups tend to do this naturally as part of their jobs. Planning and management may not have full understanding of the changing requirements.			
Action - 36: Increase budget for consumables	Increased spending on consumables and materials can provide a swift response to changing conditions. Activities might include increasing sanding material purchases/production, increasing storage locations.		1 – 5	
Action - 37: Vegetation Management	Vegetation management to reduce the amount of snow cover required to establish the portage sections of the roads.		1 - 5	

Gaps

- Determine the cost of doing nothing, this could help the business case for action
- Identify the best road surfacing packages for climate change;
- Explore surface materials and design options to protect permafrost.
- Need to understand how other jurisdictions are addressing these same issues.

Comments

Impact Area:

R- 7: Changing window for construction and maintenance of the roads and winter roads

Transport Element:

Construction and Maintenance

Description:

Changing climate factors will cause a change in the regular construction and maintenance windows of roads. Issues that might present themselves include delays to initiative winter road construction, wet conditions preventing maintenance on some all-weather roads (e.g. Liard).

Workshop rated assessment

Medium (Risk score = 9).

Expectation of the impact of climate change:

Frequency:	more often,	less often,	unknown
Impact:	more severe,	less severe,	unknown

Specific Locations / Incidents

- None specifically identified

Are noted impacts climate change related?

Adaptation Actions Identified

Action Number	Action	Locations / areas	Time Frame	Status
Medium Term (5 - 20 years)				
Action - 38: Equipment and staff scheduling	Plan for 9, then 12 month work window. In order to keep up with maintenance DOT had identified certain times of year where the equipment was being used 24 hours/day, and that as maintenance increases they will likely need to move to doing this 365 days/year		5 - 20	

Gaps

- Identify current and future material/resource needs;
- Understand the implications of climate change on O&M
- Explore opportunities to link environmental spending with infrastructure and maintenance spending.;

Comments

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Impact Area:

R- 8: Degradation of Embankments and Structures

Transport Element:

All Season Roads

Description:

Permafrost thaw results in slumping and degradation of road embankments.

Workshop rated assessment

Medium (Risk score = 9)

Expectation of the impact of climate change:

Frequency:	more often,	less often,	unknown
Impact:	more severe,	less severe,	unknown

Specific Locations / Incidents

- Dempster . Highway 8 (143-272)
- Highway 4 (0-692)
- Hwy 3 (239 - 338)
- Hwy 1 (456 – 690) subgrade failure
- Dettah access road
- Tuktoyaktuk 177
- Inuvik airport road

General:

- Culverts

Liard Highway

- Built on silt, with high shale content, so drainage problems with wet areas becoming soft and loose
- Precipitation has been increasing especially in summer
- More soft places have been occurring
- Shut downs to allow the road to dry out after spring thaw have started happening annually; 4 week shutdown in 2009
- Slope failures due to increased pore water pressure from groundwater
- Major culvert failure during installation due to heavy precipitation event

General

- Snow removal also removes road material on crown, and creates potholes
- Snow clearing leaves snow piles on shoulders which insulates embankment leading to permafrost degradation in ice-rich areas. Snow piles also lead to water pooling in spring, which further degrades permafrost

Dempster Highway

- Massive glacial ice in Peel Plateau that is warming (ground temps measured this winter were very warm)
- Slumping issues – currently off highway but moving towards it.
- Major sinkholes are appearing (fatality of Yukon minister last year)
- Caribou Creek culvert failure (likely related to age of culvert)
- Some gravel pits are starting to degrade and will need to be fixed

ITH

- Impact of building the road will be much bigger than any CC impact
- Section in trees will be different than Tundra

Are noted impacts climate change related?

Likely. These are linked to permafrost degradation

Adaptation Actions Identified

Action Number	Action	Locations / areas	Time Frame	Status
Immediate Term (1 – 5 years)				
Action - 39: Snow clearing and management	A component of permafrost preservation is the ability of the ground to sufficiently cool through the winter. Snow acts as an insulator and evidence indicates that early season snow accumulation can delay ground cooling, and late season snowfall can preserve cooler ground against warming. Possibilities include: • snow clearing from the road shoulders in the early winter to preserve permafrost quality, and • compaction of snow on shoulders to remove insulation value. These actions might require specialized adaptations to machinery or changes in road plowing practices. Suggested even to consider using rubber plow blades instead of steel.	All weather roads	1 - 5	Concept
Action - 40: Road Restrictions	• Change in road bans – prevents hauling at some times but preserves road.	Liard	1 – 5	
Action - 41: Monitoring and reporting	• Monitoring/Reporting of: • Site stability • Re-vegetation • Erosion		1 - 5	
Action - 42: Innovative financing	• Evaluate funding model and consider changes. Currently there are a range of models including: (i) DoT builds road, (ii) DoT builds but specific users make a contribution (e.g. drilling rigs etc. – confirm) and (iii) users build their own road (e.g. the JVR) • NEW example in the Liard: Prairie Creek mine (in Mackenzie Mtns. To west) will build winter access off Hwy 7 • Might request developer to support maintenance	Liard	1 - 5	
Action - 43: Review road construction and design criteria	• Design embankment and ditches to accommodate fine grain soils as construction material • Import material instead of using local silt	Liard ITH	1 - 5	

Action Number	Action	Locations / areas	Time Frame	Status
Medium Term (5 - 20 years)				
Action - 44: Evaluate new construction practices	Need for different structures in future (example geotextile reinforced soil – GRS) testing something on Hwy 3 between Behchoko and YK		5 – 20	
Action - 45: Mapping and Remote sensing	- Terrain assessment by LIDAR used to identify areas needing more detailed assessment for the ITH - Suggested to use LIDAR to track slumps (Dempster)	ITH	5 - 20	

Gaps

- Conduct hydrology and hydrogeology research and explore DOT partnerships (permafrost). In particular: vulnerability to thermo-erosion and linear erosion, impact of groundwater flow on permafrost thermal regime, impact of ponding water on freeze-back, drainage design improvement.
- Vegetation mix – Identify method for RoW management and stabilization
- Pre-design hydrological & hydrogeological studies
- Liard Highway strength study. This study does not include climate change.
- Experimental sites for culvert design on Hwy 7 and 1
- Study impacts of snow accumulation on toe of roads in ice-rich areas
- Noted that at airports, where snow is completely cleared away, DOT is seeing aggradation of permafrost. Need to study mechanism
- Peel plateau being studied by Steve Kokelj and Carleton U.
- Permafrost slump rate is increasing significantly
- EEBA studied permafrost using GPR in the '80's – information may be available
- Could cause of culvert failure be accelerated by CC? Increased moisture; increased freeze-thaw cycles, increased deformation as the permafrost degrades and road embankment subsides
- Current inspection of culverts is may benefit from improvements beyond visual inspections to include some measurements etc.

Comments

- Huge amount of traffic is expected to transport frac sand from Ft. Liard area to Ft. McMurray.
- At present heavy-load traffic is being re-routed up through NWT to go around Ft. Nelson bridge, where heavy loads are not allowed
- Noted that there is consideration of barging equipment for oil sands from Asia up Mackenzie River to Hay River and loading it on trucks to be driven through NWT – rumor of load sitting in Hay River right now (Kamran)
- Liard Highway. Currently requires on the order of \$3M/yr to maintain functionality (described by one person as “limping along”). A complete rebuild would be desirable but costs are in the range of \$1M/km. However, users (specifically general public) have expectations that this road will be in good condition.
- For new highway construction) and repairs and maintenance, the regulatory environment is more stringent. Degradation at quarries has attracted interest and quarries require management plants etc. This can increase the cost of construction materials.
- ITH will have issues with or without CC
- There has been research published on the Qinghai-Tibet highway and different mitigation strategies that the Chinese are using to address permafrost related issued. There may be some strategies that are transferable to the NT.

Impact Area:

R- 9: Travel delays: Weather / Fires

Transport Element:

All Season Roads

Description:

Extreme events can cause disruption to road travel. This category refers to events that are not directly damaging to infrastructure, but could result in a temporary impact to the transportation network. Direct weather –related events would include intense storms or freezing rain. Events that might be climate-induced – which may change in frequency or intensity with climate change – include forest fire closures of road segments.

Workshop rated assessment

Low (Risk score = 6) Note some items not specifically rated.

Expectation of the impact of climate change:

Frequency:	more often,	less often,	unknown
Impact:	more severe,	less severe,	unknown

Specific Locations / Incidents

- None specifically identified

Are noted impacts climate change related?

Adaptation Actions Identified

Action Number	Action	Locations / areas	Time Frame	Status
Immediate Term (1 – 5 years)				
Action - 46: Review design criteria	Design criteria for new road construction should include an allowance, for enhanced robustness in design to account for climate change. Most specifically, historical climate normal may not accurately represent future conditions. Design storms may need to be reviewed to determine whether they are suitable for future predictions. The desire is to accommodate potential changes in performance drivers (temperature, rainfall etc.). A key feature would be to link the design consideration directly to specific climate variable to ensure the most appropriate action is taken.	All – but most specifically for new road construction (Inuvik-Tuk, and MV all weather).	1 - 5	DoT web site – likely plus other sources are active communication
Action - 47: Reporting and Public information	Public notifications systems could be reviewed to identify new methods of reaching system users. Particularly advances in smart phone technology might be deployed for information distribution.	All	1 - 5	

Gaps

- Communication to the public: What climate change means to the NWT transportation system
- Fully understand the implications of climate change on O&M efforts and communicate these to stakeholders
- Gather weather predictability and forecasting data, which might include installation of additional weather stations to help with seasonal predictions
- Expectations of communities and users are increasing, while budget increases are not felt to allow the expected response.

Comments

None identified

Sector: Airports

Impact Area:

A- 1: Runways buckling due to changing runoff soil/ permafrost conditions

Transport Element:

Runways and taxiways

Description:

Changing substructure conditions will result in paved surfaces buckling or slumping. The greatest sensitivity is for runways which require tighter level tolerances than aprons and taxiways.

Workshop rated assessment

Medium (Risk score = 16)

Expectation of the impact of climate change:

Frequency: more often, less often, **unknown**

Impact: more severe, less severe, **unknown**

Specific Locations / Incidents

Paved Runways with issues at present include:

- Yellowknife (subsurface replaced with inclusion of an insulation layer)
- Fort Simpson
- Norman Wells (Ice under the runway)
- Inuvik: Seeing some settlement due to permafrost thawing also on service roads and culverts
- Hay River (dips form in runways, need repairs every 3-4 years at a cost of \$800k).
- Ft Smith

Smaller airports may be less of a concern due to smaller aircraft & gravel airstrips. Gravel strips do not buckle, though they can become un level and require re-grading. As well the develop depressions on the central part and longitudinal shoulder rotation cracking grading. They do sometimes see some cracking, but anecdotes are not sure this is related to climate change

Has been some flooding of airstrips eg. Aklavik

Are noted impacts climate change related?

Adaptation Actions Identified

Action Number	Action	Locations / areas	Time Frame	Status
Immediate Term (1 – 5 years)				
Action - 48: Complete airstrip risk assessments	The DoT has developed an airport climate change risk assessment protocol. It has been piloted at Inuvik airport. The protocol is a step-wise process that starts with a desk review, and progresses to site inspections, and even	All	1 – 5	

Action Number	Action	Locations / areas	Time Frame	Status
	subsurface condition testing. At each step a decision can be made whether to proceed to further analysis. For each runway an analysis must be done to the terrain analysis stage.			
Action - 49: Strategic snow clearing	Snow clearing on aprons and shoulder areas has (anecdotally) been found to preserve the permafrost integrity. Preservation of snow cover in the later season may preserve cold ground conditions. Airport operations should explore changes to snow clearing practices that may enhance permafrost formation.	Paved airstrips	1 - 5	
Medium Term (5 - 20 years)				
Action - 50: Runway rebuild	For runways that have chronic problems, a runway (full or partial) rebuild may be required. At Yellowknife airport in 2002, a section of the runway was excavated and rebuilt with insulating material included to protect the permafrost area. The paved runways are typically expected to require a major rebuild every 25 years, so at these points, subsurface evaluations and reconstruction should be considered.		Yellowknife, Inuvik Hay River	
Action - 51: Periodic regarding (gravel strips)	Gravel strips can be periodically regraded. This has a cost, and may be an adequate response. A Life Cycle cost analysis would enable the determination of the equalization point of more extensive upgrades against the cost of continued regarding.			

Gaps

- The causes may not be completely certain (e.g. is it permafrost disappearance, consolidation of fines, underflow drainage, etc.)
- Not clear whether/how slumping impacts are related to CC.
- Nunavik is doing a categorization that seems to show impacts related to building in ice-rich areas
- Many airports lack design and as-built information.
- Only airports that have recently been studied (Inuvik, Yellowknife) would have any information about the substructure and soil conditions. Limited understanding of soil conditions underneath most runways.
- Greg - some airports, even recently built runways, do not possess proper design drawings etc. for their original construction

Comments

- Clarified that risk levels on permafrost vulnerability map were from Avia, 2007.
- Buckling is an issue for paved areas. Gravel strips show unevenness which can be fixed with grading. As well frost cracking of asphalt pavement is an issue grading.

Impact Area:

A- 2: Runways / taxiways flooded

Transport Element:

Runways and taxiways

Description:

Workshop rated assessment

Medium (Risk score = 16)

Expectation of the impact of climate change:

Frequency: more often, less often, unknown
Impact: more severe, less severe, unknown

Specific Locations / Incidents

- Nahanni Butte
- Tuktoyaktuk

Are noted impacts climate change related?

Adaptation Actions Identified

Action Number	Action	Locations / areas	Time Frame	Status
Immediate Term (1 – 5 years)				
Action - 52: Grooving of runways (paved)	Grooving will enhance water drainage from runways. (Grooving may be driven more to control loss of friction than for run off)	Paved strips	1 - 5	
Medium Term (5 - 20 years)				
Action - 53: Drainage assessments	Some strips may require upgrades to drainage infrastructure.	All	5 - 20	

Gaps

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Comments

- At community sessions, Hay R., Nahanni Butte, and Tuktoyaktuk airports were specifically mentioned as problematic for drainage.

Impact Area:

A- 3: Loss of Friction

Transport Element:

Runways and Taxiways

Description:

Water or ice accumulation may result in loss of friction on the runways. As a result flights can be scrubbed. While this has happened for many years, there is anecdotal evidence that this seems to be a more chronic problem in recent years.

Workshop rated assessment

Medium (Risk score = 16)

Expectation of the impact of climate change:

Frequency: more often, less often, unknown
Impact: more severe, less severe, unknown

Specific Locations / Incidents

- Inuvik has been identified. There have been scrubbed flights due to loss of friction and in some periods (e.g. storm in 2011) the equipment fleet struggled to keep the runway clear. Response has been more sand and urea application, crews apply, then land safely - but if longer event then crews must return and clean airstrip again so next flight can land with proper friction.

Are noted impacts climate change related?

Adaptation Actions Identified

Action Number	Action	Locations / areas	Time Frame	Status
Immediate Term (1 – 5 years)				
Action - 54: Increased chemicals use	An immediate measure will be to apply more sanding and de-icing fluids (acetate – example product names “E36” and SF7”). Note that increased use of runway deicing (as well as aircraft deicing (glycol products), has required more vigilant management (and associated costs).	Paved airstrips	1 - 5	Being done informally.
Action - 55: Runway Grooving	Runway grooving improves friction in dry and frost conditions.	Paved	1 - 5	
Medium Term (5 - 20 years)				
Action - 56: Runway extensions	Extending runways can increase safety in low friction conditions.	Paved	5 - 20	

Gaps

- Impact of deicing chemicals on the thermal regime of embankment and permafrost soils

Comments

- Community stakeholders (local flying community) identified Inuvik as an area of concern.
- Some sanding material has a high fines / clay content and can actually be slippery when wet on the runway.

Impact Area:

A- 4: Increasing Maintenance burden

Transport Element:

Equipment & practices (airstrips)

Description:

Workshop rated assessment

Medium (Risk score = 12)

Expectation of the impact of climate change:

Frequency:	more often,	less often,	unknown
Impact:	more severe,	less severe,	unknown

Specific Locations / Incidents

- Example: Sanding requirements from 15 tonnes per year (pre-2000) to 150 tonnes per year (current) at Norman Wells. Cited from community consultations.

Are noted impacts climate change related?

Adaptation Actions Identified

Action Number	Action	Locations / areas	Time Frame	Status
Immediate Term (1 – 5 years)				
Action - 57: increase budgets for staff and materials	Increasing resources to apply more traction material is an obvious first step. This is a low capital and flexible response.	Paved airstrips	1 – 5	
Action - 58: Increased glycol management.	Increasing the use of glycol and ground de-icing agents will require more management activities. In some locations this might require additional capture or holding facilities to be built. Regulations require collection/treatment of glycol over a specific amount and at present only KY meets this threshold.		1 - 5	

Gaps

- Is more and more maintenance adequate, or is there a point where something different could be done.
- How is increasing glycol use related to changes in climate (more days between +10 and -10), increased traffic, different aircraft, regulatory requirements. I.E. Can the increase in glycol use be predicted? This would allow planning for building and/or expanding retention ponds.
- Glycol degradation rates not well understood in the north.
- Not clear the magnitude of extra costs incurred. Would need to review staffing or OT logs to do a rigorous analysis. Budget variances might be sufficient for a general indication.
- impact of deicing chemicals on the thermal regime of embankment and permafrost soils

Comments

- Increasing use of glycol to de-ice aircraft; DoT has to deal with contamination
- Increasing use of runway de-icing fluid and sand

Impact Area:

A- 5: Travel delays: Weather / Fires

Transport Element:

Air Travel Delays

Description:

Extreme events can cause disruption to air travel. This category refers to events that are not directly damaging to infrastructure or aircraft, but could result in a temporary impact to the transportation network. Direct weather –related events would include intense storms, freezing rain, and in particular fog. Events that might be climate-induced – which may change in frequency or intensity with climate change – include forest fire closures of road segments.

Workshop rated assessment

Low (Risk score = 6)

Expectation of the impact of climate change:

Frequency:	more often,	less often,	unknown
Impact:	more severe,	less severe,	unknown

Specific Locations / Incidents

- Fog at Norman Wells and Wekweeti
- Reported the case of a child in Ft Liard that needed medical evacuation but flights couldn't move.

Are noted impacts climate change related?

Adaptation Actions Identified

Action Number	Action	Locations / areas	Time Frame	Status
Immediate Term (1 – 5 years)				
Action - 59: Notification system	Some delays are inevitable. DoT can review and enhance notification systems.		1 - 5	
Medium Term (5 - 20 years)				
Action - 60: Improved instrument landing systems	Instrument landing systems could be implemented at more airstrips		5 – 20	

Gaps

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Comments

- Users and stakeholders are expecting 24/7 system functionality for medevac etc. This is hard to provide.

Impact Area:

A- 6: Shoreline Erosion of airstrip

Transport Element:

Airstrips and Runways

Description:

Extreme events can cause disruption to air travel. This category refers to events that are not directly damaging to infrastructure or aircraft, but could result in a temporary impact to the transportation network. Direct weather –related events would include intense storms or freezing rain. Events that might be climate-induced – which may change in frequency or intensity with climate change – include forest fire closures of road segments.

Workshop rated assessment

Low (Not formally rated. Stakeholder concern – not yet observed).

Expectation of the impact of climate change:

Frequency:	more often,	less often,	unknown
Impact:	more severe,	less severe,	unknown

Specific Locations / Incidents

- Concern about Paulatuk airport. Not impacts to date, however the airstrip is close to sea level.

Are noted impacts climate change related?

Adaptation Actions Identified

Action Number	Action	Locations / areas	Time Frame	Status
Medium Term (5 - 20 years)				
Action - 61: Monitoring	Monitor airport infrastructure for signs of degradation.	Paulatuk	5 - 20	

Gaps

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Comments

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Sector: Ferries and Crossings

Impact Area:

F- 1: Infrastructure damage or travel disruptions

Transport Element:

Ferry Landings

Description:

Ferry landings could be damaged. Potential causes include: water level fluctuation, drought (low water), intense rainfall (short term duration), of flooding / freshet.

Landing sites are gravel ramps that are constructed annually and built out through the season.

Workshop rated assessment

Medium / Low (Risk scores = 6-10) (several individual components assessed).

Expectation of the impact of climate change:

Frequency:	more often,	less often,	unknown
Impact:	more severe,	less severe,	unknown

Specific Locations / Incidents

- None reported

Are noted impacts climate change related?

Adaptation Actions Identified

Action Number	Action	Locations / areas	Time Frame	Status
Medium Term (5 - 20 years)				
Action - 62: Permanent landing structures	Permanent structures for landing sites could be considered. This is challenging considering the strength of ice and freshet forces in the river.	None specifically identified	5 - 20	

Gaps

- None identified

Comments

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Impact Area:

F- 2: Weather Related Ferry Service disruption

Transport Element:

Ferry maneuverability, operational control

Description:

Ferry service is disrupted by weather or climatic events. These disruptions could range from hours to days and are the result of short term weather events). Causes might include:

- Water level fluctuation
- fog
- Intense rainfall – short term duration
- Drought in watershed
- Extreme snow

Workshop rated assessment

Medium / Low (Risk scores = 8-10) (Note that several individual components assessed).

Expectation of the impact of climate change:

Frequency: more often, less often, unknown
Impact: more severe, less severe, unknown

Specific Locations / Incidents

- High water events where water comes up, carrying lots of trees, creates problems for the ferries and they have to be shut down until the water drops and the trees are gone. This happens on the Mackenzie and Arctic Red River ferries. DOT is seeing more of these events, with higher water than in the past.

Are noted impacts climate change related?

Adaptation Actions Identified

Action Number	Action	Locations / areas	Time Frame	Status
Immediate Term (1 – 5 years)				
Action - 63: Operational prudence	Operators on site respond to situations as they arise. Trained and experienced operators are expected to be able to respond to foreseeable impacts.	All ferry crossings	1 -5	Currently being done
Action - 64: Notifications and Public Information	If closures and service suspensions become more frequent, it may be desired to develop a more robust notification system for road users.	All ferry crossings	1 - 5	Currently done through website and on road

Gaps

None identified

Comments

None identified

Impact Area:

F- 3: Loading Ramp Activities Disruption

Transport Element:

Ramps: Activities

Description:

Loading ramp activities disruption. This impact results from damage or interference with the loading ramps. Potential causes could include water level fluctuation, deposition of debris on the ramps, scouring of the ramps. Intense short term rainfall may also affect the ramp condition.

Workshop rated assessment

Low (Risk score = 8) (several individual components assessed).

Expectation of the impact of climate change:

Frequency:	more often,	less often,	unknown
Impact:	more severe,	less severe,	unknown

Specific Locations / Incidents

- Northern Ferries: DOT is seeing more events with higher water than in the past. High water and debris issues may also damage the ferry landings so they have to be re-shaped. This is a significant cost especially since they have to use clean gravel which must be accessed from further away.

Are noted impacts climate change related?

Adaptation Actions Identified

Action Number	Action	Locations / areas	Time Frame	Status
Immediate Term (1 – 5 years)				
Action - 65: Increased ferry operations resources.	Increased resources may be required for maintaining the ferry services. Resources would include Staff time for activities (e.g. longer shifts, more overtime, etc.) as well as more disbursement costs for gravel. As well, if gravel requirements increase dramatically, then there may be a need to expand gravel storage or quarry operations.	All ferries	1 - 5	Done on an ad hoc basis as required to keep the system operational.

Gaps

- Data tracking of levels of effort required now compared to other years.

Comments

- There is some cited public perception that ramp construction activities are contributing to sedimentation in the river. One workshop expert felt that the sediment loads from other sources would be much larger than those caused by ramp construction.

Impact Area:

F- 4: Changes to bank stability and location

Transport Element:

Riverbanks

Description:

Changes to bank stability and location of banks can affect ferry operations. Reasons for these changes can be due to sloughing or banks, water scouring, or ice dynamics in the winter or during breakup.

Identified climate variables that can impact this risk include mean temperature, Intense rainfall – short term duration, annual Rainfall and ice dynamics.

Workshop rated assessment

Medium / Low (Risk score = 6 -10) (several individual components assessed).

Expectation of the impact of climate change:

Frequency: more often, less often, unknown

Impact: more severe, less severe, unknown

Specific Locations / Incidents

- None specifically identified

Are noted impacts climate change related?

Adaptation Actions Identified

Action Number	Action	Locations / areas	Time Frame	Status
Medium Term (5 - 20 years)				
Action - 66: Improve understanding of what future break-up conditions will be (more ice, less ice, more jams)	Modelling and empirical work to improve predictive abilities, working with Dr. Faye Hicks at University of Alberta	Mackenzie river	5 - 20	Some work done already

Gaps

- Some river dynamics issues not well understood

Comments

- Some communities have expressed concern about water turbidity from landing maintenance operations.

Impact Area:

F- 5: Cable ferry damage or disruption

Transport Element:

Ferry Cable (Peel R. at Ft. MacPherson only)

Description:

The cable ferry cable could be damaged – resulting in service disruption.

Identified climate variable that could cause this include: water level fluctuation, Intense rainfall – short term duration, annual rainfall, High Winds – short duration, sustained high wind, ice dynamics

Workshop rated assessment

Medium / Low (Risk scores = 6 - 10) (Note: Several individual components assessed).

Expectation of the impact of climate change:

Frequency:	more often,	less often,	unknown
Impact:	more severe,	less severe,	unknown

Specific Locations / Incidents

- Peel R. at Ft. McPherson only. This is the only cable ferry

Are noted impacts climate change related?

Adaptation Actions Identified

Action Number	Action	Locations / areas	Time Frame	Status
Immediate Term (1 – 5 years)				
Action - 67: More Maintenance as required	The cable ferry may require more maintenance, including more inspections and potentially replacement of the cable or	Peel River	1 - 5	

Gaps

None identified

Comments

None identified

Impact Area:

F- 6: Drainage Impacts to Ferry Facilities

Transport Element:

Site Drainage

Description:

Ferry waiting areas can become flooded or problematic due to poor site drainage or excessive Ferry waiting area / site disruption.

Climate variable causes include: intense rainfall – short term duration, annual rainfall, extreme snow site drainage

Workshop rated assessment

Medium / Low (Risk score = 6 - 10) (several individual components assessed).

Expectation of the impact of climate change:

Frequency:	more often,	less often,	unknown
Impact:	more severe,	less severe,	unknown

Specific Locations / Incidents

- Xxx

Are noted impacts climate change related?

Adaptation Actions Identified

Action Number	Action	Locations / areas	Time Frame	Status
Immediate Term (1 – 5 years)				
Action - 68: Review and upgrade vehicle areas for drainage	Problems would be typically addressed on site and informally. Modifications may become needed if problems are chronic.		1 - 5	

Gaps

None identified

Comments

None identified

Impact Area:

F- 7: Reduction of ferry load capacity

Transport Element:

Ferry cargo capacity

Description:

Reduction of ferry loads may be required for short periods of time. This would result in reduced carrying capacity on the ferry. Typically this might result in minor service disruptions, though it is possible that travelers could be inconvenienced overnight. Causes would be due to water level issues (low level) or possibly highly variable flows. As well, wind and storm events might temporarily hinder ferry capacity.

Climate variable causes include high temperatures, drought, water level fluctuations, and sustained high winds.

Workshop rated assessment

Low (Risk score = 6 - 8) (several individual components assessed).

Expectation of the impact of climate change:

Frequency:	more often,	less often,	unknown
Impact:	more severe,	less severe,	unknown

Specific Locations / Incidents

- None identified

Are noted impacts climate change related?

Adaptation Actions Identified

Action Number	Action	Locations / areas	Time Frame	Status
Immediate Term (1 – 5 years)				
Action - 69: Longer operational hours if required.	Additional operating hours may be required during periods when not capacity is limited and traffic is substantial.		1 - 5	
Action - 70: Re-assign the Merv Hardie	Completion of the DehCho bridge will allow the Merv Hardie to be re-deployed.		1 – 5	

Gaps

None identified

Comments

None identified

Impact Area:

F- 8: Changing operational season

Transport Element:

Ferry Operating Season

Description:

Ferry seasons will be extended due to longer ice free periods. To date, changes have not been observed in the ferry opening dates though the closing dates for the ferries have been extended in the range of 1-2 weeks over the past 20 years.

Workshop rated assessment

Low: Not previously defined as an impact

Expectation of the impact of climate change:

Frequency:	more often,	less often,	unknown
Impact:	more severe,	less severe,	unknown

Specific Locations / Incidents

- --

Are noted impacts climate change related?

Adaptation Actions Identified

Action Number	Action	Locations / areas	Time Frame	Status
Immediate Term (1 – 5 years)				
Action - 71: Prepare for longer ferry operations	Warmer conditions will result in a longer ferry season. This has already been seen over the past 2 decades.	All	1 - 5	

Gaps

None identified

Comments

- North ferry opening dates have not changed much, but closing dates are later.

Sector: River Transportation

Impact Area:

B- 1: Damage or loss of facilities

Transport Element:

Barging Infrastructure (Navigation)

Description:

Shore facilities for barging and river transportation may be disrupted by climate change. Examples include damage to piers and moorings structures. Causes are related to GSL shoreline erosion and silting (Hay River), shore erosion along the Mackenzie River (largely suspected to be due to loss of permafrost and subsequent slumping). Break up conditions may contribute, as well as intense precipitation events.

Workshop rated assessment:

Medium / Low (Risk scores = 8 - 15) (several individual components assessed).

Expectation of the impact of climate change:

Frequency: less often,
Impact: more severe, less severe,

Specific Locations / Incidents

- Silting and shoreline erosion (Hay River)
- Shoreline erosion at mooring points (throughout river)
- Visually – more landslides, more visible ice on the river

Are noted impacts climate change related?

Likely: Longer open water seasons have been linked to shoreline erosion in marine and GSL shorelines. Shoreline erosion and slumping is becoming more pronounced along the Mackenzie River.

Adaptation Actions Identified

Action Number	Action	Locations / areas	Time Frame	Status
Immediate Term (1 – 5 years)				
Action - 72: Reconstruction of structures	Hay River site may require dredging and / or reconstruction of structures.	Hay River	1 - 5	Done informally.
Action - 73: Relocation of mooring anchor points	Mooring anchors are relocated further ashore along the river. Note that many of these are informal (e.g. trees), but some are specifically constructed.	General	1 - 5	Done informally.

Gaps

- None identified

Comments

- Normal for river to change year to year. Barge operators are always adjusting routes etc.
- Permitting requirements for dredging becoming more restrictive. More time and possibly resources required.

Impact Area:

B- 2: Disruptions to capacity or utility of barges

Transport Element:

Barge Service Infrastructure

Description:

Barge serviceability or operations can be impaired by temporary or seasonal events. Damage could be Potential damage could include damage to manifolds (bulk fuel), or other shore side or barge side equipment. A possible cause of this damage includes spring break-up, washout of ramps, or blockage of landing locations.

Workshop rated assessment

Medium / Low (Risk scores = 9-15) (Several individual components assessed).

Expectation of the impact of climate change:

Frequency: more often, less often, unknown
Impact: more severe, less severe, unknown

Specific Locations / Incidents

- Tulita breakup. Ice piled on shore several meters deep. This could have threatened the fuel manifolds (did not in this instance).

Are noted impacts climate change related?

Adaptation Actions Identified

Action Number	Action	Locations / areas	Time Frame	Status
Immediate Term (1 – 5 years)				
Action - 74: Facilities Assessments	Periodic review of facilities, and tracking of conditions and incidents.	Re-supply communities	1 - 5	PPD does this for fuel facilities.

Gaps

- None identified

Comments

Permitting requirements for dredging becoming more restrictive.
More "dynamic" breakups observed and less thermal breakups. (e.g. Tulita/Norman wells 2007)

Impact Area:

B- 3: Service Interruptions

Transport Element:

Barge operations

Description:

Weather and climate related events can disrupt operations of barge services. Examples of disruptions can include:

- Cargo relays through the rapids
- General operational control difficulties
- Scheduling
- Loading / Unloading
- Unplanned Mooring
- Mooring
- Navigation systems
- Docking and Mooring
- Other navigable hazards (debris)
- Cargo capacity of barges

Several causes were identified for these disruptions including:

- Winds
- Water level
- Fog
- Rain / snow
- Waves
- Slope and permafrost changes creating more in river debris
- Lightning

Workshop rated assessment

Medium / Low (Risk scores= 8-10) (Several individual components assessed).

Expectation of the impact of climate change:

Frequency:	more often,	less often,	unknown
Impact:	more severe,	less severe,	unknown

Specific Locations / Incidents

- No specific incident reported, though anecdotal information suggests that some unusual weather becoming more common (e.g. light misty rainfall was cited).

Are noted impacts climate change related?

Adaptation Actions Identified

Action Number	Action	Locations / areas	Time Frame	Status
Immediate Term (1 – 5 years)				
Action - 75: Load and trip planning.	Weather is important for Great Slave Lake. Winds create large waves on GSL that may cause delays. Wind does not create much wave action on the river. Load management (load lightening) may also	All	1 - 5	

Action Number	Action	Locations / areas	Time Frame	Status
	be required at some locations			

Gaps

- Some conflicting predictions about how climate change impacts runoff. Impact of loss of permafrost on hydrology is not complete. Larger active layer could result in more storage and slower runoff – leading to higher water in the late summer. Evidence if this is true is not complete.
- Permafrost degradation and excess pore water pressure at the shore face may trigger slides and slumping

Comments

- Stakeholder comment (Norman Wells): River levels dropping sooner in the year, some maneuverability issues and barges getting stuck at low water (Note conflicting reports on this issue between consultation notes and workshop results – see gaps).
- The climate variables driving this impact are not new and many of these are addressed through operator skill. While these risks are real, workshop participants highlighted that if these impact your operations the you “aren’t doing your job as an operator”.

Sector: Arctic Marine / Community Resupply

Impact Area:

M- 1: Damage to props and rudders

Transport Element:

Vessel equipment

Description:

Vessel equipment can be damaged through changing or unpredictable ice conditions. While overall, the ice is thinning and being reduced in the arctic, there is more potential for unforeseen, or “not previously seen” ice conditions due to movement of the ice pack.

Workshop rated assessment

High (Risk score = 20)

Expectation of the impact of climate change:

Frequency:	more often,	less often,	unknown
Impact:	more severe,	less severe,	unknown

Specific Locations / Incidents

- None identified

Are noted impacts climate change related?

- --

Adaptation Actions Identified

Action Number	Action	Locations / areas	Time Frame	Status
Immediate Term (1 – 5 years)				
Action - 76: Route Planning and Charting	Route planning and accurate charts and weather / ice information can reduce chances of encountering unexpected conditions.		1 – 5 5 - 20	
Medium Term (5 - 20 years)				
Action - 77: Larger Vessels	Future resource development or community re-supply could pool shipping to create larger quantities. This would create a market for use of larger, more ice capable ships		5 – 20	

Gaps

None identified

Comments

In 2010 there were three groundings (2 fuel ships, one cruise ship) in Nunavut. While these are groundings, not ice damage they do highlight that incidents can occur.

Experiencing changing distribution of multi-year ice – being found in unexpected places.

While the risk rating is rated high, much of this risk is managed already through operator prudence.

Impact Area:

M- 2: Challenges to vessel maneuverability, docking and mooring

Transport Element:

Vessel Operations

Description:

Vessel movement may be disrupted by ice conditions not previously seen – such as migration of multi-year ice to new areas. Responses may be challenged by insufficient charting which may limit choices of route options etc.

Workshop rated assessment

High (Risk score = 20)

Expectation of the impact of climate change:

Frequency:	more often,	less often,	unknown
Impact:	more severe,	less severe,	unknown

Specific Locations / Incidents

- None identified

Are noted impacts climate change related?

Adaptation Actions Identified

Action Number	Action	Locations / areas	Time Frame	Status
Immediate Term (1 – 5 years)				
Action - 78: Planning and prudence – improved harbor charting	Operational prudence and skill is a key response to these conditions. Future conditions may require more planning and preparation and could be aided by improved charting, particularly for community harbors.		1 – 5	Current practice
Medium Term (5 - 20 years)				
Action - 79: New vessel types	Different vessels might need to be deployed. Features might include: advanced maneuvering capabilities (e.g. side thrusters for large vessels servicing a new resource operation) or other assistance to barge operations.		5 - 20	None identified at present
Action - 80: Upgraded shoreside facilities	It may be necessary in the future to create new facilities. An example would be the permanent landing ramps established at Paulatuk.		5 - 20	None identified at present

Gaps

- Charting in many areas is rudimentary, or outdated.
- Better navigational charts for docking
- Is there a need for improved sonar etc. on ships to detect river/ocean bottom?
- Is the bathymetry of the dock approaches changing? Is siltation of the near shore raising the river/ocean bottom? Is maintenance dredging needed?

Comments

While the risk rating is rated high, much of this risk is managed already through operator prudence.

Impact Area:

M- 3: Disruptions to re-supply activities

Transport Element:

Community Re-supply

Description:

Variable or unexpected ice and weather conditions, or high winds etc. can disrupt community re-supply efforts to arctic communities. Examples of the disruptions identified include:

- Seasonal operational window
- Scheduling disruptions of deliveries
- Failure to complete a resupply
- Temporary disruptions to re-supply efforts (e.g. being wind bound, or having to suspend unloading)

Workshop rated assessment

Medium (Risk score = 15)

Expectation of the impact of climate change:

Frequency: more often, less often, unknown
Impact: more severe, less severe, unknown

Specific Locations / Incidents

- Reported that there frequent wind events, often have to take cover and wait out wind in order to enter harbour (location not specified).

Are noted impacts climate change related?

Adaptation Actions Identified

Action Number	Action	Locations / areas	Time Frame	Status
Immediate Term (1 – 5 years)				
Action - 81: Planning	Operator prudence and planning can reduce the risk of these events disrupting supply. Ensuring that critical supplies are delivered as early as possible.	All	1 - 5	Currently done
Medium Term (5 - 20 years)				
Action - 82: Develop greater reserve supplies and capacity	Redundancy and extra capacity can be built into the systems. Cited examples include: • Maintain (and increase) the strategic fuel reserves in Tuktoyaktuk. • Ensure to have a backup option for each location (e.g. substantial air lift might require large planes and airstrip upgrades).	All	5 - 20	

Gaps

- Might need to develop more localized forecasts or predictive tools (e.g. local ice and freeze up forecasts).

Comments

- Noted that current data from ice service appears to be sufficient.

- Quite possible that a singular re-supply could be delayed or might not proceed. Unlikely that an entire summer could pass without being able to access a community at least once.

Impact Area:

M- 4: Damage to support infrastructure

Transport Element:

Support Infrastructure

Description:

Support infrastructure can be damaged examples cited include:

- Loading and unloading equipment (cranes, winches, and conveyors) – might not all be community.
- Vessel landing and Mooring
- Bulk fuel shore –based storage
- Wharves / Quays / Docks

Causes of this include: Wind waves

- High peak temperatures (fuel storage)
- Mean temperatures (long term increase affects soil and ground conditions)
- Intense Rain (erosion, flooding)
- Annual Rain
- Sustained high wind
- Landfast ice (pier damage etc.)

Workshop rated assessment

Medium (Risk score = 15)

Expectation of the impact of climate change:

Frequency: more often, less often, unknown
Impact: more severe, less severe, unknown

Specific Locations / Incidents

- No incidents identified

Are noted impacts climate change related?

Adaptation Actions Identified

Action Number	Action	Locations / areas	Time Frame	Status
Immediate Term (1 – 5 years)				
Action - 83: Infrastructure monitoring	• Tank farm inspections (Note that facilities are inspected regularly and events (e.g. damage or leaks etc.) is currently reported.		1 – 5	
Medium Term (5 - 20 years)				
Action - 84: Standards and design	• Ensure that construction standards stay current with new codes – as permafrost changes etc. (noted that infrastructure management is ongoing and that several upgrades have been made). • Evaluate structural design of facilities.		5 – 20	
Action - 85: Ice monitoring	• Evaluate if landfast ice characteristics are changing (e.g. any inter-year movement).		?	

Gaps

- Storm surge predictions might be desired for some locations.

Comments

- Is there a risk of permafrost degradation under fuel storage tanks leading to instability of the tanks and repair costs (and environmental issues if the tanks rupture)?--

Impact Area:

M- 5: Impairment of Arctic Passage support operations

Transport Element:

Arctic Passage support operations

Description:

All activities in the high arctic are weather dependent as it can be a hostile environment. Some activities that support transportation and passage in the may be affected by climate change. Identified examples include: search and rescue and navigation

Causes of these disruptions include:

- Short-duration high winds
- Sustained high winds
- Wind waves
- Extreme snow
- Landfast ice
- Fog
- Mobile ice
- Multi-year ice

Workshop rated assessment

Medium (Risk score = 16)

Expectation of the impact of climate change:

Frequency:	more often,	less often,	unknown
Impact:	more severe,	less severe,	unknown

Specific Locations / Incidents

- xxx

Are noted impacts climate change related?

Adaptation Actions Identified

Action Number	Action	Locations / areas	Time Frame	Status
Medium Term (5 - 20 years)				
Action - 86: User activities and requirements	A greater understanding and coordination may be required of what activities are being undertaken by residents and users. New technologies may need to be deployed for tracking, monitoring and search and rescue.	Arctic	5 - 20	

Gaps

- Better understanding of where vessels and community members are going, what activities they are doing, and what support they might require. This could increase as a greater variety of vessels and projects occur.

Comments

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APPENDIX E

Literature Review Compendium

LITERATURE SEARCH AND REVIEW OVERVIEW

1 BACKGROUND

The Department of Transportation (DoT) of the Government of the Northwest Territories (GNWT) is preparing a climate change adaptation plan. Part of the process is to review available literature to understand available information as well as unknowns and gaps in information.

2 PROCESS

2.1 Information Collection

Information consisted primarily of published documents, draft working documents, and PowerPoint presentations used in conferences and workshops. Source documents were obtained from:

- the GNWT DoT and provided to the project team
- the project team
- other occasional sources as identified through discussions.

The document search was focused on transportation related issues, as well as northern environments. A list of the sources was compiled and based on the titles; a prioritization was set with the objectives of reviewing documents most relevant to the north, transportation, and marine transportation. The prioritization list was provided to the DoT project manager for input and consideration.

2.2 Compilation Objectives

A literature review is necessary for the project team to assess the current state of knowledge, the available information, and to understand the nature and scope of the activities the NWT DoT is involved with.

DoT wishes to have a compilation of northern transportation-related documents “in one place.”

This activity of conducting the review process in a structured format, to extract specific information is being used with the objective of:

- Providing a mechanism for sharing information throughout the project and client team in a consistent fashion;
- Extracting from a range of documents, the relevant content applicable to transportation in the north;
- Specifically looking at the different analytical tools that can be identified;
- Evaluating through this project whether a database of these document reviews provides a useful resource to the project team and/or the client.
- The information from this activity was used to inform the development of a marine/ferry workshop briefing document as well as the final adaptation plan report.

2.3 Available Information

To June 8, 2012, 62 documents had been identified and added to the list (see Appendix A - compendium section 8) and 29 had been formally reviewed using the developed template.

In addition a set of 18 documents on climate change forecasts has been reviewed and summarized as a separate appendix of the Climate Change Adaptation Plan (see Appendix A of main report).

Other documents have been reviewed less formally for specific information and may not have been included in this listing of documents.

3 REVIEW OBSERVATIONS

While not a detailed review, a number of highlights can be drawn from the compendium. While not all are surprising, the recurrence of several themes in many of the documents is worth noting.

Observations about the type of documents available include:

- The majority of documents are at the strategic level for either a sector (e.g. impacts on roads) or an area covering many topics (e.g. a community plan that addresses many issues).
- Facility specific studies are fewer in number and are beginning to be generated (e.g. Inuvik airport terrain and geomorphology studies, PIEVC study of Highway #3).

Observations regarding the specific transportation issues identified include:

- Transportation is widely recognised as an area that will be affected by climate change and there is a need for adaptation.
- The stability of physical infrastructure is of key importance (runways, piers and pilings, buildings, etc.).
- The uncertainty of transportation (e.g. changing operations of ice roads etc.) is a frequent concern.
- All the community climate adaptation plans have identified increased uncertainty about transportation as a concern for communities including: winter road operations, airport visibility/storm operability, and impacts to marine transportation. This is not surprising given the dependence of remote communities on these transportation connections.

Observations regarding the actions recommended include:

- Many documents are focused on identifying and quantifying the issues but do not yet provide specific measures for action.
- Many actions are common between documents (e.g. virtually all the community plans identify increased runway maintenance as a key action).
- Few documents have provided a prioritization of the actions – some have grouped them into short and long term.
- Costs are typically not defined for implementing the identified actions.

APPENDIX A

COMPENDIUM OF LITERATURE REVIEWED

NWT Department of Transportation
Climate Change Adaptation Plan.

COMPENDIUM OF LITERATURE REVIEWED: JUNE 8, 2012

Revision History:

Date	Filename	Notes
Dec 23, 2011	LitRev_Compendium_2011-12-23a.docx	First compilation of literature reviewed Formal template review of 27 priority documents.
June 8, 2012	LitRev_June'12.docx	Final compilation of literature reviewed Formal template review of 29 priority documents.
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1 CLIMATE RELATED

Climate impacts reviewed separately.

2 GENERAL BACKGROUND

2.1 Permafrost: The Ground is Literally Melting Beneath our Feet – Appendix A: Community Survey Results

1	Document Name	Permafrost: The Ground is Literally Melting Beneath our Feet – Appendix A: Community Survey Results
2	Author	Northwest Territories Association of Communities
3	Year	
4	Type	Community survey results regarding permafrost degradation
5	Subjects / Key words	
6	Scope	The document provides the results of a community survey for the Statement of Knowledge Regarding Permafrost Degradation and Community Infrastructure in the NWT
7	General Data	As part of the Statement of Knowledge Regarding Permafrost Degradation and Community Infrastructure in the NWT, the NWT Association of Communities completed a survey of communities to ask questions regarding climate change, climate change impacts and adaptation, and permafrost degradation concerns. A total of 13 communities responded, ranging from Fort Smith to Ulukhaktok; most respondents were Senior Administrative Officers of the community. The document specifically includes: • A set of 16 questions with a series of responses (e.g., none, slight, somewhat, a fair amount, or expert; or not concerned, somewhat unconcerned, somewhat concerned, totally concerned) and provides a response percent and count for each question and response. • Questions included: ○ How would you rate the general public of your community's / your Council's / your knowledge of Climate Change Adaptation? ○ How concerned are the Public / your Council / you in your community about the impacts of climate change in your community? ○ Please rate the Public's / your Council's / your level of concern on each of the following climate change issues: permafrost, building codes, sea ice loss, extreme weather, water level changes, water quality, waste water, solid waste, food security, airports,

		highways, travel on water, travel on land, and forest fires ○ Do you have any of the following material that might be placed on the database? Original construction drawings for community infrastructure, geotechnical reports for community infrastructure, and geotechnical reports for other infrastructure ○ What climate change impacts are you already starting to see in your community? Warming temperature, more storms, more snow, less snow, more rain, less rain, permafrost melting, less sea ice, roads heaving, shortened winter road season, shortened ice bridge season, more cancelled/delayed flights, and challenges travelling on land ○ What climate change adaptation issue concerns you the most? (state one issue and describe) ○ If you have any other climate change adaptation concerns/issues, please list them. ○ Please indicate any other impacts that are being seen that are not on the list above. ○ Please share any unique approaches that you are taking to Climate Change Adaptation. Transportation impacts – effects on other sectors: • None provided
8	Specific Transport Mode Info / Issues	<u>AIR TRANSPORT</u> • 50.0%, 58.3% and 50.0% of respondents noted the Public, their Council, and they, respectively, were somewhat concerned with airports (as a climate change issue) • 72.7% of respondents noted more cancelled/delayed flights has already started in their community <u>ROAD TRANSPORT</u> • 53.8% and 69.2% of respondents noted the Public and their Council, respectively, was somewhat concerned with permafrost (as a climate change issue) • 46.2% of respondents noted they were somewhat concerned or totally concerned with permafrost (as a climate change issue) • 46.2% of respondents noted the Public and their Council (each) was somewhat concerned with highways (as a climate change issue) • 38.5% of respondents noted they were totally concerned with highways (as a climate change issue) • 46.2% of respondents noted the Public was somewhat concerned with travel on land (as a climate change issue) • 46.2% and 53.8% of respondents noted their Council and they, respectively, were totally concerned with travel on land (as a climate change issue) • 58.3% of respondents noted they had no copies of original construction drawings or geotechnical reports for community infrastructure • 66.7% of respondents noted they had no copies of geotechnical reports for other infrastructure • 69.2% of respondents noted permafrost melting has already started in their community • 76.9% of respondents noted heaving roads have already started in their community • 58.3% of respondents noted a shortened winter season has already started in their community • 50.0% of respondents noted a shortened ice bridge season has already started in their community • 75.0% of respondents noted challenges travelling on the land has already started in their community • Permafrost melting causing impacts on roads and other infrastructure was cited as an issue that concerns respondents most <u>MARINE TRANSPORT</u> • 46.2%, 58.3% and 41.7% of respondents noted the Public, their Council, and they, respectively, were somewhat concerned with sea ice loss (as a climate change issue) • 66.7%, and 69.2% of respondents noted the Public and their Council, respectively, was

		somewhat concerned with water level changes (as a climate change issue) • 46.2% of respondents noted they were somewhat concerned or totally concerned with water level changes (as a climate change issue) • 46.2% of respondents noted they were somewhat concerned or totally concerned with travel on land (as a climate change issue) • 53.8% and 46.2% of respondents noted the Public and their Council, respectively, was somewhat concerned with travel on water (as a climate change issue) • Loss of sea ice and early break-up with late freeze-up, shoreline erosion, and water levels, were cited as issues that concern respondents most
9	Actions defined by sector	<u>AIR TRANSPORT</u> • None provided <u>ROAD TRANSPORT</u> • None provided <u>MARINE TRANSPORT</u> • None provided
10	Tools	

2.2 With Respect, Canada's North: Sixth Report of the Standing Senate Committee on Energy, the Environment and Natural Resources

1	Document Name	WITH RESPECT, CANADA'S NORTH Sixth Report of the Standing Senate Committee on Energy, the Environment and Natural Resources
2	Author	The Honourable W. David Angus, Chair The Honourable Grant Mitchell, Deputy Chair
3	Year	May 2009
4	Type	Publication from the Government of Canada. 36 pages
5	Subjects / Key words	Canada's North, climate change, northern communities, infrastructure and research
6	Scope	This report represents the work conducted during the 39th Parliament, 2nd Session by the Standing Senate Committee on Energy, the Environment and Natural Resources. The committee examines the impact of two phenomena affecting Northern Canadians: climate change and industrial and commercial development.
7	General Data	Some evidences of climate changes are presented: • The rate of ecological change is far exceeding earlier predictions • The pace and reach of global warming are more pronounced in the Arctic than in other parts of the world • Warmer air temperatures in the Mackenzie Delta • Impact of climate change on the ice roads • Permafrost degradation and infrastructure instability • Increase in extreme weather events • Impacts on tides • Rapid rate of ecological change • Impact on caribou herds • Impacts on species distribution (e.g. of some invasive species) • Change in food security (from hunting and fishing) and community livelihoods The committee recognized the need for more comprehensive research in order to deal with climate change • Early and persistent monitoring is crucial • Need to fill gaps in the ecological knowledge <u>Committee recommendations:</u> 1. The federal government should increase and sustain its funding of research in the North and place greater emphasis on monitoring and data collection that will help track long term trends in climate change. Multi-year funding for the N.W.T.

		Cumulative Impact Monitoring Program (CIMP) should be granted immediately. 2. The federal government should increase the funding required to adapt to climate change. 3. The federal government must address the urgent need for research and development of solutions for melting permafrost. 4. The federal government is urged to provide immediate additional funding for an all-weather road from the gravel pit known as Source 177 to Tuktoyaktuk to ensure the completion of this transportation lifeline. 5. The federal government should ensure that the design of the Arctic Research Institute promised in the 2007 budget speech is centred around the concept of a northern network of researchers in various locations across the North, rather than bureaucracies placed in one or two locations. 6. The federal government should take every measure possible to make quick decisions concerning the future of the Mackenzie Valley Project when those reports are finished. 7. The federal government should recognize that its support for the people of Canada's North who face the difficult challenges associated with living in the North will be the most important component of Canada's arguments in any international forum. 8. The federal government is urged to resolve a resource sharing agreement with the N.W.T. in a way that will dedicate resource revenues to enhanced education, housing and health standards for permanent residents of the North. 9. The federal government should ensure that it places a high priority on local decision making, honouring existing collaborative frameworks and encouraging full local participation to help assure outcomes that work for northerners.
8	Specific Transport Mode Info / Issues	Impact of climate change on the Mackenzie Valley Gas Project • Increase cost • Increase construction timeline Alternative Energy • Introduction of renewable energy source such as wind power is briefly discussed • Funding for such projects is an issue
9	Actions defined by sector	• Two ways of addressing climate change: mitigation and adaptation Example of mitigation: Building repairs to address damage by melting permafrost Example of adaptation: introduction of more energy efficient building code in the NWT. • The federal government should play an important role in economic development, and supporting climate change adaptation efforts must be in partnership with all northerners and according to their vision of the future. • The government recognises that there is a need for the construction of a world class Arctic research station. Some recommend a research network rather than a single institute.
10	Tools	A tool presented in the report consists of the Northwest Territories' Cumulative Impacts Monitoring Program (CIMP).

2.3 True North: Adapting Infrastructure to Climate Change in Northern Canada

1	Document Name	TRUE NORTH: ADAPTING INFRASTRUCTURE TO CLIMATE CHANGE IN NORTHERN CANADA
2	Author	Canada. National Round Table on the Environment and the Economy
3	Year	2009
4	Type	Publication from the Government of Canada. 160 pages.
5	Subjects / Key words	Climate change, northern infrastructures, vulnerability to climate change, role of the government, adaptation
6	Scope	The document highlights the risks posed by climate change to northern infrastructures and demonstrates how the use of existing risk management tools can reduce infrastructure vulnerabilities and adapt more effectively to climate change in Canada's North.
7	General Data	<u>Overview of Canada's North:</u> • Climate data • Physical environment and permafrost • Freshwater ecosystems • Terrestrial ecosystems • Marine ecosystems • Demographic and social data • Economic data <u>Physical effects of climate change:</u> • Warming (air, ground and oceans), sea-level rise, and decreased sea-ice extent, contribute to accelerated coastal erosion. • Reduced sea-ice extent and thickness. • Melting of glaciers and ice sheets are contributing to global sea-level rise. Melting of mountain glaciers likely to affect regional hydrology. • Warming and thawing of permafrost has direct implications on groundwater • The degradation and disappearance of discontinuous permafrost zones will release GHGs (methane) into the atmosphere and further contribute to warming of the atmosphere • Earlier break-up of river and lake ice <u>Effects of climate change on ecosystems:</u> • Increased productivity, range, and abundance of certain plant species • Possible narrowing of ecological niches for high-latitude or uniquely northern species • Shifts in species composition and ecosystem structure • Increased vulnerability of freshwater and marine species • Increased threat from habitat losses and competition from northward advance of southerly species

		<u>Observations and findings:</u> • Research found that northerners are concerned that a warmer climate is already having an effect on the region's infrastructure. • All sectors of the society have a role to play in adapting to climate change • Collaboration between all levels of government (i.e. local, Aboriginal, territorial, and federal) is necessary in order to successfully adapt to climate change • Infrastructure development and renewal has emerged as a policy priority • Climate change adaptation strategies need to be flexible in order to accommodate cultural, social, political, and economic diversity of northern regions • Enhancing the resilience of northern communities is essential to face the upcoming changes • Mainstreaming adaptation into existing or newly formed institutions, such as regulatory processes, asset management plans, resource management, and community plans, can help prepare for the impacts of climate change
8	Specific Transport Mode Info / Issues	<u>Risks and opportunities of climate change on:</u> Infrastructures • Increased risk to older buildings(i.e. before 1990s) built on ice-rich soils, and those built on shallow foundations • New buildings have to consider effects of climate change in their engineering design Road transportation • Reduced reliance on winter roads and added pressure to build all-weather roads • Reduced operation period of winter roads • Loss of access to some communities Marine transportation • There is a potential for new Arctic shipping routes (longer shipping season and less hazards related to sea ice) • Increased large vessel traffic through Hudson Bay and Beaufort Sea present risks to coastal communities and small vessels • Potential for longer shipping season on the Mackenzie River • Reduced reliance on river transport due to lower water levels Energy and mining • Operational risks to offshore exploration activities (more wave action, more storm surges) • Risk of release of drilling waste linked to permafrost melting and ground instability (sump cap stability) • Risks to the integrity of linear structures, such as pipelines • Enhanced exploration potential due to reduced sea-ice conditions
9	Actions defined by sector	Four main barriers to Canada's capacity to adapt to climate change are identified in the report: 1- Capacity constraints: Refers to knowledge, technical skills, organizational and planning capabilities, decision rules, and finances that enable stakeholder participation in managing the risks of climate change

		2- Gaps in data and information: Includes information related to environment, climate, social and economic 3- Lack of guidance: Refers to agreed-upon approaches and methods to account for climate risks in routine planning and decisions 4- Issues of coordination: Refers to the mobilization of decision makers and stakeholders toward shared adaptation goals. Four priorities are highlighted in order to build northern capacity to adapt to climate change: 1- Integrate climate risks into existing government policies, processes, and mechanisms; 2- Ensure northern interests are represented and implicated in the development of climate change adaptation solutions; 3- Strengthen the science capacity and information use in the North to support long-term adaptation efforts; 4- Build community capacity to address climate risk to northern infrastructure and take advantage of opportunities. Some additional recommendations include: • The Canadian Government should adjust funding vehicles for infrastructure development and rehabilitation so that they become incentives to integrate the risk of damage from climate change in infrastructure decisions. • National codes and standards for engineering and construction should be reviewed and modified to accommodate risks of climate change. • Governments and the insurance industry need to work together so that Canadians continue to have access to affordable insurance in a changing climate and so that insurance products encourage modifications to infrastructure in light of climate risks. • The Government of Canada should invest in updating and providing more comprehensive climate and permafrost data, climate change projections, and information for infrastructure design. • Governments at all levels should collaborate with northern experts to develop the best possible design and engineering guidelines for the North. • All levels of governments, the private sector as well as research organizations need to work together in order to make existing adaptation-relevant scientific and technical data and information more accessible and usable to northern infrastructure practitioners, owners, and operators • The Government of Canada needs to share the expertise and experience of Canada's North in addressing climate risks to infrastructure with other polar nations as part of Canada's Northern Strategy.
10	Tools	Tools already in place to improve the management of climate risks include: • Codes, standards, and related instruments (CSRI) • Insurance • Disaster management plans

2.4 Permafrost, Climate Change and the Environment

1	Document Name	PERMAFROST, CLIMATE CHANGE AND THE ENVIRONMENT
2	Author	Steve Kokelj, RR&E, INAC
3	Year	2010
4	Type	PowerPoint presentation. 51 slides
5	Subjects / Key words	Permafrost characteristics and properties, Climate Change, terrestrial and environmental impacts, sumps monitoring, impacts and adaptation, NWT, Mackenzie Delta region
6	Scope	Permafrost related issues and impacts on northern environments
7	General Data	<u>Characteristics of permafrost</u> <u>Permafrost distribution in Canada</u> • Latitudinal gradient: alpine permafrost, sporadic permafrost, discontinuous permafrost, extensive discontinuous, continuous permafrost and subsea permafrost • Norman Wells, Inuvik and Tuktoyaktuk are located in continuous permafrost zone, Yellowknife in the discontinuous zone and Hay River in the sporadic discontinuous zone • Direct relationship between the annual air temperature and the permafrost thickness (colder temperatures = thicker permafrost) • Direct relationship between vegetation type and permafrost characteristics <u>Active layer</u> The surface layer of ground subject to annual thawing and freezing in areas underlain by permafrost. The thickness of the active layer is directly related to factors such as ambient air temperature, vegetation density and type, surface drainage, soil and rock types, ground water content, snow cover properties, local site topography, etc. <u>Ground ice</u> There are several types of ground ice. Ground ice occurs in pores, cavities, voids or other openings in the soils or rock. Ground ice includes pore or interstitial ice, segregated ice (ice lenses or veins, ice wedges) and massive ice. <u>Ground temperatures in permafrost regions</u> Ground temperatures are directly related to climate, soil types, presence of surface water and lakes, snow cover as well as anthropogenic disturbances • Temperature gradient vs. depth • Maximum and minimum temperature

		• Role of the organic layer, vegetation canopy and snow cover as a “buffer layer”. • Influence of the vegetation as snow on ground temperature and active layer depth. • Tundra uplands, Richards Island = Cold permafrost • Spruce forest, Inuvik = Warm permafrost <u>Regional variation in ground temperature</u> Example of the Mackenzie delta area • Ground temperature of -2 °C to -4 °C on the delta. • Ground temperature of -6 °C to -9 °C on the uplands towards Tuktoyaktuk <u>Thermal influence of water bodies on the ground temperatures</u> • Talik: a layer or body of unfrozen ground located within a permafrost area. Frequently found underlying water bodies. • Examples of hydrothermal talik in the Mackenzie Delta region. The warm temperature of the talik is maintained above freezing point by the heat supplied by the water body and underlying groundwater • Permafrost warming is causing the adjustment of the talik zones which can cause subsidence and slumping <u>Permafrost as a waste containment medium (sump)</u> Several sumps were constructed in the Mackenzie Delta region in relation with oil and gas exploration. The sumps are intended to encapsulate drilling wastes associated with drilling operations in the permafrost. Subsidence of sump covers suggests that permafrost has degraded. Sump cap stability is directly related to the local environmental conditions. The climate change problem resides in the fact that a deepening of the active layer can cause localized subsidence and an eventual loss or accidental dispersion of the drilling waste materials. Additional information on sumps includes: • General sump characteristics • Construction and closure practices • Site monitoring protocol • Relation between vegetation, snow cover and sump stability (e.g. tall shrubby vegetation will capture more snow on top of the sump and can cause thermal degradation of the sump) <u>Climate Warming and Permafrost degradation</u> • Confirmed changes in the mean annual temperature over the last 60 years • There is a significant air temperature warming trend for the Mackenzie Delta region • The deepening of the active layer will generate additional water displacement and accentuate permafrost degradation • Retrogressive thaw slump: Consists of a slope failure resulting from the thawing of ice-rich permafrost. Typical thaw slump consists of a steep headwall that retreats in a retrogressive fashion due to thawing, and a debris flow that forms by the mixture of

		thawed sediment and surface runoff. Retrogressive thaw slumps are common in ice-rich material and fine-grained deposits. • Direct link between soil moisture content / surface water / drainage and surface stability. Increase rainfall and water runoff will negatively impact the terrain stability. • Studies have proven the acceleration in frequency and magnitude of slumping over the last few decades • Presentation of a case study; Largest known thaw slump along the Dempster Highway. <u>Impact and adaptation</u> Thawing permafrost has direct impacts on: • Terrestrial ecosystem • Aquatic ecosystem • Integrity of road network • Sump material containment Long-term integrity of drilling sumps is a priority for the communities, government resources managers and industry players, in order to minimize any potential impacts of hydrocarbon exploration on the environment.
8	Specific Transport Mode Info / Issues	<u>ROAD TRANSPORT</u> • Impacts of warming permafrost on road integrity • Examples of thaw subsidence along some sections of the Dempster Highway • Climate Change is having a direct impact on road maintenance operations and costs
9	Actions defined by sector	• Need to develop northern monitoring systems • Need to increase the northern capacity in science • Develop the research infrastructure • Develop linkages between scientists, engineers, contractors and local managers
10	Tools	How to recognize thaw sensitive terrain: • Use of vegetation cover as an indicator (e.g. drunken forest as a sign of subsidence and thermokarst) • Landform interpretation (e.g. patterned ground and ice wedge polygon network) • Historical air photo interpretation as a way to monitor and assess the evolution of retrogressive thaw slumps.

2.5 Guidelines for Development and Management of Transportation in Permafrost Regions

1	Document Name	Guidelines for Development and Management of Transportation Infrastructure in Permafrost Regions, Transportation Association of Canada
2	Author	Robyn McGregor, Don Hayley, Graham Wilkins, Ed Hoeve, Ed Grozic, Vlad Roujanski, Alden Jansen, Guy Dore
3	Year	2010
4	Type	Best Practices Guide
5	Subjects / Key words	Roads, permafrost
6	Scope	Primarily applies to all- weather roads in permafrost regions of provincial and territories of northern Canada.
7	General Data	1) This is a practical step by step guide for planners and designers of all-weather roads (and other modes utilizing embankments) in permafrost conditions. It covers route planning and investigation, materials, engineering design considerations, drainage and erosion, construction and maintenance and also provides some information on emerging technologies to address the challenges of constructing and maintaining infrastructure in permafrost regions. Some of the key concepts or recommendations are highlighted below: 2) P 9/10 “It is no longer an accepted procedure to adopt historic thirty year Canadian Climate Normals that are published every 10 years as design parameters in regions of permafrost. Planning for and adapting to the future impacts of climate change in the near term is considered to be the best practice.... Given that the future impacts of climate change carry a level of uncertainty, managing from a perspective of identification of hazards and reducing risk is key. ... The greatest risk is often associated with extreme events that are now being observed in northern Canada. Unprecedented warm winters are often followed by rapid and early thaw. High snow cover years are resulting in extreme snow drifting that blankets the downwind side slopes. Insulating the surface and raising the ground temperatures under the fringes of the embankment. Standing water against the side slopes retards winter freeze back of the active layer and can accelerate thaw below the side slopes” 3) P 10 Mitigative measures that design engineers can use to manage uncertainty related to future climate trends and extremes in permafrost regions include: i) thick embankments that insulate and stabilize the active layer; ii) flattening side slopes to allow snow clearing beyond the crest onto the slope and push ponded water further from the toe; iii) use of porous embankment materials such as quarried rock to reduce the risk of ponding on side slopes; iv) adoption of construction methods that eliminate cuts and minimize disturbance to the natural vegetation before fill is placed; v) use of passive methods and protection techniques to retain permafrost and improve embankment integrity post-thaw; such as heat extraction or reinforcement geotextiles and insulation; and vi)

		careful attention to permafrost related terrain hazards when designing highway embankments and drainage structures in mountainous terrain. 4) P23, Section 2.7.1. “Highways such as those in the Yellowknife Region and northern Manitoba that cross permafrost clay soils which exhibit substantial ground ice are prone to long term thaw- settlement. In this southern fringe of permafrost, the thaw-settlement will be exacerbated by climactic warming trends and also by extremely warm winters which can trigger retrogressive thaw. The vulnerability of those roads built over warm ice-rich sub grades to climate warming should be examined as part of planning for either upgrade construction or new projects in similar conditions.....1998 PERD report “Climate Change Impacts on Permafrost Engineering Design contains a project screening tool that relates climate change sensitivity of the site to failure consequences of the structure to determine a risk level” – which suggests design effort and analysis required. “Most roads can tolerate slow retrogressive thaw that produces gradual settlement by adapting maintenance programs. Nevertheless the screening process does provide a useful basis for categorizing the vulnerabilities of a road project on permafrost to climate change. The value for a road project will be realized in planning both future maintenance and monitoring road behaviour to ensure those factors that could result in sudden grade collapse are recognized early, avoiding a serious safety hazard.” 5) P25 correcting problems with permafrost are less costly on gravel roads than for paved roads. 6) Chap 3 Route Investigations P 29 7) For new roads. Collect and review existing meteorological and terrain information to predict change in permafrost conditions. Utilize remotely sensed information to identify terrain conditions, sensitive areas and identify alternative routings. Undertake aerial based route reconnaissance to examine route alternatives, problem areas, etc. Proposes hierarchy of geophysical and geotechnical investigations along routes based on class of road – more intense as you go from lower to higher to paved class of road. Investigations need to be conducted at a frequency which will pick up changes in condition – report includes recommendations on frequency to help assess permafrost condition/depth .Profile and roughness data can help assess frost and thaw related problems 8) P 47 Investigations for Existing Infrastructure. Site investigation and characterization is an essential component of determining an appropriate rehabilitation technique. Surface inspection is the most widely used technique to assess pavement condition and performance. 9) Section 4 Embankment and Pavement Materials, P53. 10) Chapter 5, P67 – Engineering Considerations. The guiding principles for planning and designing in permafrost areas are: 1) research past precepts in the region, 2) understand the nature of the permafrost to be dealt with, 3) understand the thermal regime first, then the mechanical implications, 4) respond accordingly, and 5) be prepared to adapt normally accepted design criteria. 11) P69 Annual temperature variation in soils decreases with depth to the point at which it varies very little (depth of zero annual amplitude.) Any alteration to soil conditions from a modification to the surface will result

		in a change to the soil thermal regime. Permafrost is generally considered to be warm and potentially unstable when its annual temperature (at the depth of zero annual amplitude is warmer than – 2 degrees. Cold permafrost, usually found within the continuous permafrost zone generally has ground temperatures below – 5 degrees Permafrost between -2 and – 5 is generally found within the discontinuous permafrost zone and can behave as either warm or cold permafrost depending on the nature of disturbance and soil properties. 12) P72 In areas of cold permafrost an embankment should be designed and constructed to preserve the underlying permafrost. Designing an embankment over warm permafrost with the intent to stabilize or preserve the permafrost a site specific investigation and thermal analysis is required. In highly sensitive sections it is necessary to anticipate the thaw and design to accommodate thaw and settlement. 13) P 77 approach to embankment design in high- sensitivity permafrost is to provide for wider, thicker embankments. It may not be practical to prevent thaw and settlement from occurring following construction of an embankment. The most frequently used method is to build a structurally adequate but thermally inadequate embankment. Designers simply accept that embankment movements are going to occur and that maintenance and rehabilitation will be required. Therefore the design approach is to mitigate rather than prevent the impacts of thaw. 14) P78 Wide shoulders and gentle side slopes give an overall wider configuration to the embankment. This moves settlements away from the structural core and may also help in reducing snow cover. 15) P78 Surface and underground water transport large quantities of heat and can have a dominant effect on soil temperature regime. Design principles include: maximum effort should be undertaken to avoid the concentration of surface or subsurface water flows near embankments; if runoff water needs to be collected and channelized, it should be done at a reasonable distance from embankment (>10 m). 16) P91 Wide embankment and flat slopes are recommended to protect the structural and thermal integrity of the embankment core (underneath the traffic lanes). If cuts cannot be avoided; thaw sensitive soils on cut slopes should be stabilized. Drainage systems should be designed to avoid water concentration and if ditches are necessary, they should be designed at reasonable distances from the embankment. When designing a structure requiring high reliability in very sensitive permafrost conditions, thermal stabilization using special protection techniques (insulation, heat intake reduction etc.) may be necessary. 17) P95 Chap Six Drainage and Erosion Control. 18) Chapter 6 – Drainage and Erosion Control p95 19) P97 In general culverts do not perform well in permafrost terrain except where they are used within road sections underlain by low settling ice poor soils or bedrock with maximum possible relative thaw settlement. 20) P117 Use the water balance equation specifically developed for permafrost regions for water balance calculations when determining drainage flows. 21) Chapter 7 Construction p 119 22) Chapter 8 Maintenance p 131 23) P141 Increasing the width of the cleared lane of snow and extending

		snow removal to the shoulder and side slopes where possible will minimize the insulating effects of snow and subsequent thawing of underlying soils. 24) P143 Chapter 9 Emerging technologies 25) P143 – Air convection embankments (ACE) involve the use of clean, coarse poorly graded rock fill to create embankments with large interconnected voids. Convection can transfer heat upward out of the embankment at a rate that may be more than an order of magnitude larger than conduction, resulting in an effective winter cooling. As a result ACE increases winter time cooling rates and decreases summertime warming rates. 26) P145 “Hairpin thermosiphons in embankments – fully buried with no surface extension, conducts heat to surface of embankment – not practical in many situations. 27) P146 heat drain, GPR, polyurethane insulation, soil stabilization
8	Specific Transport Mode Info / Issues	This guide primarily applies to all- weather roads in permafrost areas but also is useful for other transportation modes where embankments are used (rail, airports)
9	Actions defined? by sector	
10	Tools	This is a best practices guide for planning, designing and maintaining embankments in permafrost zones. It provides the reader with a guide on how to proceed based on the best available knowledge. Numerous case studies and references are included. Appendices include instructions on geophysical and geotechnical investigations and in-situ permafrost soil testing.

3 TRANSPORTATION: GENERAL OR MULTIPLE MODES

3.1 Climate Change and Transportation in the NWT

1	Document Name	Climate Change and Transportation in the NWT
2	Author	Prepared by Dillon Consulting Limited for the NWT Department of Transportation
3	Year	March 31, 2007
4	Type	Consultant's Report about risks to transportation infrastructure in NWT
5	Subjects / Key words	
6	Scope	Covers all transportation modes in northern and permafrost environments
7	General Data	- Climate Trends – based on ACIA 2004, arctic warming more rapidly than rest of world and at greater magnitude. Temperatures predicted to warm 4-7degrees over next 100 years. IPCC 2007a) and b) noted temp at the top of permafrost has warmed up to 3 degrees, average Arctic temps have increased at twice the global average, increased and earlier spring runoff, increase in depth of active layer. - Observed impacts of climate change from interviews and workshop with stakeholders (DOT staff, winter road and road contractors, transportation companies): Increased settlement of road embankments and culverts with increased rate of failure, change in runoff conditions – occurring earlier in year before culverts are clear resulting in sheet flow and erosion, standing water transfers heat and accelerates permafrost melting. More freezing rain requiring maintenance modifications. Warmer temps affecting windows for working in water as prescribed by DFO. Runway settlement due to permafrost degradation, more freezing events require more de-icing. Shortened and varying winter road seasons. Generally decreasing water levels affecting ferry operation, plus increased variability, sedimentation and effects of changes in upstream watersheds on river levels. Potential for increased length of summer construction season; however, it was reported that the length of the shoulder seasons were increasing. Increased costs of reactive response to impacts of climate changes is \$XXXX - Projected Future Impacts (of Climate Change): GSC developed numeric model to identify potential changes to the permafrost regime in the Mackenzie Valley where permafrost is subject to change where terrain data was available at a suitable scale for numeric modelling. GSC has used available data to develop permafrost models and impacts from climate change in the Mackenzie Valley. Modelling was completed for 3 climate scenarios for 2000, 2025 and 2050. The following is based on the medium climate change scenario. Modelling predicts a general warming of ground temperatures with temperatures higher in the south than north. In FGH area shrub lands and open forest underlain by till are expected to experience the greatest increase in thaw depth. Similar in Norman Wells area with permafrost loss of 6m depth predicted in open forest moraine fine grained till. 88-96% of FGH and NW areas underlain by permafrost, dropping to 42% in Wrigley area. By 2055 it is expected that only 28% of the Wrigley area will have permafrost, completely disappearing in a number of fine and coarse grained areas. Estimated that approximately 26% of the highway ROW in Fort Simpson area is underlain by permafrost decreasing to 18% by 2055. In Ft Liard area, permafrost predicted only in areas of peat, permafrost thickness expected to decrease by approximately up to 1m or 10% by 2055. In the Hay River- Fort Providence area, permafrost is expected to be reduced in thickness by 3-5metres by 2055, except in wetland areas where the reduction is predicted at about 0.5 m. In the Yellowknife area, permafrost thickness expected to decrease by 5 m in moraine till areas and be eliminated in some bedrock and till areas. Model limitations to be considered: caution in attributing a prediction to a specific location due to uncertainties in the data, modelling is for terrain adjacent to the roadbed, not conditions underneath the roadbed. IN GENERAL AREAS WITH LIMITED VEGETATIVE COVER ARE EXPECTED TO WARM MORE QUICKLY THAN DENSLEY FORESTED AREAS WITH ORGANIC COVER. WHILE TEMPERATURES IN COARSE GRAIN SOILS ARE EXPECTED TO WARM QUICKER THAN FINE

		GRAINED SILTS AND CLAYS. IT IS UNCERTAIN IF THE PRESENCE OF A ROADBED ACCELERATES OR DECELERATES PERMAFROST DEGRADATION AND UNDER WHAT TERRAIN CONDITONS. THERE IS GREATER CONFIDENCE IN THE PREDICTIONS MADE IN THE MACKENZIE VALLEY THAN IN HAY RIVER/PROVIDENCE AND YELLOWKNIFE AS A RESULT OF MORE STUDY AND GROUND TRUTHING ALLOWING FOR MODEL CALIBRATION IN THE MACKENZIE VALLEY. NUMERIC MODELLING ALLOWS BROAD LEVEL PREDICTIONS ON PERMAFROST RESPONSE TO WARMING TEMPERATURES ACCORDING TO SURFICIAL GEOLOGY, VEGETATION CHARACTERISTICS AND CLIMATE MODELLING. THE LEVEL OF CONFIDENCE DEPENDS ON THE DATA USED. ACQUIRING THE LEVEL OF DATA TO INCREASE THE CONFIDENCE IN PREDICTIONS IS PROHIBITIVE IN TERMS OF COST AND TIME. • Review of existing literature and DOT Input. Loneragan et al (1993) estimated that economic output would be greater primarily due to the increased use of water transportation and lower associated costs. US Arctic Research Committee (2003) thawing of upper layers of permafrost will allow thawed organics to release more GHG, more thermokarst action and differential settlement will occur. Auld et al (2006) recommended adopting codes and standards to address design under the changing permafrost conditions. Haas et al (2006) recommended that asphalt design may need to change to adapt to warming temperatures and that further investigation of the potential scouring of bridge abutments from increased flows may need investigation. Some anecdotal comments from DOT: winter construction season decreased and increased shoulder season where no work can be done, increased precipitation and climate variability, permafrost degradation threatening foundations, dikes and other structures; more rapid spring runoff; more deciding and increased use of airports due to shorter winter road season; • Ranking of climate change risks; Risks to transportation issues and infrastructure ranked qualitatively as Inconclusive, low, medium, high or extreme. High risks included permafrost melting and infrastructure failure, effects of more freezing rain and increased spring melt and resultant effects. • Adaptation measures and Best Practices: Either reactive (current) or anticipatory or planned approach. Table 4-1 on p 77 provides a number of possible adaptation actions (physical activity and research) for consideration in adapting to the risks posed by climate change, including: increased data collection and modelling to better understand priority areas, removal or protection of permafrost, weather forecasting, changes to culvert design and installations, increased application of sand, gravel and glycol, monitoring, building all-weather roads, reduce standing water beside structures, • Cost Implications. Reaction to impacts of climate change is estimated to cost \$1.2m annually. Based on the predicted impacts to permafrost from the numeric modelling, this cost is expected to rise to \$3m annually. • Conclusions and Recommendations: Next steps include – planning for climate change in new infrastructure, increased modelling (and data for inputs), determine vulnerability of airports as they will become even more important as winter roads become less reliable, more monitoring, and formalized reporting of maintenance and emergency activities related to climate change to better understand the challenges
8	Specific Transport Mode Info / Issues	<u>AIR TRANSPORT</u> • Permafrost degradation effects on structure integrity • Thaw settlement • Increased freezing rain and need for de-icing • Busier airports resulting from shorter winter road season <u>MARINE TRANSPORT</u> • Decreasing water levels • Increased variability of water levels • Increased sedimentation effects on navigation channels <u>ROAD TRANSPORT</u> • Thaw settlement from permafrost degradation from warmer temperatures and increased standing water • Pavements and summer heating • Increased and earlier spring melt flows before culverts open causing erosion • Pavement icing and safety issues, changes in maintenance practices • Shorter winter road season

		<u>OTHER</u> • Longer summer construction season, shorter winter construction season • Increased length of shoulder seasons where no work can be done. • Lack of detailed terrain, permafrost and climate data reduces confidence in modelling
9	Actions defined by sector	1) ACTIONS for Each Mode of Transport • Types of Action or Means Used in adaptation plans • Players involved: owners, managers, other stakeholders, communities • Screen out documents not considering adaptation or impacts on the transport sector • Screen out documents focussing on mitigation of GHG. 2) ACTIONS • Eliminate or protect permafrost • Improve drainage • Collect data on terrain on opportunistic basis • Plan for climate change in new infrastructure • increased modelling (and data for inputs) • determine vulnerability of airports as they will become even more important as winter roads become less reliable • more monitoring of infrastructure • Formalized reporting of maintenance and emergency activities related to climate change to better understand the challenges.
10	Tools	

3.2 Adapting to Climate Change in the NWT

1	Document Name	ADAPTING TO CLIMATE CHANGE IN THE NWT
2	Author	Greg Cousineau Senior Transportation Planner Planning, Policy & Environment Department of Transportation Government of the Northwest Territories
3	Year	2008
4	Type	PowerPoint presentation. 24 slides
5	Subjects / Key words	NWT transportation system, Climate Change impact on infrastructures, knowledge and predictions, adaptation planning
6	Scope	• General presentation of the NWT Transportation system • Focus on climate change and its impacts on the various transportation sectors
7	General Data	<u>NWT transportation system:</u> • Department of Transportation (DOT) is responsible for the acquisition, design, construction, operation and maintenance of the public transportation infrastructure in the NWT. • The system includes highways and roads, community airports, marine infrastructures <u>Climate Change General Knowledge</u> • Climate change is happening and is happening at a greater rate in the Arctic and it will continue to happen for decades despite any mitigation actions to reduce GHG emissions • Northern communities are highly vulnerable to the impacts of climate change due to the high climate sensitivity of resources, limited economic diversification, more restricted access to services and the strong community links to the land. • Impacts are most often at local and sectoral level and adaptation actions will originate at the local level <u>Climate change predictions:</u> • More maintenance of the transportation infrastructures • More disruptions in service and road closures • More permafrost degradation • More difficulty building winter roads ice crossings • More freeze/thaw cycles

		• Later winter freeze up and early spring thaw • More marine traffic in the Arctic and along the Mackenzie River
8	Specific Transport Mode Info / Issues	<u>Road and terrestrial infrastructures</u> • NWT highway system consists of approximately 2,200-kilometres of all-weather road and 1,425-kilometres of publicly constructed winter road • Includes over 75 major bridges, 300 large diameter culverts and well over 3,000 small culverts. • Includes numerous privately constructed winter roads for oil and gas development and mine resupply <u>Impacts of climate change on road network:</u> • Increased permafrost degradation resulting in heaving, thawing, sinkholes, and potholes. • Increase precipitation leading to greater ground absorption and impacted culverts. • Increase settlement of highway surface and side slope, sloughing, culvert failures, and shoulder sinking and cracking. • Warmer winters producing more freezing rain resulting in icy road conditions and an increase in the measures required to maintain safe road conditions. Increased degradation of roads causing vehicle wear and tear and a decrease in safety perception. • Permafrost degradation and slumping threatening pile foundations, dikes, bridges, and other structures. • Shorter windows of operation of winter roads and ice bridges • Construction of ice more problematic • Increased snow insulates the land <u>Air transport infrastructures</u> • DOT is responsible for the maintenance, operation, rehabilitation and upgrading of 27 community based airports • “Hub and spoke” operation: Yellowknife as the main access (gateway hub), Inuvik and Norman Wells as regional hubs, deserving the surrounding 24 community-based airports <u>Impacts of climate change on airports:</u> • Increased permafrost degradation resulting in heaving, thawing, sinkholes, and potholes • More freezing rain • More use of Glycol for de-icing <u>Marine transport and related infrastructures:</u> • DOT provides seasonal ferry services at five river crossings • DOT is responsible for the maintenance, operation and upgrading of vessels and support facilities • DOT is responsible for constructing a series of ice-bridges after freeze at these locations

		<u>Impacts of climate change on marine transport:</u> • Increasingly variable water levels • Reduced Arctic sea ice
9	Actions defined by sector	Extra knowledge needed: • Better climate change projections • Detailed inventories of NWT infrastructures • How changes in temperature, storm severity, water levels, freeze/thaw cycles and other climate changes will effect construction of infrastructure • What will be the effects on maintenance costs Who needs to get involved: • Decision makers • Communities • Stakeholders • Front line staff • Scientists • Governments – partnerships Action needed: • Incorporate climate change in all decisions • Inventory of critical infrastructure • Adopt risk-based approaches to decision making • Improve communications • Implement monitoring technologies • Share best practices • Re-evaluate design standards • Develop partnerships • Strategic planning
10	Tools	As part of the development of <i>Change and Transportation in the Northwest Territories</i>, the Geological Survey of Canada (GSC) was engaged to develop a numerical model to identify the potential changes in permafrost regime within the Mackenzie Valley in response to specified future climate change scenarios. These are some general conclusions reached from the modeling: • There is a clear north-south trend in permafrost temperature • It is predicted that thaw depths will increase and permafrost thicknesses will decrease in all study areas • A number of areas may be permafrost free by 2055 • Large scale modelling would be prohibitive in terms of cost and time. A preferred approach is to undertake scaled-down modelling on a project by project basis as an initial planning exercise • The modelling should be re-evaluated as more region-specific climate change projections become available

3.3 Green Light: Signaling the Department of Transportation's Commitment to the Environment

1	Document Name	GREEN LIGHT: SIGNALLING THE DEPARTMENT OF TRANSPORTATION'S COMMITMENT TO THE ENVIRONMENT
2	Author	Department of Transportation , Government of the Northwest Territories
3	Year	Unknown
4	Type	Government publication. 16 pages
5	Subjects / Key words	Northwest Territories Department of Transportation, Action Plan, Environmental Management System (EMS), environmental policies, climate change
6	Scope	The document's goal is to highlight existing environmental practices and to further foster a corporate culture of environmental excellence at DOT and throughout the northern transportation industry.
7	General Data	The document presents an Action Plan to improve the environmental performance of the Department of Transportation (see below for short and long term actions)
8	Specific Transport Mode Info / Issues	Climate Change Impacts on the Transportation System: • Warmer temperatures generally result in less extensive ice cover and shortened winter construction seasons • Projected warming temperatures and increases in early winter snow precipitation retards ice growth and increases highway maintenance activities and spending. • Permafrost degradation and instability leads to structural problems for roads, runways and bridge structures due to heaving, thawing and the emergence of sinkholes and potholes These and other impacts have serious implications for the stability and reliability of the territorial transportation system
9	Actions defined by sector	The Action Plan presents the frame work for priority actions in the short term (0 to 2 years) and medium term (2 to 5 years). Short term actions: • Determining appropriate roles and responsibilities to address priority environmental challenges • Fostering Employee commitment • Develop an Environmental Management System, EMS (e.g. standardize the Environmental Site Assessments process)

		• Conduct the assessment and remediation of a series of contaminated sites that are under DOT ownership of responsibility • Gathering important baseline information in order to better measure the performance of its new environmental approaches. Baseline data collection will utilize traditional and scientific knowledge. • Developing clear and practical environmental policies such as a Green House Gas (GHG) Emission Reduction Plan. • Develop a Climate Change Adaptation Plan in order to help understand the impacts climate change is having on the NWT. • Develop Worksite Specific Plans in order to improve environmental performance • Engage the transportation industry and the public on the environment issues Medium term actions: • DOT will promote appropriate environmental training and education to its staff • Implementation of the required policies and plans under a new departmental Environmental Management System (EMS) • Implementation of a Climate Change Adaptation Plan. The Adaptation will help the Department preserve its core assets, and to plan and design infrastructure that is less vulnerable to the impacts of climate change and climate variability • Implementation of worksite specific plans and priority environmental initiatives The overall goal of Green Light is to improve the environmental performance of the Department of Transportation. All policies, guidelines and initiatives stemming from Green Light will complement and enhance existing GNWT programs and initiatives related to environmental protection. These include the GNWT Sustainable Development Policy, the NWT Greenhouse Gas Strategy, the Climate Change Adaptation Strategy and DOT's Drive Smart Program.
10	Tools	• Employee Training and Education • Environmental Management System (EMS) • GHG Emissions Reduction Plan • Climate Change Adaptation Plan • Worksite Specific Plans
11	Gap Identified	• DOT recognises the current lack of key environmental baseline information in order to effectively address pressing environmental challenges • DOT must improve their understanding of where and how critical impacts are occurring. • DOT recognizes the need for Consolidated Environmental Policies and Guidelines as well as the need to enhance the Corporate Culture

3.4 Climate Change Adaptation Risk Assessment Workshop Report for the NWT Transportation System

1	Document Name	CLIMATE CHANGE ADAPTATION RISK ASSESSMENT WORKSHOP REPORT: FOR THE NWT TRANSPORTATION SYSTEM
2	Author	Stantec Consulting Ltd.
3	Year	2010
4	Type	Workshop report. 58 pages.
5	Subjects / Key words	Climate change, adaptation plan, risk assessment, Northwest Territories
6	Scope	The document summarizes the outcomes of the preparation and delivery of a two-day climate change adaptation Risk Assessment workshop held on October 5 and 6, 2010 in Yellowknife, NWT. Participants included senior staff from the Department of Transportation (DOT) as well as external specialists in atmospheric and terrain science.
7	General Data	<u>Objectives of the workshop:</u> The workshop represents one of the first steps of a climate change risk assessment that will inform the development of the DOT Adaptation Plan. The intent of the workshop was to: • Engage participants to identify the impacts and events that a changing climate is causing and will have on the NWT transportation system, • Develop a better understanding of long-term climate change trends that will affect the NWT over the next 50 to 80 years, with an emphasis on medium-term affects that should be considered when making 20 year planning decisions, • Identify the range of impacts that climate change will have on the DOT's operations, • Identify what infrastructure is most vulnerable and what infrastructure is most resilient (and to whom), • Identify information gaps and determine where R&D funds should be focused, • Identify gaps in knowledge for monitoring and further research, • Identify mitigative actions for the DOT Adaptation Plan, • Identify key stakeholders for an engagement plan. <u>Methodology:</u> The risk assessment process follows the protocol document: <i>Managing the Risks of Climate Change: A Guide for Arctic and Northern Communities</i>, which was developed by Indian and Northern Affairs Canada (INAC). The methodology includes the following steps: • Complete a literature review and strategic interviews with DOT senior managers to understand major climate hazards affecting NWT infrastructure, • Complete a preliminary analysis of climate hazards, impacts, and events,

		• Review and improve the preliminary analysis with DOT staff, • Estimate the frequency or consequence of each event, • Evaluate risks of each event, • Determine appropriate actions for events, including timelines, costs, stakeholders, and potential partners, • Determine key stakeholders including their interests, engagement challenges, as well as opportunities for consultation activities. <u>Workshop results:</u> The preliminary analysis of the risk assessment involved the definition and identification of major hazards, impacts and resulting events of climate change. Hazards: a major change in climate conditions – e.g. weather variability Impacts: physical outcomes of hazards (land and/or weather) – e.g. increased precipitation Events: the problem to deal with – e.g. culvert failures Two major impacts and corresponding hazards have been identified: • Permafrost degradation: impacts include warming and thawing of permafrost as well as the uncertainty of site conditions. • Weather variability and change: impacts include more snow precipitation, wetter snow, more freezing rain, flooding, more intense freeze and thaw cycles, extreme weather events, warmer temperature, change in thaw cycles and wind properties. A series of priority events have been identified and are further discussed in the report: • Embankment / Structure Degradation / Uncertainty / Insulation / Design • Drainage / Water Levels • Travel Delays • Equipment, Material, Infrastructure Strain • Length Construction / Maintenance Window • Winter Road Viability • Community Resupply The risk estimation process evaluates the frequency, consequence and risk of each event occurrence. <u>Stakeholder plan:</u> A stakeholder plan was developed during the workshop. The plan identified the key stakeholders, their general interest, and the challenges and opportunities present, as well as appropriate consultation methods that should be applied. • Key stakeholders include adaptation planning experts, regulators, industry players, transportation carriers, government and aboriginal groups, as well as communities and public. • Stakeholder's interests are diverse and range from safety and access, to research and applied sciences, regulation compliance, impacts on the environment, etc. • Present and upcoming challenges are related to costing, human resources, timeline and expectations, etc. • Opportunities are multiples and are related to elements such as: research and

		monitoring opportunities, knowledge and information sharing, funding, etc. • Appropriate consultation methods include: technical peer review, conferences, public consultations, forums and workshops, etc. Gaps in knowledge and research opportunities identified during the workshop: • Explore opportunities to link environmental spending with infrastructure and maintenance spending • Determine the cost of doing nothing, this could help the business case for action • Conduct hydrology and hydrogeology research and explore DOT partnerships (permafrost) • Gather weather predictability and forecasting data, which might include installation of additional weather radars to help with seasonal predictions • Explore causes of Highway 1 sub grade failure • Identify the best road surfacing packages for climate change • Explore surface materials and design options to protect permafrost • Identify current and future material/resource needs • Understand the implications of climate change on O&M • Vegetation mix – Identify method for RoW management and stabilization • Pre-design hydrological & hydrogeological studies • Permafrost context description and conditions in various regions • Further permafrost research in Mackenzie area and high arctic and begin research on highways and the North Slave areas • Permafrost design R&D
8	Specific Transport Mode Info / Issues	<u>Permafrost degradation</u> Permafrost degradation affects all components of the northern infrastructure network: roads, airports, ferries and marine transportation
9	Actions defined by sector	The workshop represented the first step in completing the Risk Assessment to support the development of a Climate Change Adaptation Plan for the DOT. Next steps include: • Discussing the preliminary results of the workshop with stakeholders to gather further input on hazards and impacts as well as to get an understanding of the stakeholders' perceptions of probabilities and consequences associated with climate change. • Additional workshop on specific operation of DOT (e.g. winter roads and ferry services) • Continue to revise actions, refine research needs, meet with stakeholders, and complete the adaptation strategy planning process to address how current and future climate change challenges can best be overcome • Complete a Climate Change Adaptation Plan by March 31, 2012
10	Tools	The protocol entitled "Managing the Risks of Climate Change: A Guide for Arctic and Northern Communities" was used to guide the two-day Risk Analysis workshop.

3.5 Adapting Transportation to the Impacts of Climate Change

1	Document Name	ADAPTING TRANSPORTATION TO THE IMPACTS OF CLIMATE CHANGE
2	Author	Transportation Research Board Special Task Force on Climate Change and Energy
3	Year	June 2011
4	Type	Publication of the U.S based Transportation Research Board
5	Subjects / Key words	Climate change, transportation, adaptation
6	Scope	The document focuses on transportation adaptation practices that can be implemented to yield benefits now and in the longer term. It highlights what climate change adaptation means for the transportation industry and why it is so important. Note: The document refers to climate change impacts to the entire U.S. rather than focusing on northern communities and environments
7	General Data	<u>Example of climate Change Impacts:</u> • Rising sea levels will place people, homes, businesses, and infrastructure at risk, especially along the Atlantic and Gulf Coasts and Alaska. • Heat and warming temperatures will be a growing concern throughout much of the United States. • Water levels in the Great Lakes will drop, impacting shipping through the Saint Lawrence Seaway, but elsewhere higher temperatures of inland waterways and the Arctic will lengthen the shipping season • With the shift in temperatures, there will be a concomitant migration of plant, insect, and disease vectors northward • Increased intensity of precipitation in many parts of the continental United States and perhaps Alaska will place new stresses on the environment. • Alaska is a special case as temperatures are expected to rise much more rapidly in far northern regions. • Rising temperatures cause unprecedented thawing of permafrost, including longitudinal shoulder cracking along roadsides, thaw settlement, and buckling and cracking of road structures. • Increases in average temperatures (air and ocean) in many parts of the world, • Increases in average sea level and in the maximum extent of storm surges, • Changes in average precipitation amounts and increases in precipitation intensity, increases in wind speeds and storm intensities. • Changes in plant and animal migrations, diseases, extinctions and habitats.

8	Specific Transport Mode Info / Issues	<u>Example of climate change impacts on airports:</u> • Operational impacts from airport closure and delayed aircraft operations due to flooding or storm water overload, • Increased energy consumption for heating, ventilation, and air conditioning due to extreme heat events, • Water quality violations from increased de-icing, • Computer system downtime or data loss and cyber security risks due to power failures or building damage related to wind, • Operations and maintenance disruptions due to all of the above, • Public health risks (air, water, sanitation, infectious disease) during mass strandings and extended disruptions, • Airport employee chaos due to regional and family demands for their services, • Tenant or contractor lack of performance due to equipment, supplies, or labour unavailability, and economic loss to regional businesses. <u>Example of climate change impact on ports:</u> • Rising sea levels will cause increased flooding and exacerbate the damage to ports from storm surge during severe weather events. • Increase in storm surges • Increase rainfall events and impacts on flooding and stormwater management
9	Actions defined by sector	<u>Example of adaptation measures:</u> • Identify areas with accelerated permafrost thawing. • Develop new designs for constructing transportation systems on less stable soils. • Dikes or levees to protect vulnerable coastal communities. • Move at-risk coastal communities <u>Identified research needs:</u> • Develop a collaborative decision-making framework for climate change mitigation and adaptation • Explore adaptation as a defensive strategy to address climate variability impacts on critical transportation infrastructure • Identify and develop climate change modelling outputs and climate scenarios to support transportation agencies in assessing climate risks and adaptation strategies • Explore the effects of aspects of climate change on transportation infrastructure • Identify and explore the implications of climate change for rail and barge freight demand, services, and networks.
10	Tools	

4 MARINE / FERRY / SHIPPING

4.1 Hay River Water Depths

1	Document Name	HAY RIVER WATER DEPTHS
2	Author	Mariport Group Ltd.
3	Year	July, 2011
4	Type	Technical Report. Includes maps, diagrams, climate data, hydrographic data
5	Subjects / Key words	Hay River, hydrology, water depth, marine transportation
6	Scope	Focus on marine issues. Reduced water levels and impact on shipping and port activities.
7	General Data	Hay River hydrology data: • Hay River water levels are directly related to level changes on Great Slave Lake • Hay River water levels are directly related to siltation • Rapid river infill observed in areas previously being dredged (i.e. loss of water depth) • Impacts of climate change are already being observed • Reduced flow rates in the Hay River • Dramatic increase in flooding events for the period 2000-2009 Climate Data: • Recent decline in precipitation • Extreme summer heat • Increased evapotranspiration • Lower water levels on major lakes and rivers
8	Specific Transport Mode Info / Issues	<u>MARINE TRANSPORT</u> • Barge loads and draft capacities are directly related to water levels • Draft capacity is decreasing due to low water levels and accelerated saltation • Reduced water depth directly impacts the marine transportation sector • Impact on transportation will directly impact sectors such as: fuel and food distribution, energy system, communities' developments, etc. • Northern Transportation Company Limited (NTCL) is the primary transportation operator • Communities impacted are: Norman Wells, Delin�, Tulita, Fort Good Hope, Colville Lake,

		Tuktoyaktuk, Sachs Harbour, Ulukhaktok, Paulatuk • Some communities are highly dependent on water transportation • Alternatives: all weather roads, winter roads, air transport (note that not all communities are reachable by road) • Shipping rates are much higher by truck than by barge (30-50% higher) • Barge shipping rates are likely to increase by 40-45% to cover up for the reduced cargo volume capacity • Impact on commercial operations of companies such as Imperial Oil Limited (IOL is providing heating oil to several communities such as Norman Wells, Inuvik and Aklavik) • Servicing the North Warning Sites by Department of National Defense (DND) • Limits the Canadian Coast Guard (CCG) operations on the River and the Arctic (Operational base in Hay River) • RCMP (Jet A1 deliveries to Inuvik) • Environment Canada (Jet A1 deliveries to Inuvik) • Indian & Northern Affairs (Jet A1 deliveries to Inuvik) • Parks Canada (heating oil deliveries to Inuvik) • Natural Resources Canada (Jet B deliveries to Sachs Harbour and Cambridge Bay) • Reduced draft will significantly impact operation costs of government departments such as: DND, CCG, RCMP, Environment Canada, INAC, Parks Canada, Natural Resources Canada
9	Actions defined by sector	• No specific actions defined
10	Tools	

4.2 Western Arctic Access Routes

1	Document Name	WESTERN ARCTIC ACCESS ROUTES
2	Author	Mariport Group Ltd.
3	Year	July 2011
4	Type	Technical Report. Includes maps, diagrams, climate data, hydrographic data
5	Subjects / Key words	Western Arctic marine routes, Mackenzie River, water depth, marine transportation
6	Scope	The document presents an overview of marine access to communities in the Western Arctic, and whether climate change might suggest opportunities for an enhanced navigation and shipping season due to climate change.
7	General Data	The report presents specific data on the three available routes into the Western Arctic: two via ocean transit from either the Pacific or Atlantic, and one via the Mackenzie River (see below).
8	Specific Transport Mode Info / Issues	<u>Ocean Access</u> - Arctic Shipping Pollution Prevention Regulations (ASPPR) controls ocean access to the Canadian Arctic. The System consists of 16 geographic zones and an associated table that shows when a vessel of a specific class is permitted to enter a zone. The zones and dates are based on ice data from the 1960's, and there have been no changes to the basic System since implementation. - Access from the Pacific is controlled by ice conditions between Point Barrow and Mackenzie Bay - Access from the Atlantic is controlled by ice conditions in Peel Sound - The Mackenzie River access was, until a few years, the traditional service route into the Western Arctic - The season is typically 1st June to mid –October (137 days) - The seasonal variations in water depth are closely related to winter conditions as well as ice and water levels of Great Slave Lake <u>Main results and conclusions of the Western Arctic access routes study:</u> - The analysis of ice data has shown a steady increase in the mean access days into the Western Arctic from the Pacific (from 46 days in the 1980s, to 65 days in the 2000s), - The reliability of the season opening has increased from 8 out of 10 years in the 1980s to 10 out of 10 years in the 2000s. - Ice analysis indicates a much shorter open season for the Western route than suggested

		for ASPPR zone 12 in the NRC's proposed Hybrid System, • Access from the Atlantic has also improved. For example, Peel Sound, now has 44 mean access days compared with 22 and 26 days in the 1980s and 1990s respectively, • Reliability of the ocean routes is still an issue • The ice analysis suggests a much longer open zone is achievable for the Eastern route than in the proposed Hybrid System, • Access days via James Ross and Rae have improved considerably in the last decade compared with Victoria Strait, However, charting for James Ross and Rae is poor and a new separate large-scale chart is needed. • The ice analysis suggests a later opening than the proposed Hybrid System and a much shorter open zone. The ice analysis also suggests a much later season opening than the ASPPR zone date system. • Under the zone date system, deep draft routes through either Prince of Wales or McClure Strait are not permitted for Type B vessels, which have been analysed in the study. • A Very Open Draft (VOD) route in these straits has been observed infrequently in the last decade, but as climate change proceeds, the frequency of VOD conditions will increase. • Tuktoyaktuk shows very little change over the last three decades with around 87 mean access days, • Sachs Harbour, Paulatuk and Ulukhaktok have shown material • improvements in very open draft (VOD) access days within the last decade to around 84 mean access days, • The Mackenzie River route is challenged by many climate related factors that will lead to reduced reliability of the route and potentially lower water levels during the navigation season • Factors affecting the Mackenzie River route reliability include: variability in snow pack in the Rockies, reduced glacier flow, increased early season temperatures leading to more rapid snow melt degradation of forest cover resulting in faster water run-off, and increased water demand on the Athabasca River due to oil sands
9	Actions defined by sector	• No specific actions defined
10	Tools	

5 ROADS

5.1 Climate Change Impacts and Adaptation: Case Studies of Roads in Northern Canada

1	Document Name	CLIMATE CHANGE IMPACTS AND ADAPTATION: CASE STUDIES OF ROADS IN NORTHERN CANADA
2	Author	EBA Engineering Consultants Ltd. Robyn V. McGregor, M.Sc., P.Eng., Senior Transportation Engineer and Principal Consultant Masood Hassan, Ph.D., P.Eng., Senior Transportation Engineer Don Hayley, P.Eng., FEIC, Director - Arctic Resource Development
3	Year	2008
4	Type	Paper prepared for presentation at the “Climate Change and the Design and Management of Sustainable Transportation” Session of the 2008 Annual Conference of the Transportation Association of Canada Toronto, Ontario
5	Subjects / Key words	All-weather and winter roads, impacts of climate change, adaptation strategies
6	Scope	The paper presents two case studies of all-weather and winter roads in Northern Canada and describes the issues pertaining to the impacts of climate change and the adaptation strategies that have been or are being implemented to cope with the impacts.
7	General Data	- The majority of Canada’s northern communities and industries are dependent on a single all-weather or winter road (i.e. the Tibbitt to Contwoyto Winter Road) <u>Weather data – Climate Warming</u> - Climate warming is putting transportation infrastructures at risk by impacting road structures that overlie permafrost, and by shortening the duration of winter roads built on ice or seasonally frozen ground - In the 65 years of operating, two warmest winters have occurred in the past 8 years (1999 and 2006) - Historical data shows a mean annual air temperature warming of 0.5°C per decade <u>Permafrost data</u> - Permafrost terrain is ground that remains below 0°C year around - Active layer is the ground surface layer that thaws every year

		• Ground ice-content is highly variable • Thermal stability of the frozen ground is sensitive to minor changes in heat transfer at the ground surface • Changes in surface properties such as stripping vegetation or changes to moisture retention capacity of the soil can alter the surface heat balance • Changes in surface property can initiate thaw and increased active layer thickness, as well as produce substantial settlement, surface subsidence and retrogressive thaw slumps • Subsidence and settlement rates are highly variable and difficult to predict <u>Consequences of climate change on the operation of the winter and all-weather roads:</u> • Increased costs for construction and maintenance of northern roadway systems; • Reduction in the ability to maintain an acceptable level of service throughout the roadway system; • Increased vigilance to maintain safe performance of the roadway system; and • Decreased transportation efficiencies that are reflected in increased costs for goods and services, throughout Canada
8	Specific Transport Mode Info / Issues	<u>ROAD TRANSPORT</u> Three categories of road type impacted by changes in climate: • All weather roads constructed on permafrost soils • Winter roads over ice or compacted snow • Road structures where freezing and thawing determines seasonal weight limits. <u>Case Study:</u> <u>Yellowknife Highway (NWT Highway 3) reconstruction</u> • The road is 340 km in total and extends from the Mackenzie River around the north shore of Great Slave Lake to Yellowknife • The road was built in the 1960's and has been upgraded to modern standards over the last 15 years • The southern portion of the route is characterized by warm discontinuous permafrost <u>Issues:</u> • Poor original alignment geometry • Warmer air temperatures are affecting the stability of the permafrost <u>Tibbitt to Contwoyto Winter Road</u> • The road starts 70 km east of Yellowknife and is approximately 600 km long • 85% of the road is over lake ice • Traffic volumes in this construction and resupply corridor are expected to increase as resource development keeps growing • 2007 was the best season on record with over 10,000 loads being hauled over 72 days. In contrast, 2006 was the warmest winter with less than 6,000 loads being hauled over 49 days <u>Issues:</u>

		• Warmer air temperatures are affecting the stability of the permafrost, the seasonal ground freezing window and the integrity of ice covers that are used for transportation • Climate warming is directly responsible for the decline of the available safe operation period of the winter road • Shorter operating season, higher traffic volumes, increase pressures to operate = increase risks • Season shortening places community resupply at risk • Safety issues due to increase in ground and ice instability • Cost issues due to reduced weight load and operating season • One alternative to the winter roads is air transport. Very costly. • Predictions show that operating season could drop from 65 days now to only 54 days by 2020 • Improved technology alone won't achieve satisfactory risk reduction.
9	Actions defined by sector	<u>Adaptation Strategies</u> The following features were adopted to mitigate climate change effects and retard the rate of thaw along the Yellowknife Highway (NWT Highway 3): • The core of the embankment comprises a minimum of 2 metres of quarried rockfill, providing internal strength to even out future settlements; • A sacrificial shoulder and flat side slopes were provided on the embankment as it was recognized that the permafrost soils supporting the slopes would be the first to thaw; • A snow management system was adopted to encourage removal of snow from the sideslopes wherever practical; • Side slopes as gentle as 4 or 6 horizontal to 1 vertical were adopted for low fills to push standing water away from the toe and reduce snow drifting; and • A ground temperature monitoring system was implemented to track permafrost response. New technologies and strategies were developed in order to optimize the shortening operating period along the Tibbitt to Contwoyto Winter Road: • Technical improvements in ice stress analyses • Improved techniques for assessing the ice capacity (e.g. radar) • Improved traffic management • Improved routing studies to allow rapid rerouting in case of ice deterioration • Move the southern 170 km off lake ice alignment and construct a parallel seasonal road overland • Greater use of bridges to replace ice-bridges • Create a winter or all weather road north to the Arctic Coast and a shipping route south from there
10	Tools	

5.2 Willow River Gravel Source Access Road Planning Study: Hamlet of Aklavik, NWT

1	Document Name	WILLOW RIVER GRAVEL SOURCE ACCESS ROAD PLANNING STUDY HAMLET OF AKLAVIK, NORTHWEST TERRITORIES
2	Author	Nehtruh – EBA Consulting Ltd.
3	Year	September 2009
4	Type	Technical Report. 77 pages
5	Subjects / Key words	Gravel source, access road, Aklavik,
6	Scope	The Hamlet of Aklavik has retained the services of Nehtruh-EBA to undertake a planning study of potential all-weather road from Aklavik to the Willow River Gravel Source, which would replace the 27 km ice/winter road currently utilized for the gravel haul to Aklavik. <u>The study scope includes:</u> route location, preliminary engineering (recommended geometric design criteria, planning level quantity and cost estimate), environmental scoping, regulatory permitting requirements, and a preliminary economic analysis comprising a discussion of the gravel cost reduction and other economic benefits of the all-weather road. <u>Methodology:</u> Compilation and review of existing information (maps, air photos, previous reports and interviews)
7	General Data	- Aklavik is located in the Beaufort Delta region of the Northwest Territories and has a population of 655, - Air transportation is the only year round access to Aklavik, - Annual resupply of fuel and bulk dry cargo is barged to the hamlet in the summer and early fall, - Surface access to Aklavik is available for approximately four months in the winter via a 115 km ice road built on the frozen channel of the Mackenzie River. The ice road is open to all light vehicles as well as trucks up to 55,000 kg gross weight.
8	Specific Transport Mode Info / Issues	Aklavik's gravel comes from the Willow River Gravel Source (Gravel Source No. 467). The gravel is transported in the winter, from the pit located at the edge of the Richardson Mountains, via a 27 km winter road. The road consists of a 17 km ice road along the Peel Channel and a 10 km overland winter road north towards Willow River. <u>Impact of climate change:</u> - Climate uncertainties and warming trends associated with climate change phenomena will mean a potentially shorter operating window and smaller load capacities on the winter roads. - Analysis of historical data for the Tibbitt to Contwoyto Winter Road has indicated predictions of a loss of about 0.5% of the available ice road freezing capacity each decade. - Climate warming trend could affect the critical annual resupply into the Hamlet of Aklavik. <u>Information on the proposed all-weather road:</u> - Funding for the study was provided by the Department of Transportation and the federal government through the research and development component of the Building Canada Plan. - Initial all-weather routing was provided by the Hamlet. - The proposed alignment traverses across the delta for the first 12 km to 12.5 km from the community before reaching higher ground that looks to be less ice-rich and contains far fewer lakes. - The first 12 km of the alignment are characterized by several lakes that appear very sensitive to permafrost degradation. Drainage is also an issue as the area is characterized by high water levels during the spring melt out period. - Approximately 17.9 km of the proposed alignment are located on Gwich'in Private Lands within

		the Inuvialuit Settlement Region (ISR), and 1.3 km is located on Gwich'in Private Lands within the Gwich'in Settlement Area (GSA). - Discussions were held in June of 2009 <u>Conclusion of the access road planning study:</u> - The preliminary alignment, with some adjustments due to terrain and other aspects, is a viable concept to pursue for the all-weather road initiative, - The transportation needs in the immediate and long term future consist of the construction of a 7 m wide gravel all-weather road that is similar in concept and operation as other low volume highways in the Northwest Territories, - The total capital cost of the 19.2 km all-weather road is estimated at \$19 million and includes approximately \$1.2 million for environmental, consultation and engineering work, - The total estimated operation and maintenance cost is estimated at \$190,000 per year, - The all-weather road to Willow River Gravel Source will provide cost saving for gravel supply to the community as well as other economic and social benefits - One major benefit is the elimination of the reliance on a winter road that is subject to increased uncertainty and challenges in the face of climate change. - Proceeding with the all-weather road initiative will require next steps in engineering, design, consultation, permitting, cost estimate, and other related activities before going to construction.
9	Actions defined by sector	The next steps towards the development of an all-weather road to the Willow River Gravel Source include: - Assess potential funding opportunities and develop a plan to secure funding commitments for the road, - Negotiate land tenure and access with GTC, - Consult with Inuvialuit Regional Corporation, - Develop a program for environmental baseline studies, topographic survey, hydrologic, geotechnical and terrain investigations, - Proceed with road design and submit a project description document for screening level review to the GTC, GLWB and EISC. - Secure appropriate approvals and proceed with construction
10	Tools	A community consultation took place on February 25, 2009 and covered the following topics: - Other information about the preliminary alignment - Gravel use - Cost for operating the winter road to the gravel source - Environmental and regulatory concerns - Timing

5.3 Documentation of Tuktoyaktuk to Source 177 Site Visit

1	Document Name	DOCUMENTATION OF TUKTOYAKTUK TO SOURCE 177 SITE VISIT
2	Author	EBA, A Tetra Tech Company
3	Year	July 6, 2011
4	Type	Field Report. Includes field photos
5	Subjects / Key words	Tuktoyaktuk, Borrow Source 177, road infrastructure, permafrost monitoring
6	Scope	Gathering comments from Permafrost experts concerning the development of a permafrost monitoring program related to northern infrastructure
7	General Data	- The report documents a one day field visit along transportation infrastructures in the Tuktoyaktuk area (access road to borrow source 177) - Group of experts from the Network of Expertise on Northern Transportation Infrastructure Research, includes experts from the GNWT, Yukon-Highways and Public Works, Transport Canada, INAC, Universities, and consulting firms The document comprises expert opinions on: - Permafrost monitoring techniques and methodology specific to road infrastructure - Monitoring equipment to be used (e.g. the use of thermistors, inclinometers, remote sensing techniques) - Design and construction techniques related to road infrastructure (e.g. use of geotextile, settlement plates, the use of culverts v/s bridges) - Terrain and permafrost conditions along sections of the Inuvik-Tuk Highway (Source 177 access road).
8	Specific Transport Mode Info / Issues	<u>ROAD TRANSPORT</u> - Terrain and permafrost conditions along the road are discussed - Road conditions are directly related to permafrost integrity
9	Actions defined by sector	Recommendations for Performance Monitoring - Monitor thermal regime along creeks and culverts - Monitor snow accumulation along road embankments - Monitor drainage along embankments - Install inclinometer in deep fill areas - Study lake bathymetry to address potential water level fluctuations - Use of settlement plates in deep fill areas Design and Construction Considerations - Use of geotextile in specific areas - Appropriate use of banded culvert vs. multi-plate culvert and bridge
10	Tools	The use of a series of monitoring techniques and tools are proposed (e.g. thermistor cables, inclinometers, etc.)

5.4 Guidelines for the Construction and Operation of Winter Roads

1	Document Name	Guidelines for the Construction and Operation of Winter Roads, Final Report, Transportation Association of Canada.
2	Author	Transportation Association of Canada
3	Year	2011
4	Type	Best Practices Guide
5	Subjects / Key words	Winter roads, ice roads
6	Scope	Primarily applies to temporary winter roads in permafrost regions of provincial and territories of northern Canada.
7	General Data	1) The main objective of these guidelines is to provide winter road designers with a planning tool which enables them to provide recommendations for the construction and operation of winter roads. The expected outcome is the guidelines would become a nation-wide reference document for designing, constructing and operating winter roads. These guidelines can be used in turn as a basis for developing manuals which are tailored to a particular geographic location, its climatic conditions/changes, and operational requirements. The document also covers other relevant topics such as: a. The need for managing the risk of a breakthrough in case of floating ice covers, b. The relationship between monitoring and safety, and between monitoring and optimizing the use of ice covers, and c. The importance of including snow management in winter road planning. 2) P11 "Extended freezing temperatures are the primary climate factor in developing ice covers over lakes and rivers and for freezing wet and soft muskeg terrain. Prevailing winds, snow accumulation and reduced solar radiation (short daylight hours) are secondary climate factors influencing the development of ground and ice conditions for winter roads. As discussed in Chapter 4, national winter temperatures show a warming trend since 1948 and a reduced snow fall trend since 1977. Climate change trends are not only affecting long term changes in temperatures and snow fall, but also the extremes in warm winters. The national average winter temperature of Canada in 2009/10 broke the warm record set in 2005/06 (Environment Canada 2010). Recurring winter roads are vulnerable to both long-term climate change trends. Hayley and Proskin (2008) noted the impact of recent warming trends on the reduction in operating window for the TCWR. Single season winter roads are also vulnerable to warmer than climatic average winters as a result of climate change and without the ability to make up for the loss the following year. These guidelines will address the adaptation strategies available to current and anticipated impacts of climate change. Discussion begins in Chapter 4 and continues through in Chapters 5 and 7 under the engineering of winter roads."

		3) Chapter 4, Practice For Planning Winter Roads, P34 4) P35 Section 4.1.1 “Climatic conditions are the principal factor determining the most probable range of operating period. Construction of overland snow and ice surfaces can typically begin after enough depth of ground freezing has occurred to support equipment. Construction startup is usually determined by ambient air temperatures (correlated to ground temperature conditions) and snow cover, which determine the rate of ground freezing. Experience with snow and ice surfacing in cold regions suggests that construction and operations are limited to periods when ambient temperatures are less than about -10°C. However, insufficient ground freezing and snow or ice cover may further narrow the potential operating season. The start of operations over floating ice covers is controlled by the natural ice thickness under snow cover and the ability to get lightweight equipment onto the ice to clear the early snow to accelerate ice formation. “ 5) P 39 Section 4.2.1.3 “Permafrost underlies about half of Canada’s landmass, and most of the nation’s winter road territory is found within permafrost terrain. Often, permafrost terrain contains ground ice that is sensitive to changes in thermal conditions (temperature) and the ground conditions (vegetation cover, soil type). Since peat is a good insulator, muskeg areas tend to be associated with permafrost in northern Canada. Disturbing muskeg usually reduces its insulative properties and permafrost is more likely to thaw. TAC (2010) notes changing the thermal or ground conditions will lead to thawing of the ground ice and can cause long term settlement, sinkholes, and slumping. General guidelines for reducing problems associated with thawing permafrost are; avoid ice rich ground such as patterned ground areas, avoid peat deposits and muskeg, and choose routes with coarse grained soils, such as moraines and outwash areas. In areas of discontinuous permafrost, south-facing slopes in valleys may not have permafrost and would be preferred over north-facing slopes.” 6) P 42 Section 4.3.1 “Temperature and snowfall meteorological records near a proposed winter road should be reviewed to determine the winter air temperatures and the distribution and timing of snowfall. Winter air temperatures are the primary control on rate of ground freezing and ice cover formation. The freezing index (the sum of the sub-zero mean daily air temperature) is a useful parameter to assess the cumulative freezing potential for different locations or different years. As discussed in Chapter 5, it was found that once the cumulative freezing index has reached 305 °C days ground has frozen sufficiently to support winter road construction vehicles. As discussed in Chapter 6, freezing index is correlated to ice cover thickness.” 7) P 43 Section 4.3.3 Climate change is affecting long-term temperature and snowfall patterns challenging the assumption that previous climate records can be extrapolated into the future. Environment Canada (2010) has concluded winter national temperatures show a warming trend of 2.5°C/decade from 1948 to 2010. Lemmen et al. (2008) found the 1948-2006 average national temperature warmed by 1.3°C. In northwestern Canada winter temperatures have warmed more than 3°C between 1948 and 2003 while cooling trends up to -2.5°C were observed in parts of the eastern Arctic. Since 1997, winter temperatures have remained warmer

		than average. Environment Canada has also concluded most winters have precipitation at or below normal since 1977/78 as compared to the 1951-80 mean. Lemmen et al. (2008) have observed the following; 10% decrease in snow cover over the northern hemisphere over 1972-2003, 20% decrease in the duration of snow cover in Arctic since 1950, and 1-2 month reduction in ice cover season on the Great Lakes. 8) P 43 Sidebar - There are increased risks when extrapolating previous trends in climate and ice conditions to future operations at both current and new winter road sites. These increased risks should be considered when developing various winter road options.
8	Specific Transport Mode Info / Issues	This guide applies to the planning, design, construction and operation of winter roads on ice and land.
9	Actions defined by sector	Exercise caution when planning for winter road construction and operating season using opening/closing dates from previous years under changing climate conditions. Use adaptive planning so a backup plan is in place if unexpected conditions are encountered.
10	Tools	This is a best practices guide for planning, design, construction, operation and maintenance of winter roads. It provides the reader with a brief history and classification of winter roads, and guide on how to proceed based on the best available knowledge. Numerous case studies and references are included. Appendices include a comparison of Canadian Guides for Working or Travelling over Floating Ice and ice thickness measurement methodologies.

6 AIR TRANSPORT

6.1 Preliminary Terrain Analysis: Inuvik (Mike Zubko, CYEV) and Déline (CYWJ) Airports

1	Document Name	Preliminary Terrain Analysis: Inuvik (Mike Zubko, CYEV) and Déline (CYWJ) Airports
2	Author	John Tunnicliffe and Chris Burn Carleton University Department of Geography and Environmental Studies
3	Year	2011
4	Type	University Publication. 19 pages
5	Subjects / Key words	Climate change impacts, airports, transportation
6	Scope	The scope of work included: - Conduct a vulnerability assessment of northern airports to determine how permafrost changes will impact airports. - Demonstrate the use of terrain analysis as a planning and explanation tool for the behaviour and integrity of runways in the NWT. The work consisted of a desktop review of terrain conditions (including the review of geotechnical information) at two airports in Inuvik and Déline.
7	General Data	- There are three permafrost zones within the NWT. - Permafrost stability changes are influenced by changes in ground temperature due to climate warming. As permafrost degrades the stability and bearing capacity changes. - Stability changes may potentially have significant impacts to infrastructure in the north (highways, airports, etc.,) - Some airports have more terrain data than others. This project focused on two airports (one large and one small) that would represent the type of facilities in the NWT. <u>Inuvik</u> - Constructed in 1958. Prior to construction, two lakes were located on the east and west ends of the airport runway. - Within continuous permafrost zone. Annual mean temp -8.7°C, expected to rise 0.5°C over the next decade. - Depth to bedrock at airport 1.6 m to 10 m below grade. Thick layer of glacial drift underlies the area. The area is sparsely vegetated. Permafrost thickness is 90 m. Ground temperatures measured - 1.6°C. Active layer ranges from 0.5 to 2.5 m. - Settlement /subsidence issues have been identified on the northern half of the runway, including the north shoulder and the slope of the runway near the east end. Areas of settlement have generally been infilled. In 2011, another area having settlement / subsidence issues was identified at the FOL site.

		- Review of the Site using a Digital Elevation Model determined that the airport lies in a former drainage area. - Understanding the location of former drainage areas is an important tool for long term planning as flow paths in permafrost carry water via surface and subsurface. Areas where the drainage paths intersect the runway are considered as potential problem areas. - Based on the available information, a general terrain classification was completed. The materials underlying the airstrip consist of shallow moraine material and alluvium. As the deposit is heterogeneous with a significant portion of sands and gravels, large scale subsidence is not a concern. - Areas of greater concerns are the east and west portions of the runway, which may have a higher proportion of ice lenses and segregated ice content as these areas previously contained lakes featuring silt rich lacustrine bodies. Déline - Gravel runway built in 1998 and is located on the northern edge of the discontinuous permafrost zone. The airport is underlain by permafrost and ice rich frozen soils; however, in many locations, ground ice is not encountered due to the well-drained soil. In areas lacking well drained soil (for example in drainage areas), there is 3 m or more of ground ice. - Considering climate information from surrounding communities of Norman Wells and Fort Simpson, there has been some warming over time. - There is limited data on the permafrost conditions in the Déline area. Other data collected from the Enbridge pipeline – indicate ground temperatures in this area are close to 0°C. - Construction activities in 2001 were conducted to correct some of the settlement issues; with future settlement work required. - The Site is situated at the northern edge of a distinctive scored and lineated trough. Surrounding terrain is generally bedrock covered with thin drifts of till and scattered lakes. - The thickness of organic cover of peat and moss in the area are approximately 0.4 m or less. - Surface water does not flow in well-defined channels; it seeps into the organic layers. - Limited geotechnical information – however, boreholes advanced southeast of the old airport identified a compacted peat layer overlying mostly gravels, sand and some fines. - Review of the Site using a Digital Elevation Model determined that the airstrip is positioned to intercept overland flow on the north site. - Points where the old drainage network crosses the present airport pathway can be a problem spot for maintenance in the long term. - Based on the available information, a general terrain classification was completed. This classification identified that the airport was sitting in an area of glaciofluvial material with three categories. The first category, the well-drained topographical highs, present the highest concern, both in controlling runoff / drainage and due to its susceptibility to settlement as a result of permafrost thaw.
8	Specific Transport Mode Info / Issues	<u>Air transport infrastructures</u> - Subsidence and settlement issues <u>Impacts of climate change on airports:</u> - Rising ground temperatures causing thawing of permafrost and decreasing the strength of ice rich soils.
9	Actions defined by sector	No specific actions defined
10	Tools	No specific tools defined

11	Gaps Identified	Limited geotechnical and climate data for smaller communities.

6.2 Adapting Transportation to the Impacts of Climate Change – Climate Change Adaptation and Preparedness Planning for Airports

1	Document Name	Adapting Transportation to the Impacts of Climate Change – Climate Change Adaptation and Preparedness Planning for Airports
2	Author	Transportation Research Board Special Task Force on Climate Change and Energy
3	Year	June 2011
4	Type	Publication of the U.S Based Transportation Research Board.
5	Subjects / Key words	Climate change, airports, transportation
6	Scope	The document focuses on transportation adaptation practices at airport facilities. Specifically it discusses how climate change will affect airports, outlines the adaptation actions required and identifies further research requirements to allow the transportation industry to adapt more quickly and efficiently. Note: The document refers to climate change impacts to the entire U.S. rather than focusing on northern communities and environments.
7	General Data	Climate change impacts and adaptation actions will vary widely due to the differing characteristics (size, location, topography, hydrology, etc.,) of airports. <u>Items that will be affected by climate change include:</u> • Infrastructure – Utility and storm water infrastructure may become overloaded. • Ground transportation systems – road and rail systems to and from the airport are susceptible to climate impacts. • Operation of aircraft, airport and airspace – Machinery are sensitive to salt water, dust, etc. • Airports as emergency response centres. These facilities may be vulnerable if damaged by storms or sea level rise. <u>Three levels of climate change effects on airports</u> 1. Direct Changes • Increases in average temperatures. • Increases in average sea level. • Increases in maximum extent of storm surge. • Changes in average precipitation amounts. • Increases in precipitation intensity. • Increases in wind speeds and storm intensity. 2. Secondary effects of those changes on the ecosystem • Increased runoff and erosion due to dryer soil conditions (increasing airborne dust and potentially affecting wildlife). • Increase in forest and grassland fires (smoke would affect aircraft operation). • Reduction in mountain snow pack and impacts to stream flow changes (timing and volume). These impacts would change the availability of water, increase erosion and change wildlife habitats). • Changes in plant and animal species migration, disease, extinction and habitats. • Changes in human migration (changing the demand on air travel). 3. Tertiary effects of ecosystem change on the human environment (such as insurance costs) • Changes in populations and air service markets • Higher insurance costs for property and liability coverage • Increased role in regional emergency management • Expectations for airports to prevent climate change impacts and decrease greenhouse gas

		emissions. <u>Adaptations</u> Adaptation strategy needs to consider both the unique characteristics of each airport and those potential impacts identified. This will include work in three areas: 1. Hardening of the Physical Plant Incorporating the consideration of risks into existing design specifications, asset management systems, and maintenance work order systems. - Airports can assess each facility / infrastructure and evaluate its susceptibility to various risk factors (precipitation, temperature, winds, etc.) to develop best management practices. Examples include: - Revising design standards - Developing plans to increase runway lengths - Rebuilding storm water infrastructure - Hardening facilities to higher wind loads - Rebuilding, relocating or abandoning shoreline facilities. These sorts of climate adaptation actions should be incorporated in to the master planning and asset management process for the airport. This ensures that the changes are well thought out, minimizing the cost and maximizing efficiency. 2. Addressing Operational Risks Assess and adapt to operational risks and opportunities that affect the airport. Risks include: - Operational impacts from airport closure and delayed aircraft operations due to flooding or storm water overload, - Increased energy consumption for heating, ventilation, and air conditioning due to extreme heat events, - Water quality violations from increased de-icing, - Computer system downtime or data loss and cyber security risks due to power failures or building damage related to wind, - Operations and maintenance disruptions due to all of the above, - Public health risks (air, water, sanitation, infectious disease) during mass strandings and extended disruptions, - Airport employee chaos due to regional and family demands for their services, - Tenant or contractor lack of performance due to equipment, supplies, or labour unavailability, and economic loss to regional businesses. - Economic loss to regional businesses. 3. Communication and Collaboration - Building communications, collaboration and strategic alignment with airport stakeholders. - Every airport will have a different approach
8	Specific Transport Mode Info / Issues	<u>Air transport infrastructures</u> Subsidence and settlement issues
9	Actions defined by sector	Identified Research Needs: - Understanding and accounting for regional variations in climate change effects - Methods for regional data sharing of climate change data and forecasts - Effects of sea level rise on water tables and soil / structure foundations - Effective building shell treatments for higher velocity winds and precipitations densities - Materials science implications for higher average temperatures and higher extremes - Public health implications of new invasive species and vector-borne diseases

		• Efficient methods for storing and handling alternative fuels • Methods for valuing and pricing climate change adaptation actions • Ways to incorporate climate change considerations into risk management and asset management systems • Community mapping and other ways to assure comprehensive stakeholder involvement in adaptation planning and implementation.
10	Tools	No specific tools identified
11	Gap Identified	No gaps identified

6.3 Inuvik Airport Geophysics Investigation: Final Report

1	Document Name	Inuvik Airport Geophysics Investigation: Final Report
2	Author	Jon Tunnicliffe and Chris Burn, Carleton University, Department of Geography and Environmental Studies. Alex Becker, University of California, Earth Sciences Division, Geophysics Department. Patrick Finlay, EBA Engineering. Koichi Hayashi, OYO Corporation / Geometrics, San Jose. Lothar Schrott, Geomorphology and Environmental Systems Research Group, University of Salzburg.
3	Year	September, 2011.
4	Type	Scientific Paper. 33 pages.
5	Subjects / Key words	Permafrost,
6	Scope	The purpose of this project was to evaluate the use of different geophysical techniques in the evaluation of permafrost at airports. One of the intentions of the work was to develop linkages between the larger scale terrain classification and smaller scale issues found on runways and associated infrastructure.
7	General Data	The work was completed at the Inuvik Mike Zubko Airport. This airport was selected for this study because it has a large amount of background information [borehole logs, ground temperatures, previous ground penetrating radar (GPR) surveys, etc.]. Four geophysical instruments proved to be useful during the study: 1. Capacitively-coupled resistivity (Ohm-Mapper) 2. Conventional resistivity (Mini-Res), 3. GPR, and, 4. Multi-channel analyses of surface waves (MASW). Due to technical difficulties the Ohm-Mapper method was not implemented during the study. The study included the completion of four different instrument setups to evaluate 12 different locations including three runway profiles, five transverse sections, two taxiways and two of the proposed runway extension centerlines. The purpose of using each of the three geophysical units included: • MiniRes - To assess the physical parameters of the subsurface materials (including ice content and type of the material). • GPR – To assess stratigraphic boundaries and subsurface structures. • MASW – Used to assess the seismic velocity of shear waves within the surface. The use of this technology in ice rich terrain is not common; therefore, shear wave velocities are not well characterized. Results • The runway is constructed on a peat layer situated above a thick layer of crushed rock. The rock is underlain by basal till overlying bedrock. • Longitudinal runway profiles completed with each instrument showed similar stratigraphy consistent with the historical geotechnical information collected (borehole logs). • In contrast to longitudinal profiles, latitudinal profiles show more differences. Taxiway alpha and the FOL taxiway exhibit older drainage pathways, resulting in heterogeneous resistivity's and evidence of deep ground ice. • Taxiways highlights problems associated with former drainage channels and lakes that were filled during the course of construction. Three sites (Taxiway Alpha, FOL Taxiway and the eastern end of the runway) showed evidence of ground ice degradation.

		Conclusions of the Study - Overlying the results of the different methods can identify more information than the use of one single system. - The study proposes use of the MASW and the resistivity approaches together as evaluative tools to identify areas of concern. - The remote sensing findings are generally consistent with the geophysical surveys completed at the Site. This will present an opportunity for desktop assessment of aerial images to target geophysics work and minimizing time evaluating terrain that will not present issues. - More work experience working on runways and permafrost will help address some of the uncertainties in the interpretation of geophysical investigations of subsurface conditions. Findings regarding the Inuvik Airport - The Inuvik airport has an intermediate to low risk rating. Significant settling in the east, but it has now stabilized. - Some areas of subsidence identified (1000 ft. marker) may continue to present issues since the subsurface soft zone is larger than the subsidence identified on the surface. Settlement will occur on the west end – but this will stabilize with time.
8	Specific Transport Mode Info / Issues	<u>Air transport infrastructures</u> Subsidence and settlement issues
9	Actions defined by sector	No specific actions defined
10	Tools	No specific tools defined
11	Gaps Identified	- Use of the MASW techniques is evolving and its use will increase in engineering studies. This will allow for the revision of processing and interpretation techniques. Currently, the unit works well only on the paved runway surface rather than off of it. Some work is needed to ensure the same quality of result on gravel runways. - Further drilling work required to confirm the observed stratigraphy and establish ice content. - Further investigation of the eastern end of the runway of the Inuvik Airport is necessary. - Findings propose that assessment of other airports includes a terrain assessment be conducted first, followed up by a geophysical survey using the resistivity and surface wave analysis techniques

6.4 Towards a Protocol for Airport Infrastructure Risk Assessment: Managing Long-Term Infrastructure Risks in Permafrost Terrain.

1	Document Name	Towards a Protocol for Airport Infrastructure Risk Assessment: Managing Long-Term Infrastructure Risks in Permafrost Terrain.
2	Author	Jon Tunnicliffe and Chris Burn, Carleton University Department of Geography and Environmental Studies
3	Year	September, 2011.

4	Type	Scientific Paper. 32 pages.
5	Subjects / Key words	Permafrost, risk assessment, vulnerability assessment, airports,
6	Scope	The purpose of this paper was to provide guidance on the completion of risk assessments on NWT airport infrastructure. The purpose the assessment would be to evaluate the risks present and prioritize the facilities requiring rehabilitative actions.
7	General Data	• Risk and vulnerability analysis is a tool for developing short term objectives to achieve long term goals including improving safety, achieving economic benefits, maintaining capacity for larger aircraft, and enhanced delivery of services. • Risk assessment is an adaptive process requiring updating and revision. • Risk assessment has four main stages: 1. Identification of information needs and knowledge gaps ▪ This is completed via a desktop study. ▪ Documentation reviewed would include climate data, terrain reports, geotechnical data, surface drainage and hydrology (generation of Digital Elevation Models, etc.), engineering reports, maintenance reports, operational reports, infrastructure inventories, air photos, satellite imagery, other geospatial data, and interviews / correspondence with knowledgeable persons (which may include runway management staff, maintenance and repair personnel, engineers, airline managers, pilots, DND personnel). ▪ Consultation of available data resources specializing in climate change issues. ▪ Evaluation of the infrastructure assets (including age, life expectancy, runway type, operation and maintenance practices, performance measures, etc.,) ▪ The results of Step 1 can be used to rank airports by the extent of hazards. A numerical framework then can determine what airports require further investigation. 2. Site Investigation ▪ Completed after the information review has been conducted. ▪ The purpose is to further assess hazards and improve the estimates of the frequency and magnitude of risks. ▪ Tasks include: Inspect runway, interview personnel, look for problems that cannot be determined through the desktop remote sensing work. ▪ Geotechnical studies may be required to collect additional data. These studies may involve topographic surveys, geophysical surveys, soil sampling or drilling. ▪ Results will provide a quantitative assessment of risks posed by permafrost and ground ice. ▪ Numerical modelling may be applied during this stage to forecast warming scenarios 3. Monitoring, Validation and Training ▪ Once the desktop study and the site assessment are completed; the ranking should be updated. The results should identify vulnerabilities. ▪ These areas require further study – through site monitoring 4. Prioritization ▪ This stage involves the prioritizing of risk in terms of probability and severity. The facilities are then ranked. ▪ Approach is semi-quantitative. ▪ Prioritization amongst airports can be derived by: a) Total score from the assessment b) The importance of each facility c) The total number of aircraft movements.
8	Specific Transport	<u>Terrain Concerns</u> • Sloughing, heave, subsidence, and failure of the runways, taxiway and apron embankments.

	Mode Info / Issues	- Runway surfaces: micro and macro texture, cracks depressions and deformation - Compromised integrity of building foundations, increased creep rate of piles and footings - Subsurface infrastructure: susceptible culverts, cabling and ducts. <u>Snow and surface / Subsurface water flow:</u> - Loss of bearing strength, erosion and ravelling, - Ponding and flooding, further melting - Unpredictable surface conditions <u>Changing Weather Conditions</u> - Reduced runway friction, runway length may be inadequate for larger aircraft - Impacts to lighting, navigation and communications equipment - Flight delays, increasing failure to meet visual meteorological conditions <u>River and Coastal Issues</u> - Loss of bearing strength, erosion and ravelling, - Inundation, flooding <u>Other Impacts</u> - Reduced winter road access and higher overall maintenance needs, leading to increased passenger traffic and cargo volumes - Impacts on the road network lead to increased operating costs, maintenance, supplies and fuel - Handling regional emergencies adds pressure to airport usage.
9	Actions defined by sector	- Risk Assessment on a site by site basis - Vulnerability Assessment on a regional basis
10	Tools	Tools included in this paper include the Risk Assessment Framework.
11	Gaps Identified	- Long term climate normals not available in many of the smaller communities - Ground temperatures and active layer depth information not routinely collected at airports. - Topographic information generally limited to Digital Elevation Models (DEMs) with a 30 m resolution; therefore it is difficult to do surficial flow modelling - Long term monitoring / repeat geophysical surveys to characterize changes to the subsurface seasonally or yearly.

7 COMMUNITY ACTION PLANS

7.1 Climate Change in the Tlicho Region: Scientific and Local Findings

1	Document Name	Climate Change in the Tlicho Region: Scientific and Local Findings
2	Author	Ecology North (D. T'selie)
3	Year	
4	Type	Climate Change Review for the Tlicho region
5	Subjects / Key words	
6	Scope	The document reviews existing climate data for the Tlicho region, local observations and climate predictions for the region. The document then discusses potential impacts of climate change to Tlicho communities and next steps in planning for it. Climate Change Planning Project undertaken by Tlicho Government and Ecology North.
7	General Data	Ecology North began developing climate change action plans for all Tlicho communities in 2008 and held a regional meeting with a Community Advisory Committee in January 2009. The Community Advisory Committee met with Ecology North staff four times throughout the action plan development to ensure they are representative of Tlicho values, culture and community priorities. Information was gathered using several techniques including Elders interviews and public meetings in each community, and research and consultation with experts. The document specifically includes: • Results of a search for historical climate data for the Tlicho region – limited results ○ Data Gap: No consistent, long-term data set from any one location in the Tlicho ○ Data from one station may only span a brief period of time and there are differences in data collection techniques between stations (e.g., one station may record daily temperature and heat degree days while another may record hourly temperature and wind speed) ○ Need for baseline or predictive scientific data • Discussion on changing temperatures around Yellowknife and snow depths in the Snare River Basin (both have increased over the monitoring period) • Local observations of climate change by Tlicho people – warmer winters and melting ice, changing rain and snow patterns, non-native species, changing and unpredictable water levels, more forest fires, and reduced native species • Predictions about the Tlicho region's future climate – more rain, less snow cover, thawing permafrost, changing forest fire patterns, accidental species introductions • Potential impacts of climate change on Tlicho communities – unstable infrastructure, increased snow loads, risks to sewage lagoons, disrupted transportation (including likelihood of the impact), threatened food security, altered water quality and quantity • Next steps in planning for climate change – collaborating with various levels of government Transportation impacts – effects on other sectors: • Food security – rising costs of food (flown-in) • Personal transportation in/out of communities connected by winter roads • Increased use of chemicals (de-icing) and effects on surrounding environment
8	Specific Transport	<u>AIR TRANSPORT</u> • Shortened season for ice-based airstrips

	Mode Info / Issues	• Permafrost degradation affecting runways and airstrips (certain to occur, high risk) • Increased instances of freezing rain and freeze-thaw cycles affect safety on airstrips (highly probable, high risk) • More storms may ground planes and create need for better navigation aids • Frequent de-icing of planes due to changing weather conditions and increased use of chemicals (highly probable, medium risk) • Longer ice-free season for float planes cited as positive impact • Increased pressure on air transportation systems to move people and goods <u>ROAD TRANSPORT</u> • Warmer winters are shortening the ice-road season • Icier roads due to build-up of snow on roads and increasing temperatures • Thawing permafrost can affect community infrastructure as the ground shifts – more freeze-thaw cycles cause a lot of pot-holes, slumping and cracking; these in turn reduce road safety and increase maintenance costs (certain to occur, high to medium risk) • Permafrost degradation threatening bridges, pile foundations, dikes and other infrastructure (highly probably, high risk) • Increased costs to maintain all-weather roads over permafrost terrain • More freezing rain resulting in increased maintenance to maintain safe conditions on roads (highly probable, high risk) • Costly ice road delays and early closures • Travel on land becomes unsafe due to unpredictable weather patterns and extreme weather • Increased precipitation may impact culverts (possibly occur, inconclusive risk) • Road washouts due to rapid spring run-off (highly probably, high risk) • Increased stress on vehicles due to poor road conditions (highly probable, medium risk) • Shorter winter for instream work due to higher temperatures (possible, low risk) <u>MARINE TRANSPORT</u> • Ferry and ice crossing schedules less predictable due to low water, ice jams or floods • Higher waves and intense storms threaten safe navigation • Need improved search and rescue capacity • Travel on water becomes unsafe due to changing water levels and thin ice • Longer open water seasons and fewer ice problems cited as positive impacts
9	Actions defined by sector	<u>AIR TRANSPORT</u> • Collaborate with GNWT-DOT regarding airports in Gameti, Wekweeti and Whati <u>ROAD TRANSPORT</u> • Collaborate with GNWT-DOT regarding winter roads to Gameti, Wekweeti and Whati and Highway No. 3 • Collaborate with GNWT-MACA regarding municipal infrastructure (community roads) <u>MARINE TRANSPORT</u> • Collaborate with INAC Water Resources Division, as well as Environment Canada, the GNWT and Wek'eezhii Land and Water Board regarding water quantity monitoring
10	Tools	

7.2 Building a Climate Change Action Plan for Behchoko

1	Document Name	Building a Climate Change Action Plan for Behchoko
2	Author	Ecology North
3	Year	
4	Type	Community Action Plan for Behchoko
5	Subjects / Key words	
6	Scope	The document outlines the climate change risks to the community of Behchoko, along with strategies and options for dealing with these risks. The document also considers any opportunities that may be presented by climate change.
7	General Data	Ecology North began developing climate change action plans for all Tlicho communities in 2008 and held a regional meeting with a Community Advisory Committee in January 2009. The Community Advisory Committee met with Ecology North staff four times throughout the action plan development to ensure they are representative of Tlicho values, culture and community priorities. Information was gathered using several techniques including Elders interviews and public meetings in each community, and research and consultation with experts. This CCAP specifically includes: • Potential impacts, sources of the impacts and adaptive strategies that are specific to the community as a result of climate change ▪ Topics include thawing permafrost, unstable infrastructure, disrupted transportation, threatened food security, altered water quality and quantity, animal health and invasive species, and social and cultural impacts • Data gap noted for lack of detailed permafrost knowledge in Behchoko area; effect of permafrost on different types of infrastructure; appropriate and cost-effective construction technologies and techniques; and, capacity to construct permafrost-appropriate infrastructure • Data gap noted for lack of long-term climate and weather data for Tlicho region as a whole; includes: ▪ Need climate modelling work for Tlicho region to assist with climate change planning ▪ Need more data collection on weather in the Tlicho region – important for long-term trend analysis and for accurate and timely access to weather patterns by community members • Positive effects of climate change on the community – climate change opportunities, sources of opportunities and adaptive strategies • Recommended short-term implementation activities, as well as planning, partnership building, and awareness activities to be undertaken by Behchoko, as well as actions requiring collaboration between Tlicho communities and different levels of government. Transportation Impacts – effects on other sectors: • A shorter winter road season will affect community members ability to travel to other Tlicho communities as well as traditional hunting and trapping • Increased icing on roads may mean more dangerous driving conditions and increased use of gravel, sand, salt and other traction and de-icing aids on Behchoko roads – may affect nearby water quality and animals
8	Specific Transport Mode Info / Issues	<u>AIR TRANSPORT</u> • Runway integrity compromised from ground settlement due to degrading permafrost • Ice build-up on runways becomes more frequent due to increased freezing rain and warmer temperatures • Use of potential contaminants to combat ice build-up becomes more frequent (e.g., glycol, salt) due to increased freezing rain and warmer temperatures • Increased disruption of air transportation systems (extreme and unpredictable weather)

		• Fire smoke disrupts air transport and travel on land due to more frequent forest fires <u>ROAD TRANSPORT</u> • Increased damage to roads (potholes, sinkholes, heaving, etc.) due to degrading permafrost • Washout sections of roads due to increased spring run off • Travel on the land becomes more dangerous due to warmer weather, thin ice, less snow and more extreme and unpredictable weather • More stress and damage to vehicles due to poor road conditions (e.g., more potholes) • Use of potential contaminants to combat ice build-up becomes more frequent (e.g., glycol, salt) due to increased freezing rain and warmer temperatures • Fire smoke disrupts air transport and travel on land due to more frequent forest fires • Longer construction season due to longer summers (climate change opportunity) <u>MARINE TRANSPORT</u> • Travel by boat becomes more difficult and dangerous and traditional water transport routes may not be viable; resulting from changing water levels in streams and rivers, and possible formation or disappearance of small lakes and wetlands
9	Actions defined by sector	<u>AIR TRANSPORT</u> • Increased runway maintenance • Excavate permafrost if it is thin and sporadic • Use gravel, sand and de-icing agents • Monitor potential environmental impacts of de-icing agents • Contain de-icing agents (e.g., ethylene glycol) after application for proper disposal • Immediately communicate bad weather to all communities, persons and business that might be affected (air traffic disruption) • Engage in community forest fire planning and ensure the community's emergency plan is updated regularly • Behchoko should consult with experts to assess the vulnerability of community infrastructure to melting permafrost <u>ROAD TRANSPORT</u> • Increase road maintenance • Excavate permafrost if it is thin and sporadic • Ensure proper drainage in and around roads • Manage snow build-up so spring melt does not impact roads • Make sure the community has people who can respond to emergencies (e.g., Canadian Rangers) • Use sand/gravel to increase traction and use salt to combat ice build-up • Engage in community forest fire planning and ensure the community's emergency plan is updated regularly • Behchoko should consult with experts to assess the vulnerability of community infrastructure to melting permafrost • Take the time to plan new infrastructure to withstand the effects of climate change (climate change opportunity) <u>MARINE TRANSPORT</u> • Consider finding new areas for harvesting or new ways of travel on the land
10	Tools	

7.3 Climate Change Adaptation Action Plan, Community of Paulatuk, Northwest Territories

1	Document Name	Climate Change Adaptation Action Plan, Community of Paulatuk, Northwest Territories
2	Author	ArcticNorth Consulting (submitted to INAC Climate Change Adaptation Program)
3	Year	
4	Type	Action Plan for Paulatuk
5	Subjects / Key words	
6	Scope	The project engaged community members, scientists and decision makers to identify and characterize key climate change vulnerabilities, adaptation actions and resources for implementation, as a basis for developing the Action Plan for Paulatuk.
7	General Data	Transportation and Infrastructure was one of five sectors identified as particularly vulnerable. The Action Plan presents Adaptation Action Tables for each identified sector to summarize results of research and consultation. For each sector, the Adaptation Action Table lists the following: • Adaptation Actions – actions that would reduce climate change vulnerability and build adaptive capacity • Priority – identified for each Adaption Action (High: needs immediate attention, Medium: important to consider soon, and Low: not urgent) • Climate Change Issue – describes the climate-related change observed or anticipated and associate impact on the community; includes community concerns • Desired Outcome – describes the future state the Adaptation Actions aim to achieve • Resources and Leadership – summarises programs, organizations, etc., who could help implement Adaptation Actions. Transportation Impacts – effects on other sectors: • Changing and unpredictable travel conditions are affecting access to country foods and increase threat to personal safety
8	Specific Transport Mode Info / Issues	<u>ROAD TRANSPORT</u> • Increased blowing snow creates hazardous and obstructing snow drifts • Rising sea levels and increased storm activity are contributing to shoreline erosion, potentially impacting roads and other community infrastructure (e.g., graveyard, buildings) • More open water along over-land travel routes necessitates detours • Increased volume of spring melt leads to formation of large puddles in the spring
9	Actions defined by sector	<u>ROAD TRANSPORT</u> • Install snow fencing in strategic locations (High priority) ○ Hamlet has the materials; slated for installation in summer/fall 2010 • Have shoreline erosion assessed by engineer to determine threat to roads and other infrastructure, and options for reinforcement (High priority) ○ The Hamlet has hired an engineering consultant (2010) ○ Collaborate with Natural Resources Canada • Construct bridges along travel routes where open water necessitates detours (Low priority)

		○ The Hamlet is contributing funding to bridge construction • Consider installing natural culverts that can withstand heavy machinery, like a snowplough • Take natural drainage paths into account when developing new roads or buildings (Low priority) ○ The Hamlet can collaborate with the GNWT-MACA • Several Hamlet employees have partaken in a permafrost and infrastructure workshop in Inuvik <u>GENERAL</u> • Establish best practices for construction and development in consultation with local residents and accounting for ramifications of climate change in the North • Conduct cost-benefit analysis on expensive infrastructure improvement projects
10	Tools	

7.4 Things Change, We Change: Planning for Community Resilience in Tuktoyaktuk – Part II – A Community Climate Change Adaptation Plan

1	Document Name	Things Change, We Change: Planning for Community Resilience in Tuktoyaktuk – Part II – A Community Climate Change Adaptation Plan
2	Author	??
3	Year	
4	Type	Climate Change Action Plan for Tuktoyaktuk
5	Subjects / Key words	
6	Scope	The document outlines the climate change adaption research and planning undertaken for the community of Tuktoyaktuk. The project involves adaptation planning in two other communities (Sachs Harbour, NT, and Gjoa Haven, NU) as well however the Tuktoyaktuk effort serves as a case study for the larger project: looking at ways to plan for climate changes with the Arctic populations they will affect. The Tuktoyaktuk CCAP represents the issues, impacts and ideas that Tuktoyaktuk residents have identified in recent climate change adaptation planning efforts.
7	General Data	The work for Tuktoyaktuk included preliminary familiarization and local pre-planning, data compilation for the community and environmental change, local planning consultations, and preparation of the adaptation plan with stakeholder review and editing. This document specifically includes: • Discussion on what Adaptation is, on Managing Community Change, what a Community Adaptation Plan is, and describes the adaptation planning project and the specific process in Tuktoyaktuk • Discussion on a comparison of community planning and resilience approaches – community can update their existing municipal plan to reflect physical and economic adaptations but a more comprehensive, assets-oriented approach is required to examine the community’s resilience to change • Overview of the Tuktoyaktuk CCAP ○ CCAP organized by Four Dimensions of Community Resilience: People, Organizations, Resources and Relationships ○ Includes dimensional goals, objectives for each goal, actions and rationale • Data gap: need for further research to understand the process of on-going coastal changes within Hamlet boundary. NRCan active in Tuktoyaktuk for many years collecting information on local erosion, subsidence and relative sea level rise. Regular monitoring of local ice thickness, active layer depth, and snow drifting and distribution would provide a large amount of information for design and planning purposes. • Data gap: need for information about conditions existing outside and in the immediate vicinity of the Hamlet boundary to help with development and infrastructure relocation/Hamlet expansion Transportation impacts – effects on other sectors: • None identified

8	Specific Transport Mode Info / Issues	<u>ROAD TRANSPORT</u> - Increased costs of road maintenance due to increased road wash-outs from rising sea levels - Need to identify new land development areas suited to community development as land around Tuktoyaktuk very limited
9	Actions defined by sector	<u>ROAD TRANSPORT</u> - Update current Community Plan to reflect the flood risk information generated by NRCan - Possible relocation of existing land uses (infrastructure) from identified flood plains
10	Tools	

7.5 Climate Change Adaptation Action Plan, Community of Ulukhaktok, Northwest Territories

1	Document Name	Climate Change Adaptation Action Plan, Community of Ulukhaktok, Northwest Territories
2	Author	ArcticNorth Consulting (submitted to INAC Climate Change Adaptation Program)
3	Year	
4	Type	Action Plan for Ulukhaktok
5	Subjects / Key words	
6	Scope	The project engaged community members, scientists and decision makers to identify and characterize key climate change vulnerabilities, adaptation actions and resources for implementation, as a basis for developing the Action Plan for Ulukhaktok.
7	General Data	Transportation and Infrastructure was one of five sectors identified as particularly vulnerable. The Action Plan presents Adaptation Action Tables for each identified sector to summarize results of research and consultation. For each sector, the Adaptation Action Table lists the following: • Adaptation Actions – actions that would reduce climate change vulnerability and build adaptive capacity • Priority – identified for each Adaption Action (High: needs immediate attention, Medium: important to consider soon, and Low: not urgent) • Climate Change Issue – describes the climate-related change observed or anticipated and associate impact on the community; includes community concerns • Desired Outcome – describes the future state the Adaptation Actions aim to achieve • Resources and Leadership – summarises programs, organizations, etc., who could help implement Adaptation Actions. Transportation Impacts – effects on other sectors: • Changing and unpredictable travel conditions are affecting access to country foods and increase threat to personal safety
8	Specific Transport Mode Info / Issues	<u>AIR TRANSPORT</u> • Prevailing winds can affect ability of planes to land safely <u>ROAD TRANSPORT</u> • Increasingly dry summers and speeding ATVs contribute to dustier roads, increasing incidence of respiratory illness, sore throats and eyes <u>MARINE TRANSPORT</u> • Changing sea ice conditions can affect the timing of the barge • Less multi-year ice means more ship traffic (cruise ship and others) in the waters around Ulukhaktok • Concern about sewage discharge and other contaminants from ships being dumped into the water

		• Increase in storm activity, sea level and decrease in sea ice all contribute to shoreline erosion • Changing conditions make travel on the sea ice more dangerous; younger generations at higher risk
9	Actions defined by sector	<u>AIR TRANSPORT</u> • Consider developing alternative landing strip in line with direction of prevailing winds (Low priority) ○ Resources/Leadership: none identified <u>ROAD TRANSPORT</u> • Continue to water roads during dry periods (High priority) • Apply sealant to the roads (preferably biodegradable) (High priority) • Educate youth on effects of driving fast (High priority) • Stricter by-law enforcement for speeding (higher fines) (High priority) • Pursue research on effects of dust pollution on human health (High priority) ○ Resources/Leadership: Health Centre, Community Health Representative, Helen Kalvak Elihakvik, Hamlet <u>MARINE TRANSPORT</u> • Have an emergency fuel reserve for diesel generators and vehicles (Low priority) ○ Resources/Leadership: Co-op store (manages fuel contract) • Find out who monitors ship traffic and identify how the community can be consulted (High priority) • Have a local 'Environmental Monitor' monitor ships when they are anchored near the community (High priority) ○ Resources/Leadership: Inuvialuit Regional Corporation, Transport Canada, Fisheries and Oceans, Hunters and Trappers Committee • Undertake hazard mapping to highlight high-risk areas (Medium priority) • Future development should account for risk of erosion (Medium priority) ○ Resources/Leadership: Engage scientific community to identify future risks • Review and update search and rescue measures in light of new dangers • Provide access to safety equipment (beacons, radios, satellite phones) through Hamlet or Hunters and Trappers Committee • Offer training workshops for various things (e.g., reading weather forecasts, mapping, using a GPS, sea ice map reading, tracking, satellite phones, etc.) • Mark dangerous spots on the land and ice and communicate to community • Increase capacity to treat accidental injuries locally ○ Resources/Leadership: Hamlet, Hunters and Trappers Committee, Health Centre, Helen Kalvak Elihakvik
10	Tools	

7.6 Building a Climate Change Action Plan for Wekweeti

1	Document Name	Building a Climate Change Action Plan for Wekweeti
2	Author	Ecology North
3	Year	
4	Type	Action Plan for Wekweeti
5	Subjects / Key words	
6	Scope	The document outlines the climate change risks to the community of Wekweeti, along with strategies and options for dealing with these risks. The document also considers any opportunities that may be presented by climate change.
7	General Data	Ecology North began developing climate change action plans for all Tlicho communities in 2008 and held a regional meeting with a Community Advisory Committee in January 2009. The Community Advisory Committee met with Ecology North staff four times throughout the action plan development to ensure they are representative of Tlicho values, culture and community priorities. Information was gathered using several techniques including Elders interviews and public meetings in each community, and research and consultation with experts. This CCAP specifically includes: • Potential impacts, sources of the impacts and adaptive strategies that are specific to the community as a result of climate change ○ Topics include thawing permafrost, unstable infrastructure, disrupted transportation, threatened food security, altered water quality and quantity, animal health and invasive species, and social and cultural impacts • Data gap noted for lack of detailed permafrost knowledge in Wekweeti area and Tlicho region; effect of permafrost on different types of infrastructure; appropriate and cost-effective construction technologies and techniques; and, capacity to construct permafrost-appropriate infrastructure • Data gap noted for lack of long-term climate and weather data for Tlicho region as a whole; includes: ○ Need climate modelling work for Tlicho region to assist with climate change planning ○ Need more data collection on weather in the Tlicho region – important for long-term trend analysis and for accurate and timely access to weather patterns by community members • Positive effects of climate change on the community – climate change opportunities, sources of opportunities and adaptive strategies • Recommended short-term implementation activities, as well as planning, partnership building, and awareness activities to be undertaken by Wekweeti, as well as actions requiring collaboration between Tlicho communities and different levels of government.

		Transportation impacts – effects on other sectors: • Infrastructure failures, such as damage to roads, could affect essential services like water delivery or sewage pump out • Use of potential contaminants to combat ice build-up becomes more frequent (e.g., salt, glycol) – potential impacts to surrounding environment • Shorter winter road season forces more air transport of food – causes increased food prices at local stores
8	Specific Transport Mode Info / Issues	<u>AIR TRANSPORT</u> • Runway integrity compromised from ground settlement due to degrading permafrost • Increased reliance on air transport increases cost of living; resulting from shorter winter road season due to warmer winter temperatures • Ice build-up on runways becomes more frequent due to increased freezing rain and warmer temperatures • Use of potential contaminants to combat ice build-up becomes more frequent (e.g., salt, glycol) due to increased freezing rain and warmer temperatures • Increased disruption of air transportation systems due to more extreme and unpredictable weather • Fire smoke disrupts air transport and travel on land due to more frequent forest fires <u>ROAD TRANSPORT</u> • Increased damage to roads (potholes, sinkholes, heaving, etc.) from degrading permafrost • Washout sections of roads due to increased spring run-off • Shorter winter road season due to warmer winter temperatures • Travel on land becomes more dangerous due to warmer weather, thin ice, less snow and more extreme and unpredictable weather • More stress and damage to vehicles due to poor road conditions (i.e., more potholes) • Driving conditions become more dangerous due to icy road conditions resulting from increased freezing rain and warmer temperatures • Fire smoke disrupts air transport and travel on land due to more frequent forest fires • Longer construction season due to longer summers (climate change opportunity) <u>MARINE TRANSPORT</u> • Travel by boat becomes more difficult and dangerous and traditional water transport routes may not be viable; resulting from changing water levels in streams and rivers, and possible formation or disappearance of small lakes and wetlands

9	Actions defined by sector	<u>AIR TRANSPORT</u> • Increase runway maintenance • Excavate permafrost if it is thin and sporadic • Increase capacity for air transportation (e.g., possibly consider a runway extension to accommodate larger aircraft) • Local production of food, goods and energy to limit need for imports • Construct over-land winter road • Use sand, gravel and de-icing agents • Assess potential environmental impacts of de-icing agents • Contain de-icing agents (e.g., glycol) after application for proper disposal • Immediately communicate bad weather to all communities, persons and businesses that might be affected • Engage in community forest fire planning and ensure the community's emergency plan is updated regularly <u>ROAD TRANSPORT</u> • Increase road maintenance • Excavate permafrost if it is thin and sporadic • Ensure proper drainage on and around roads • Manage snow build-up so spring melt does not impact roads • Local production of food, goods and energy to limit need for imports • Construct over-land winter road • Increase capacity for air transportation (e.g., possibly consider a runway extension to accommodate larger aircraft) • Make sure the community has people who can respond to emergencies (e.g., Canadian Rangers) • Increase vehicle maintenance • Use sand/gravel to increase traction and salt to combat ice build-up • Engage in community forest fire planning and ensure the community's emergency plan is updated regularly • Take the time to plan new infrastructure to withstand the effects of climate change (climate change opportunity) <u>MARINE TRANSPORT</u> • Consider finding new areas for harvesting or new ways of travel on the land
10	Tools	

7.7 Building a Climate Change Action Plan for Whati

1	Document Name	Building a Climate Change Action Plan for Whati
2	Author	Ecology North
3	Year	
4	Type	Community Action Plan
5	Subjects / Key words	
6	Scope	The document outlines the climate change risks to the community of Whati, along with strategies and options for dealing with these risks. The document also considers any opportunities that may be presented by climate change
7	General Data	Ecology North began developing climate change action plans for all Tlicho communities in 2008 and held a regional meeting with a Community Advisory Committee in January 2009. The Community Advisory Committee met with Ecology North staff four times throughout the action plan development to ensure they are representative of Tlicho values, culture and community priorities. Information was gathered using several techniques including Elders interviews and public meetings in each community, and research and consultation with experts. This CCAP specifically includes: • Potential impacts, sources of the impacts and adaptive strategies that are specific to the community as a result of climate change ◦ Topics include thawing permafrost, unstable infrastructure, disrupted transportation, threatened food security, altered water quality and quantity, animal health and invasive species, and social and cultural impacts • Data gap noted for lack of detailed permafrost knowledge in Whati area and Tlicho region; effect of permafrost on different types of infrastructure; appropriate and cost-effective construction technologies and techniques; and, capacity to construct permafrost-appropriate infrastructure • Data gap noted for lack of long-term climate and weather data for Tlicho region as a whole; includes: ◦ Need climate modelling work for Tlicho region to assist with climate change planning ◦ Need more data collection on weather in the Tlicho region – important for long-term trend analysis and for accurate and timely access to weather patterns by community members • Positive effects of climate change on the community – climate change opportunities, sources of opportunities and adaptive strategies • Recommended short-term implementation activities, as well as planning, partnership building, and awareness activities to be undertaken by Whati, as well as actions requiring collaboration between Tlicho communities and different levels of government. Transportation impacts – effects on other sectors: • Shorter winter road season forces more air transport of food – causes increased food prices at local stores • Use of potential contaminants to combat ice build-up becomes more frequent (e.g., salt, glycol) – potential impacts to surrounding environment
8	Specific Transport Mode Info / Issues	<u>AIR TRANSPORT</u> • Runway integrity compromised from ground settlement due to degrading permafrost • Increased reliance on air transport increases cost of living; resulting from shorter winter road season due to warmer winter temperatures • Ice build-up on runways becomes more frequent due to increased freezing rain and warmer temperatures

		• Use of potential contaminants to combat ice build-up becomes more frequent (e.g., salt, glycol) due to increased freezing rain and warmer temperatures • Increased disruption of air transportation systems due to more extreme and unpredictable weather • Fire smoke disrupts air transport and travel on land due to more frequent forest fires <u>ROAD TRANSPORT</u> • Increased damage to roads (potholes, sinkholes, heaving, etc.) from degrading permafrost • Washout sections of roads due to increased spring run-off • Shorter winter road season due to warmer winter temperatures • Travel on land becomes more dangerous due to warmer weather, thin ice, less snow and more extreme and unpredictable weather • More stress and damage to vehicles due to poor road conditions (i.e., more potholes) • Driving conditions become more dangerous due to icy road conditions resulting from increased freezing rain and warmer temperatures • Fire smoke disrupts air transport and travel on land due to more frequent forest fires • Longer construction season due to longer summers (climate change opportunity) <u>MARINE TRANSPORT</u> • Travel by boat becomes more difficult and dangerous and traditional water transport routes may not be viable; resulting from changing water levels in streams and rivers, and possible formation or disappearance of small lakes and wetlands
9	Actions defined by sector	<u>AIR TRANSPORT</u> • Increase runway maintenance • Excavate permafrost if it is thin and sporadic • Increase capacity for air transportation (e.g., possibly consider a runway extension to accommodate larger aircraft) • Local production of food, goods and energy to limit need for imports • Construct over-land winter road • Use sand, gravel and de-icing agents • Assess potential environmental impacts of de-icing agents • Contain de-icing agents (e.g., glycol) after application for proper disposal • Immediately communicate bad weather to all communities, persons and businesses that might be affected • Engage in community forest fire planning and ensure the community's emergency plan is updated regularly <u>ROAD TRANSPORT</u> • Increase road maintenance • Excavate permafrost if it is thin and sporadic • Ensure proper drainage on and around roads • Manage snow build-up so spring melt does not impact roads • Local production of food, goods and energy to limit need for imports • Construct over-land winter road • Increase capacity for air transportation • Make sure the community has people who can response to emergencies (e.g., Canadian Rangers) • Increase vehicle maintenance • Use sand/gravel to increase traction and salt to combat ice build-up • Engage in community forest fire planning and ensure the community's emergency plan is updated regularly • Take the time to plan new infrastructure to withstand the effects of climate change (climate change opportunity) <u>MARINE TRANSPORT</u>

		• Consider finding new areas for harvesting or new ways of travel on the land
10	Tools	

7.8 Creating a More Resilient Yellowknife: Climate Change Impacts and Municipal Decision Making

1	Document Name	Creating a More Resilient Yellowknife: Climate Change Impacts and Municipal Decision Making
2	Author	Pembina Institute (J. Pryor and P. Cobb)
3	Year	
4	Type	Community Action Plan
5	Subjects / Key words	
6	Scope	The document outlines the results of consultation with elected officials in Yellowknife and describes the development of risk management and evaluation tools, as well as a series of recommendations. The objective of the project was to develop the tools, capacity and decision-making processes necessary for the City to systematically address any community climate change impact as it emerges. The project aimed to provide a systematic and comprehensive review of how prepared the municipality is to make decisions on climate change adaptation.
7	General Data	Three half-day workshops were held for elected officials (decision-makers) to create a common understanding of climate change adaptation, engage participants in identifying impacts, develop risk assessment and decision-making criteria, identify how to add value to other processes, and identify decision-making triggers. Following the workshop and development of risk management and evaluation tools, the Pembina Institute developed a set of recommendations for the City's consideration in developing an implementation plan. This document specifically includes: • Methodology of the project, including rationale for the project and workshop objectives • Discussion on historic climate data for Yellowknife ○ Data available from 1940s to 2005 (and onward) ○ Increases in temperature (mean annual, mean winter, mean spring and mean summer), precipitation (mean annual, mean spring, mean summer and mean fall) • Discussion on anticipated future climate ○ 50-year horizon used ○ Climate change scenarios for Yellowknife obtained from Canadian Climate Impacts Scenarios (www.cics.uvic.ca/scenarios/) ○ Indicate shift of +2°C to +4°C in temperature, -5% to +23% change in precipitation • Climate change impacts and responses in the city ○ Identified observed climate change impacts and City responses to existing impacts ○ Discusses anticipated future climate change impacts • Best Practices and case studies ○ Discusses the decision-making process (types of decisions and identifying an approach) ○ Reviews case studies from other Canadian and international jurisdictions and municipalities who are engaged in climate change planning – adaptation tools being used and how other municipalities have tied climate change adaptation into programs and projects ○ Case studies include Toronto, Halifax, Iqaluit and Nunavut, London (UK), and other northern initiatives • Results of the workshops • Recommendations for the City of Yellowknife • Discussion on evaluation of the project and workshops Transportation impacts – effects on other sectors: • Economic challenges and opportunities of requiring design standards that take into account the

		uncertainty of the future climate
8	Specific Transport Mode Info / Issues	<u>ROAD TRANSPORT</u> - Observed impacts: - Longer construction season - Higher maintenance and construction costs for roads due to permafrost issues - Shorter ice road season resulting in increased air transport – social and economic impacts (on local carriers and aircraft noise) - Shore ice road season resulting in higher costs of flying goods in rather than trucking - Big snow dumps (especially in November) creating greater need for snow clearing services (increased costs, labour, equipment) - Icy roads requiring more maintenance - More freeze-thaw cycles - Anticipated impacts: - Increased road operation and maintenance costs – sanding, pot holes, shortening lifetime for surface - Increased infrastructure costs due to climate change (capital and O&M) - Challenge for budgeting on snow removal - More permafrost degradation - Increase costs for roads will make infill development more economical
9	Actions defined by sector	<u>ROAD TRANSPORT</u> - More resources – higher standards for building roads, etc. - Have guaranteed long term funding for adaptation - Developing smart growth – infill, density, zoning
10	Tools	

7.9 Gwichya Gwich'in Climate Change Adaptation Planning Project

1	Document Name	Gwichya Gwich'in Climate Change Adaptation Planning Project
2	Author	??
3	Year	
4	Type	Community Action Plan
5	Subjects / Key words	
6	Scope	The collaborative project drew knowledge and expertise from the community and technical experts in the Northwest Territories. A workshop with a Local Advisory Committee (LAC) was held to discuss climate change adaptation. The outcomes of the workshop were further developed to complete a risk assessment analysis of potential impacts and provide recommendations.
7	General Data	The document includes: • Background on climate projections for Inuvik area and a potential climate scenario for Tsiigehtchic to 2050 • Climate change impacts are organized into six broad landscape level categories – seasonal and weather changes, changes to flooding regime, changes to forest fire regime, changes to wildlife, permafrost degradation, and water quality • Results of the LAC workshop and corresponding results of the risk assessment, including priority ratings of impacts, • Opportunities arising from climate change • Recommended adaptations to mitigate effects of climate change • Lack of monitoring data was brought up – see it as crucial for developing baseline data and determining change ○ Encourage Gwich'in Tribal Council and INAC to map and monitor landslides in the Gwich'in Settlement Area ○ Develop linkages with scientists, DFO and local harvesters to monitor breeding times, invasive species, population trends and water quality. Ensure this information is available widely. ○ Work closer with ARI to bring scientific study results back to the community.
8	Specific Transport Mode Info / Issues	<u>AIR TRANSPORT</u> • Concern about fuel leaks at helipad fuel storage site (??) <u>ROAD TRANSPORT</u> • More difficult and dangerous travel on the land • Municipal drainage issues result in flooding and road erosion <u>MARINE TRANSPORT</u> • Longer open water season and shorter ice season will affect ferries and ice roads • Potential greater variability in river flows (Mackenzie) could affect ferry service to the community (lower water levels in the fall) •
9	Actions defined by sector	<u>AIR TRANSPORT</u> • Work with DOT to ensure fuel is stored safely at the helipad <u>ROAD TRANSPORT</u> • Provide safe snowmobiling lessons in school (Medium priority) • Hamlet to Develop Municipal Drainage Plan as per Tsiigehtchic Land Use Plan

		(Medium/High priority) • Potentially install larger culverts (Medium/High priority) • Develop a desktop level Community Permafrost Map to inform future land use and development <u>MARINE TRANSPORT</u> • Obtain a new ferry, better for ice-breaking (Low/Medium priority) • Construct a pier to improve the ferry landing (Low/Medium priority) • Work with the DOT on a ferry landing study (Low/Medium priority) • Mapping of sandbars on river (Medium priority) ○ Already undertaken by DOT and INAC but could better communicate with community
10	Tools	

8 LIST OF LITERATURE IDENTIFIED

Possible Additional documents:

AMAP, 2011. Snow, Water, Ice and Permafrost in the Arctic (SWIPA): Climate Change and the Cryosphere. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. xii + 538 pp.

Furgal, C. and Prowse, T.D. 2008. Northern Canada: in From Impacts to Adaptation: Canada in a Changing Climate. 2007, edited by D.S. Lemmen, F.J. Warren, J. Lacroix and E. Bush. Government of Canada, Ottawa, pp. 57 – 118

Hayley, D.W., (2005). Northern Transportation Infrastructure Construction and Operation Challenges, Northern Transportation Conference, Yellowknife. www.vanhorne.info/NT%20Conference%202005.htm

Holubec, I. 2007. Design requirements for climate warming in permafrost. Presentation at Yellowknife Symposium, May 24, 2007.

LeBouthillier, S., (2005). Climate Change in the NWT-A Transportation Perspective, Northern Transportation Conference, Yellowknife. www.vanhorne.info/NT%20Conference%202005.htm

Throop, J. , Smith, S.L., and Lewkowicz, A.G., 2010. Observed recent changes in climate and permafrost temperatures at four sites in northern Canada. Proceedings, 6th Canadian Permafrost Conference/63rd Canadian Geotechnical Conference, Calgary AB. pp. 1265 – 1272.

Woo, M.-K., Mollinga, M. And Smith, S.L. 2007. Climate warming and active layer thaw in the boreal and tundra environments of the Mackenzie Valley. Canadian Earth Sciences Journal, 44: 733 – 743.

Document List to June 8, 2012

Climate Related	Reviewed using Template
Rio Tinto CC Adaptation Project – Appendix X-8 Climate Projections - “Climate Change Impacts in the Diavik Region of Northern Canada	
Arctic Climate Impact Assessment (ACIA) Ch. 2 Arctic Climate Past and Present	
ACIA Ch. 4 Modelling and Scenarios	
IPCC Working Group 2 (WGII) AR4 2007 Global Climate Projections – Particularly Sections 10.5.1 (sources of Uncertainty) and 10.6 – Sea Level Change	
IPCC WGI AR4 2007 REGIONAL Climate Projections – Particularly sections 11.5 North America, 11.8 .1 Polar (Arctic) Regions	
AULD Yellowknife Oct 4-2011 PPT	
Climate Information for Engineering Decisions. Giselle Bramwell. April 19 (PPT file)	
General Background Info on Northern Adaptation	
TAC – Guidelines for Development and Management of Transportation Infrastructure within Permafrost	Y

Regions – 2010 – 177pg	
Pan-territorial – undated PowerPoint – YTG, GNWT, GN – 32 pg	
With respect... - Senate Ctee report – May 2009 – 3 sections; 1 on climate change – 36 pg	Y
Permafrost, Climate Change & the Environment, Kokelj-DOT_SVK_2010.ppt - 51 slides	Y
Permafrost: The Ground is Literally Melting Beneath our Feet – Appendix A: Community Survey Results. NWTAC	Y
True North – Nat'l Round Table - 2009 - risks to northern (YT, NWT, Nunavut) infrastructure and opportunities for adaptation – 160 pg	Y
Transportation: General or Multiple Modes	
Climate Change and Transportation - Dillon for DOT – Mar 2007 - modeling for some communities and about 10 pages on adaptation, best practices etc. with a table of risks – 240 pg	Y
NWT Climate Change: Impacts and adaptation – ENR - 2008 – 31pg	
Adapting to Climate Change in the NWT 2008 Final.ppt – 24 slides	Y
DOT Risk Assessment – Stantec for DOT – workshop report – 2010 – 58 pg	Y
Green Light – DOT – undated – policy statement about commitment to env't; mentions climate change – 16 pg	Y
Impacts to adaptation – GC- 2007 – pg 57-118	
TRB - Adapting Transportation to the Impacts of CC.pdf – 64 p.	Y
On the Front Lines of Climate Change PDF 34 pg	
Sturm et al. Climate PPT Presentation – Arctic Mining and Oil Exploration PDF 35 slides – Good Ice Road info re: NWT, discussion of current and potential adaptations	
AULD Yellowknife Oct 4-2011 PPT – good climate summary and discussion of potential impacts to northern transport	
Engineers Perspective on Alaska CC (PDF of PPT)	
Potsdam Institute- Adaptation_to_climate_change_in_the_transport_sector (PDF)	
Inland Transport and CC - Lit Review Report (PDF)	
Alaska-DecisionMakingForCommunitiesAtRisk.pdf	
Transportation in Cold Regions - RAIL Emphasis - Ferrell_MS_Report (PDF)	
GIANSPRshort_07282010.doc – 4pg - General Ground Transport Infra and Permafrost	
http://ine.uaf.edu/accap/research/cryosphere_hazards.htm	
Literature Review Climate Change Adaptation _Oswald_090728	
Managing the risks of.. guide for northern communities - CIER (Centre for Indigenous Environmental Resources) – undated - 63pg (v 1); 40pg (v 2)	
Marine/Ferry/Shipping Related	
Hay River Water Depths Final Sep Edit.pdf - 21pg	Y
TRB - Adapting Transportation to the Impacts of CC.pdf – 64 p.	
Western Arctic Access Routes Final Sep Edit.pdf – 42pg	Y
Roads	
Hwy 3 Climate Vulnerability Report - BGC Engineering for DOT – Final report; August 2010 – follows PIEVC assessment protocol for highway 3	

Climate_Change_And_Canadian_Mining.pdf – 160 pg - Focus on:	
TAC 2008 McGregor Hassan Hayley, Climate Change Canadian Roads.docm – 14pg	Y
V33101019 Willow River Gravel Source Access Road Planning St.pdf – 77pg	Y
Y14101219 Documentation of Tuktoyaktuk to Source 177 Site Visit.pdf – 10pg.	Y
Guidelines for the Construction and Operation of Winter Roads, Final Report, Transportation Association of Canada.	Y
Highways and Climate Change - Climate Change Vulnerability Assessment, Risk Assessment, and Adaptation Approaches – FHWA	
Air Transport	
Runway Vulnerability Protocol.docx – 35pg	Y
Inuvik Airport Geophysics Investigation.docx – 11pg	Y
TRB - Adapting Transportation to the Impacts of CC.pdf – 64 p.	Y
Airport Terrain Analysis_Submitted.pdf – 21 pg	Y
Community Climate Adaptation Plans	
Climate Change in the Tlicho Region: Scientific and Local Findings	Y
Building a Climate Change Action Plan for Behchoko	Y
Climate Change Adaptation Action Plan, Community of Paulatuk, Northwest Territories	Y
Things Change, We Change: Planning for Community Resilience in Tuktoyaktuk – Part II – A Community Climate Change Adaptation Plan	Y
Climate Change Adaptation Action Plan, Community of Ulukhaktok, Northwest Territories	Y
Building a Climate Change Action Plan for Wekweeti	Y
Building a Climate Change Action Plan for Whati	Y
Creating a More Resilient Yellowknife: Climate Change Impacts and Municipal Decision Making	Y
Gwichya Gwich'in Climate Change Adaptation Planning Project	Y