

Communications, Infrastructure and Transportation Systems in the Canadian North:

Recent Advances and Remaining Knowledge Gaps and Research Opportunities

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Abstract and Methodology

This summary presents research gains, gaps and opportunities related to communications, infrastructure and transportation systems that have been gathered by the Canadian Polar Commission in fulfillment of its mandate to monitor and communicate polar knowledge in Canada and around the world. It is focused on the Canadian North, comprising the Yukon, Northwest Territories, Nunavut, Nunavik, and Nunatsiavut, during the seven-year period beginning with the International Polar Year (IPY) in 2007. The following observations are organized under recent advances and knowledge gaps and research opportunities. They are based on semi-structured interviews with northern housing research experts and practitioners, which have been supplemented and validated with both peer-reviewed and 'grey' literature.

Overview

- Infrastructure, including water, wastewater, schools, hospitals, community centres, airports, roads, and marine infrastructure, has been identified as a key priority facing the North (Northern Development Ministers Forum, 2010). While it is needed to encourage and support economic development, it is also essential to the delivery of services and the movement of people and goods including food, energy, building materials and other supplies (Government of Yukon et al., 2008; Northern Development Ministers Forum, 2010). This is especially true for smaller, more remote communities that rely on marine and air access (Government of Yukon et al., 2008).
- Many northern communities lack sufficient infrastructure and may have insufficient access to adequate and reliable drinking water and sewage disposal methods, which can be negatively impacted by climate change (Martin et al., 2007; Goldhar et al., 2012; Gunnarsdóttir et al., 2013). There are a number of implications of inadequate infrastructure in smaller northern communities that can challenge their sustainability, including a higher cost living, difficulty staffing offices in these communities, difficulty accessing adequate health care and education, and difficulty attracting and supporting economic development activities.
- Communications infrastructure and telecommunications services are important in the North in areas such as government operations, transportation navigation, emergency response, economic development, education, healthcare, and the delivery of other services (Kativik Regional Government & Makivik Corporation, 2010; Imaituk, 2011; Fiser, 2013). The gap in the level of communications service between the North and southern Canada is, however, growing (Imaituk, 2011). There is a shortage of affordable bandwidth, frequent network outages, and scalability challenges (Kativik Regional Government & Makivik Corporation, 2010; Imaituk, 2011; Fiser, 2013). As well, there is inadequate geographic coverage in some areas, including along many roads in the Yukon and NWT (Imaituk, 2011).
- With respect to transportation, Yukon relies on highways, winter roads and air; the Northwest Territories relies on highways, winter roads, rail, air and marine; and Nunavut, Nunavik, and Nunatsiavut rely on air and marine access (Government of Yukon et al., 2008; Kativik Regional Government & Makivik Corporation, 2010; Goldhar et al., 2012). More localized transportation methods such as boats, ATVs or snowmobiles, which are used to travel between communities and access hunting areas, are being impacted by climate change (Ford et al., 2010; Bolton et al., 2011).
- With reduced sea ice, there is the potential for increased marine traffic from shipping, tourism, and resource development activity, with implications for transportation infrastructure, the marine environment and emergency management capacity with respect to human safety and environmental disasters (Arctic Climate Impact Assessment, 2004; Government of Yukon et al., 2008; Prowse et al., 2009; Smith & Stephenson, 2012).
- Much of the existing infrastructure in the North including buildings, transportation systems and municipal infrastructure is underdeveloped, aging, in need of repair and/or expansion to support current and future use, especially in terms of encouraging and sustaining resource development activities, and to reduce the

extent to which deterioration is occurring. Upgrades are also needed to ensure compliance with new and evolving standards and regulations (e.g. security, safety) (Government of Yukon et al., 2008). For example, many airport runways in Canada's North are unable to accommodate more efficient and cost effective newer-generation aircraft because they are outdated and unpaved (Weber, 2013).

- There is a reliance on federal grants to fund large infrastructure projects (Northern Development Ministers Forum, 2010). In the case of small communities that have limited access to employment opportunities, it is difficult to implement and rely on user fees to establish and sustain community infrastructure that requires high capital costs (e.g. arenas) as a cost-recovery method, especially if it reduces accessibility. As well, infrastructure and associated research and development needs often exceed available funding.
- Poor human practices in terms of infrastructure design, construction, and maintenance that have not been appropriately adapted to the northern environment, sometimes as a result of the lack of knowledge of permafrost conditions, are triggering problems related to infrastructure settlement, and are aggravated by climate warming (Allard et al., 2012). In many areas of the North, there has been a reliance on, or insufficient attention given to permafrost, snow and ice in relation to infrastructure stability (National Round Table on the Environment and the Economy, 2009). Understanding of the current and future state of Canada's northern environment and the associated impacts is, therefore, essential given the implications for the design, operation, and maintenance of infrastructure, in order to ensure that existing and planned infrastructure and related activities can be appropriately adapted (Instanes, 2005; Prowse et al., 2009). In terms of infrastructure, permafrost degradation; warmer temperatures, changing precipitation patterns, and weather extremes; flooding and stream flow change; sea-ice loss and coastal erosion; and wildfires are of significant concern (National Round Table on the Environment and the Economy, 2009). Rapidly thawing permafrost is impacting the reliability, stability and durability of northern infrastructure (Government of Yukon et al., 2008; Allard et al., 2012). Changing sea ice patterns and rising sea level is increasing the likelihood of storm surges that can cause damage to coastal infrastructure (Instanes, 2005; Government of Yukon et al., 2008).
- Capacity is a challenge as a result of small populations spread across vast geography and limited skill sets. Construction and repair techniques might not be transferred locally, and it is difficult to adopt new technology solutions as the associated servicing costs (for materials, equipment, transportation, etc.) can sometimes outweigh the benefits. It is also challenging to secure qualified and experienced individuals to plan, deliver, operate and maintain infrastructure in the North (National Round Table on the Environment and the Economy, 2009).
- It is difficult to adequately maintain infrastructure given the high cost of materials, lack of capacity, and accelerated wear as a result of intensity of use and the harsh northern environment. It can be difficult, especially for small, remote communities, to access funding for maintenance, which can result in deferred maintenance, and in turn an increased infrastructure deficit (National Round Table on the Environment and the Economy, 2009; Northern Development Ministers Forum, 2010).

- There is often reliance on research and development from southern-based institutions, which can be inappropriate and difficult to apply in a northern context. It is important to develop northern infrastructure solutions from a holistic perspective with community consultation, incorporating cultural, health, social, economic, and environmental considerations in order to facilitate sustainability.

Recent Advances

- The 2009 Report by the National Round Table on the Environment and the Economy (NRTEE), *True North: Adapting Infrastructure to Climate Change in Northern Canada* highlighted risks of climate change to northern infrastructure and provided several related key findings, including limited interaction between stakeholders (including scientists, designers, builders, and policy-makers) when identifying problems and applying solutions; inadequacy of national codes and standards in a northern context; gaps in data and information availability and accessibility to inform risk management (e.g. projections of climate change impacts and demand for infrastructure); and lack of capacity to assess and respond to risks of climate change (National Round Table on the Environment and the Economy, 2009). In response, the Standards Council of Canada is overseeing the Northern Infrastructure Standardization Initiative, with support from Aboriginal Affairs and Northern Development Canada, to incorporate climate change impact considerations in building codes and standards. The CSA Group will be developing standards under this initiative in the following four areas: design, installation and maintenance of thermosyphon foundations; changing snow loads on roofs; managing effects of permafrost degradation on existing buildings; and community drainage plans (Standards Council of Canada, 2012; CSA Group, 2012).
- The Public Infrastructure Engineering Vulnerability Committee (PIEVC) Engineering Protocol, a risk assessment procedure/tool completed in 2008, was applied in the assessment of some facilities in the territories with flat loop thermosyphon foundations in warm permafrost (I. Holubec Consulting, 2008) and of NWT Highway 3 (BGC Engineering, 2011) to assist in projecting “the nature, severity and probability of future climate changes and events” to identify adaptive measures (Engineers Canada, 2013). Recommendations included ensuring that there is baseline documentation to support monitoring and future studies, and preparing guidelines to facilitate “the collection of data, design, construction, operation, maintenance and monitoring of thermosyphon foundations” (I. Holubec Consulting, 2008; BGC Engineering, 2011).
- In addition to highlighting priority infrastructure needs including roadwork, water/wastewater, electricity, and broadband, the 2010 *Northern Infrastructure* report released by the Northern Development Ministers Forum (NDMF) also provides an overview of infrastructure challenges, best practices, and current and potential sources funding for infrastructure initiatives. The report also notes community buy in, long term planning, and private sector engagement and partnerships as best practices with respect to infrastructure development and maintenance (Northern Development Ministers Forum, 2010).

- There is better understanding of permafrost degradation processes and the factors that aggravate or accelerate these processes. As well, some adaptation methods have also been explored in terms of building techniques, land use planning, and delivery of municipal services. For example, the Salluit community in Nunavik has benefited from this, with the potential for lessons learned to be applied in other communities in response to permafrost degradation issues (Natural Resources Canada, 2007; Allard et al., 2012).
- Hazard/ landscape mapping has been undertaken in some communities in the Yukon, Nunavut and Nunavik, including permafrost characterization and surficial geological mapping, to support community infrastructure planning and adaptation (Kennedy & Kinnear, 2010; LeBlanc et al., 2011; Gibéryen & Allard, 2011).
- The Arctic Development and Adaptation to Permafrost in Transition (ADAPT) program involves the development of an Integrated Permafrost Systems Science framework that aims to take into account the impact of permafrost and snowfall changes on land and water to in turn inform permafrost engineering and sustainable adaptation strategies (Université Laval, 2011).
- The 5-year Arquluk Permafrost Program which began in 2012 is targeting the development of cost-effective solutions for the design and management of road, airstrips and railways constructed on permafrost. The program aims to increase understanding of factors contributing to permafrost degradation under transportation systems, improve investigative techniques for identifying sensitive permafrost, and develop engineering tools to support design and management of transportation infrastructure in northern Canada (Yukon College, 2012).
- With respect to building science, vacuum insulation panels (VIPs), which are up to ten times more energy efficient than traditional insulating materials, have been tested in Whitehorse, YT in order to inform adaptation to arctic construction, with initial observations demonstrating reduced heat loss (National Research Council, 2011).
- The GNWT publishes regular Reports on Drinking Water, which provide an overview of initiatives underway pertaining to drinking water quality, and information regarding community drinking water systems. For example, the Slave River and Delta Partnership was formed in 2010 among community members, Aboriginal groups and governments, environmental NGOs, academics and the territorial and federal government to conduct a vulnerability assessment and identify monitoring priorities (Government of the Northwest Territories, 2011).
- Research in two Nunatsiavut communities highlighted the need to monitor water quality and weather conditions. It was also noted that lake water was more contaminated than running water, and that containers used to store water should be disinfected regularly (Martin, 2008).
- Research in Nunavik and Nunatsiavut has increased understanding of the relationship between weather, water quality and occurrence of infectious gastrointestinal illnesses, and highlighted the need for enhanced capacity to manage and monitor both public and private water sources and treatment systems, systematic collection of baseline information through community participation, and

greater awareness of risks associated with drinking untreated water (Martin et al., 2007; Harper et al., 2011).

- A 2009 report released by Ecology North provided an assessment of potential impacts of climate change on water and wastewater systems in the NWT and identified ways in which the capacity of communities in the NWT might be strengthened to enable adaptation, which included conducting site-specific vulnerability assessments and implementing source water, wastewater and landfill leachate monitoring programs (Ripley, 2009).
- The Centre for Alternative Wastewater Treatment examined existing wetland treatment systems for wastewater in six Nunavut communities in the Kivalliq Region including their performance and efficacy, and how engineered constructed wetland treatment systems could function in an Arctic environment to inform design models. Some of the key gains from this initiative included the determination of an optimal treatment period for wastewater in the Region; better understanding of the performance of these systems to inform compliance reporting and regulatory standards; the development of a pilot constructed wetland in Baker Lake, NU; and the development of the Subsurface Wetland Model software SubWet 2.0 with the United Nations Environmental Programme to support decision makers when modeling and sizing wetlands for wastewater treatment in an Arctic environment (United Nations Environmental Programme, n.d.; Centre for Alternative Wastewater Treatment, 2013).
- A municipal wastewater management research program is underway until 2015 between Dalhousie University and the Government of Nunavut, which involves environmental monitoring programs in six communities. It aims to examine the performance of current wastewater treatment systems (lagoon and wetland) and risks to human and environmental health to identify cost-effective sewage management approaches that comply with Environment Canada's new Wastewater Systems Effluent Regulations (which include National Performance Standards), and inform wastewater treatment standards for Canada's North (Krkosek et al., 2012; Jamieson & Krkosek, 2013).
- *Cold Regions Engineering 2012: Sustainable Infrastructure Development in a Changing Cold Environment* details recent knowledge gains with respect to civil engineering (geotechnics, transportation, pavements, structure, rivers and ports, and water management) in cold regions (Morse & Doré [Eds.], 2012).
- Federal, territorial and provincial governments have recently undertaken important research initiatives to improve knowledge of permafrost, the factors affecting its stability, and appropriate methods of construction on unstable permafrost. This research, which was conducted through simulation with the help of numerical models, laboratory experimentation and/or on-the-ground experimentation, is informing the improved performance and durability of infrastructure. Some monitoring and adaptive measures have been put in place in response to climate change impacts on infrastructure. In response to foundation issues resulting from permafrost degradation, for example, the GNWT's Department of Public Works and Services installed a series of thermistors under facilities that were identified as high risk in order to monitor ground temperatures and facilitate the tracking of building

movement. The Ministère des Transports du Québec implemented a monitoring program and related research projects to understand, predict, and quantify the impacts of thawing permafrost on airport infrastructure in Nunavik, and identified adaptation and stabilization techniques that can be used (Boucher & Guimond, 2012). Experiments with several techniques have been undertaken on a portion of the Alaska Highway to assess potential in reducing or preventing permafrost degradation under road embankments. Several of these techniques, including air convection ducts, an air convection embankment and a sun shed have demonstrated good early performance (Coulombe et al., 2012; M-Lepage & Doré, 2012).

- A number of guides have been developed to communicate best practices. For example, the Transportation Association of Canada's *Guidelines for Development and Management of Transportation Infrastructure in Permafrost Regions* synthesize best practices to assist individuals who are involved in the development, planning, design, construction, maintenance and rehabilitation of transportation infrastructure in permafrost regions (Transportation Association of Canada, 2010). The GNWT's Department of Public Works and Services released *Good Engineering Practice for Northern Water and Sewer Systems* and *Good Building Practice for Northern Facilities* to assist those are involved in the design, construction and operation of infrastructure in a northern context to encourage the use of proven methods and materials, while supporting improved building performance and new technology (Public Works and Services – Government of the Northwest Territories, 2004 & 2011).
- The 2011 *Arctic Communications Infrastructure Assessment* examined issues and challenges associated with connectivity in the Canadian Arctic, including lack of choice for consumers, ensuring adequate geographic coverage, keeping pace with technological change, addressing the growing gap in service levels and associated costs both within the North and between the North and southern Canada, and addressing a human resources gap. It also included a look at strategies used by regulators and governments in other jurisdictions such as setting a minimum level of service. Recommendations were also made, including committing to a service parity and minimum connectivity standards for Arctic communities and ensuring that investment models allow and encourage competing services to promote choice and innovation (Imaituk, 2011). The 2014 report *Northern Connectivity: Ensuring Quality Communications* was commissioned by the Northern Communications Information Systems (NCIS) Working Group to develop an implementation plan to address recommendations from the 2011 *Arctic Communications Infrastructure Assessment* to improve the quality of communication services in the North, in consideration of user needs, network infrastructure and technology, financial sustainability and economic impact. The report recommends “a minimum broadband target speed and service standards for northern households, businesses and governments” of 9 Mbps download and 1.5 Mbps upload in the territories. Four backbone (or base network) options were developed along with cost estimates for third-party service providers for operation, maintenance, and the sale of services. It was found that a financial incentive payment for a third-party service provider

would likely be required, as well as a recurring annual subsidy for every low-income household (Nordicity, 2014).

- A 2013 Centre for the North report examines long-term options with respect to connectivity in Canada's North. Report recommendations include increasing capital investments, addressing IT capacity challenges, improving network diversity and redundancy, examining the relevancy of a northern subsidy for residential broadband services, carefully considering the implications of regulatory decisions on incumbent carriers and competitors in terms of their investment in next-generation networks, developing more Aboriginal content, and providing more support for digital literacy (Fiser, 2013).
- The 2009/10 Nunavut Housing Needs Survey, which included questions regarding residential Internet and phone access, was administered door-to-door and provided more complete information regarding household broadband adoption in Nunavut (Nunavut Bureau of Statistics, 2010). A broadband socioeconomic impact assessment was undertaken in 2011 to establish a baseline against which social and economic impacts of broadband access and use in Nunavut could be measured (Strategic Networks Group, 2012).
- A needs analysis was undertaken by the Nunavut Broadband Development Corporation to better understand current and future bandwidth needs for personal and work use and inform its business plan for broadband services in Nunavut. In terms of personal use, it was found that while people rely on the internet for online banking and for obtaining and submitting government information, not many people use it for communicating in Inuktitut or sharing cultural knowledge. In terms of work use, it was found that document collaboration is a key tool used to share information and build capacity, that large file transfers are common, and that there is a need for more targeted support for aggregate marketing and associated capacity development. It was also found that more knowledge is needed to support more effective planning and use of bandwidth in a satellite context (Nunavut Broadband Development Corporation, 2008).
- Research examined the impact of information and communication technology (ICT) on social capital in Aboriginal communities through case studies which included the Qiniq network in Nunavut. It was found that the way in which ICT community networks are developed and implemented can have an influence on a community's social capital, and that community ownership and implementation of ICT networks is essential to successful implementation. The role of government was also highlighted including providing adequate and reliable funding, and establishing legislation that "levels the playing field for community enterprises vis-à-vis private corporations" (Mignone & Henley, 2009).
- McMahan et al. examined broadband use in First Nations and Inuit communities in the areas of health and wellness, education, culture and language, economic development and government, including community-based broadband projects and federal broadband initiatives. Challenges with existing government initiatives were outlined such as lack of support for community-based initiatives and use of short-term and project-based funding models, as well as ways in which 'first mile oriented broadband infrastructure' (i.e., broadband infrastructure and connectivity

development arising from the needs and context of local communities) can be supported, such as recognizing remote community realities and supporting local engagement (McMahon et al., 2010).

- Fiser examined the distribution of broadband availability (no broadband infrastructure, limited broadband, or residential internet access) and of access management models (third-party commercial, indigenous commercial, indigenous social enterprise, or First Nations authority) in Aboriginal and northern communities. In addition to Incumbent Local Exchange Carriers (ILECs) and other third party commercial providers, Indigenous social enterprises are noted as important players in some remote and northern Aboriginal areas that are considered to be high-cost serving areas (Fiser, 2010).
- A study was conducted to better understand the feasibility of establishing a high capacity network in Nunavik, including cost and timeframe, with feasible technologies identified as an undersea optical fibre network, a microwave tower network, and a high capacity satellite network. This study found that a high capacity network is feasible in Nunavik, and that it would be more cost efficient than Nunavik's current network (Salter Global Consulting Incorporated, 2013).
- A fibre optic feasibility study was conducted for Nunavut which included a review of technologies, landing points, potential impacts including socioeconomic impacts, and private public partnership models, with associated recommendations for implementing and financing the network (Salter Global Consulting Incorporated, 2012).
- A study was conducted to examine the feasibility of establishing a high-speed fibre optic link from Fort Simpson to Inuvik, NT, and of extending this to Tuktoyaktuk, NT. It was found that it would be technically feasible, with government investment required, and the opportunity for private sector contribution and long-term economic and social development related benefits (Salter Global Consulting Incorporated, 2011).
- In 2008, the territorial governments jointly released *Northern Connections: A Multi-Modal Transportation Blueprint for the North*, which provided an overview of the current transportation system and associated challenges, with a vision for future transportation infrastructure development to support economic development and connect northern communities (Government of Yukon et al., 2008).
- The Centre for the North's 2011 report *Northern Assets: Transportation Infrastructure in Remote Communities* identifies policy issues and areas pertaining to northern transportation infrastructure that require further research (Bristow & Gill, 2011).
- Arctic Maritime and Aviation Transportation Infrastructure Initiative (AMATII), conducted under the Arctic Council's Sustainable Development Working Group, involves the assessment of the current state of Arctic marine and airport infrastructure in consideration of future needs with respect to community development, resource development, search and rescue capability and environmental disaster response to identify gaps and provide guidance with respect to the effective and prioritized application of resources to address gaps (Institute of the North, 2011).

- Transport Canada commissioned a Northern Transportation System Assessment in 2011 to estimate and assess the demand for sealift, inland marine, highway transport systems, air passenger and cargo systems that is needed over the next 20 years and the improvements that would be required to support development in the North (Prolog Canada, 2011).
- Research has been undertaken in the NWT to plan for the construction (which began in 2013) of an all-weather road from Inuvik to Tuktoyaktuk, including an economic analysis and risk assessment. Reports are available on the GNWT Department of Transportation website, along with the final report prepared by the Environmental Impact Review Board (EIRB) regarding biophysical and socio-economic impacts (Department of Transportation – Government of the Northwest Territories, n.d.).
- Transport Canada established a Network of Expertise in Northern Transportation Infrastructure Research and a Network of Expertise on Transportation in Arctic Waters. These networks, which are composed of experts from governments, academia and the private sector, are in place to promote information sharing, foster and facilitate collaboration between the research community and northern-based practitioners, and identify priority needs. They are also used as a source of advice regarding potential projects to be supported under Transport Canada’s Northern Transportation Adaptation Initiative (NTAI), which offers grants and contributions to support the collection of baseline data and data modeling for transportation infrastructure, climate change vulnerability assessments, capacity building initiatives and development, and the evaluation and testing of tools, technologies and best practices (Transport Canada, 2012a & b).
- Potential alternative modes of transportation have been considered (Bristow & Gill, 2011). For example, a paper by Prentice et al. explored the potential for airships in Canada’s North as a way to transport freight and passengers, noting that the associated technology would require further development (Prentice et al., 2005). As well, the potential for airships to support wildlife research and management has also been identified (Dick & Gallagher, 2005).
- Brooks & Frost examined and compared shipping services to remote Arctic communities in Nunavut and Greenland and associated management practices to identify ways in which services might be provided more cost-effectively on the part of vessel operators and government departments. It was noted that there is a more fragmented approach and lack of investment in terms of freight services operations in Nunavut. The need to remove the duty for the temporary importation of vessels was noted as a way to potentially encourage new investment in domestic shipping and in turn lower vessel capital costs and freight rates for Nunavut (Brooks & Frost, 2012).
- The 2009 *Arctic Marine Shipping Assessment* released by the Protection of the Arctic Marine Environment (PAME) Arctic Council working group provided better understanding of the current and future use of ships in the Arctic Ocean and the potential impact, both for humans and the environment, as well as the marine infrastructure that will be required as a result. Some of the key findings of this assessment included that there is a lack of marine infrastructure; that the costs and

benefits associated with increased shipping will likely be unevenly distributed; and that there are numerous potential environmental impacts including ship emissions, oil spills and disruption of marine mammal migration which can impact hunting practices (Arctic Council, 2009).

- Lasserre & Pelletier examined the interest of shipping companies in maritime transport in the Arctic to better understand whether or not marine traffic will in fact increase with the melting of sea ice. It was found that there was not much interest among container shipping firms, but that there was reasonable interest among bulk shipping firms in terms of destination traffic (Lasserre & Pelletier, 2011).
- The 2012 *Oil Spills in Arctic Waters* white paper published by the United States Arctic Research Commission, which includes an inventory of 203 research projects related to oil spills in the Arctic, notes that foundational research has been undertaken regarding the behaviour and fate of oil in ice-covered waters which can be used to inform applied research and engineering designs to reduce the risk of an oil spill and develop improved techniques for oil spill response and recovery (United States Arctic Research Commission, 2012).
- The 2011 report *Behaviour of oil and other hazardous and noxious substances (HNS) spilled in Arctic waters (BoHaSA)* released by the Arctic Council's Emergency Prevention, Preparedness and Response Working Group outlines what is known about the behaviour of these substances in Arctic waters in terms of the transport, production and storage of oil and HNS; risks of oil and HNS spills; and past incidents including behaviour of spills and response (Singsass & Lewis, 2011).
- The National Research Council publication *Avoiding the next Titanic: Are we ready for a major maritime incident in the Arctic?* highlights some of the research that has been conducted to examine and test the adequacy of thermal protective equipment and preparedness such as life rafts, life boats, and immersion suits to identify minimum criteria required for survival and inform survival prediction tools (Boileau et al., 2010). Work is being undertaken by Canadian and international governments, universities and companies to examine current thermal protective equipment and preparedness in order to improve safety and inform regulations. This includes conducting clothing ensemble testing with thermal manikins and with human subjects and a physiology experiment that involves the testing of sustainable shivering duration in order to simulate survival scenarios (Mak et al., 2011).

Knowledge Gaps and Research Opportunities

- There is a need for improved climate data and projections that can be used to inform infrastructure planning, design, construction, maintenance and operations (National Round Table on the Environment and the Economy, 2009; Ford et al., 2010; Bolton et al., 2011; Bristow & Gill, 2011; Allard et al., 2012); improved baseline data (e.g. maintenance practices, problematic areas on highways, etc.); and ongoing monitoring to better identify and assess impacts of climate change and human practices on infrastructure, and evaluate the effectiveness of response measures and adaptation efforts (Prowse et al., 2009; BGC Engineering, 2011).

- There is a need for more ground temperature reference data that is accessible, complete, and up-to-date to support the design of infrastructure and monitor the impacts of climate warming on permafrost (I. Holubec Consulting Inc., 2008).
- Continued assessment of the current and future vulnerability of infrastructure is needed, with consideration of climate projections and human use and practices, and research to inform a risk-based management approach (e.g. assessment of the risks to human or environmental health in terms of likelihood and magnitude of impact) to inform and prioritize appropriate investment options (e.g. upgrade, adjust maintenance practices, etc.) that achieve value for money (I. Holubec Consulting Inc., 2008; Bolton et al., 2011; Bristow & Gill, 2011; BGC Engineering, 2011; Allard et al., 2012). There is a strong need for further applied research that can identify practical measures that can be taken by planners, builders, and operations and maintenance personnel to appropriately adapt existing and future infrastructure in response to what is known about current and predicted demand for infrastructure and impacts of the changing northern environment (National Round Table on the Environment and the Economy, 2009).
- Further research is needed to enhance understanding of the effects of human activities on permafrost, and improve methods of detecting and characterizing permafrost that is vulnerable to these effects in order to support the planning of infrastructure for development and for community use in a way that minimizes impact on permafrost. Enhanced permafrost maps and permafrost characterization are also needed to support infrastructure planning (Allard et al., 2012), risk assessments and adaptation plans for communities situated on permafrost. Further research is also needed to improve design, construction and maintenance methods to minimize the impact of human activities in sensitive permafrost environments.
- There is a need for further identification and testing of low-cost, energy-efficient building envelope options and cost-effective cold climate technologies and tools that are durable in harsh northern conditions (such as instruments to maintain frozen ground) that enable the adaptation of infrastructure and operations to climate change.
- There is an opportunity to investigate best practices in other circumpolar countries with respect to infrastructure and transportation planning, design, operation, maintenance, and adaptation, and the extent to which they can be applied in Canada's North.
- Several groups/organizations in the NWT that participated in a 2011 workshop hosted by the NWT Cumulative Impact Monitoring Program indicated the state of water as a research priority, as well as the associated impacts of resource development activities on water (NWT Cumulative Impact Monitoring Program, 2011).
- There is a need for further research regarding public health issues that pertain to drinking water quality and water security more generally in Canada's North.
- Further local monitoring of infrastructure such as water and wastewater systems in relation to human health is needed (Parkinson & Berner, 2009). There is a need for more monitoring of drinking water sources and treatment systems (both public and private) and wastewater and landfill leachate; further systematic collection of

baseline information through community participation; and the further conduct of site-specific climate change vulnerability assessments (Martin et al., 2007; Ripley, 2009; Harper et al., 2011; Allard et al., 2012).

- There is a need to further identify and assess solid waste management options in a changing northern environment, with consideration of aspects such as waste capacity levels, storage impacts, and how permafrost and solid waste interact including the extent of the associated impacts (Government of the Northwest Territories, 2009).
- Further research and development is needed to identify and test simple, robust wastewater treatment units for small, remote communities that include composting processes and involve freezing to enhance treatment (Gunnarsdóttir et al., 2013). As well, further research is needed to better understand the use of wetlands in terms of wastewater treatment in an Arctic environment to inform guidelines regarding design and use (Wootton & Yates, 2010).
- There is a need for the development of best practices for cost-effective delivery of municipal services in isolated, remote and harsh climates.
- There is an opportunity to examine the implications of infrastructure density on quality of life, infrastructure maintenance and operation, and funding relationships and allocations (e.g. base funding vs. per-capita funding).
- There is a need to examine the cultural, social, and community implications of infrastructure associated with economic development. There is also a need to identify approaches for integrating and optimizing resource development infrastructure with service infrastructure (Université Laval, 2012).
- There is a need for more data regarding the number of Aboriginal and northern households that subscribe to broadband/high speed Internet service to better understand access (Fiser, 2010). There is also a need for further research to better understand what factors affect adoption between communities and within communities.
- Further research is needed to better understand how to implement and develop information and communication technologies in Aboriginal communities and develop best practices. This requires further examination of the role of community-owned networks and power relations among various stakeholders including those in the public and private sectors to inform policies, programs and community initiatives (Mignone & Henley, 2009).
- Further research is needed to better understand the impact of connectivity, including social, cultural and economic, to inform ICT implementation and development initiatives and support further investment (Mignone & Henley, 2009; Université Laval, 2012).
- There is a need to develop an inventory of connectivity related projects and services in the North to share best practices and lessons learned (Imaituk, 2011).
- There is a need to conduct a “review of long term pan arctic communications alternatives with interested territorial, provincial and Aboriginal governments, together with the federal government” (Salter Global Consulting Incorporated, 2012).

- There is a need for further work to examine and document current creative uses of telecommunications services and related tools in the North.
- There is an opportunity for further research to examine the application of technology in the areas of language protection and promotion.
- There is a need for more research regarding municipal roads (e.g. cost-effective ways to manage dust in the NWT; appropriate road construction practices in communities with low precipitation but high intensity events, etc.).
- There is a need to further assess changing conditions associated with the operation of winter roads, including river/lake ice conditions and management, terrain and hydrologic conditions associated with winter overland transport (Prowse et al., 2011; BGC Engineering, 2011).
- The development of a framework is needed to facilitate quantitative analysis of the full range of life-cycle costs and benefits associated with transportation infrastructure investment and implementation in the North, such as reduced costs for the delivery of health care and education (Bristow & Gill, 2011).
- Further innovation and research is needed regarding alternate transportation technologies (e.g. lighter than air vehicles, airships in the Arctic) and alternative transportation routes such as barge transport or all-weather roads (Prentice et al., 2005; Prowse et al., 2009 & 2011; Bristow & Gill, 2011). For example, with respect to supporting the use of airships in Canada's North, further research is needed to demonstrate the extent to which they can regularly transport goods and people, to test and certify their use in cold climates, and improve their lift capacity (Dick & Gallagher, 2005).
- Research is needed to better understand the role and responsibilities of the public and private sector with respect to developing and maintaining northern transportation (Bristow & Gill, 2011).
- The 2009 *Arctic Marine Shipping Assessment* released by the Protection of the Arctic Marine Environment (PAME) Arctic Council working group notes a number of areas requiring further attention including improved mapping and charting data for shipping routes to support safe navigation; examination of Arctic indigenous marine use; further research regarding the effects of shipping on marine mammals; development of enhanced practices and technologies for ships to reduce current and future emissions of GHGs, NOx, Sox, and PM; research to improve real-time acquisition, analysis and of transfer of meteorological, oceanographic, sea ice and iceberg information to support search and rescue (SAR) activities; and, continued development of a comprehensive marine traffic awareness system to facilitate SAR and disaster management (Arctic Council, 2009; Protection of the Arctic Marine Environment, 2011; Department of Transportation – Government of the Northwest Territories, 2012). A 2013 report released by the Arctic Monitoring and Assessment Programme, Conservation of Arctic Flora and Fauna, and Sustainable Development Working Group identifies marine areas of heightened ecological and cultural significance, which include the Beaufort Sea, Central Arctic Ocean, Canadian Arctic Archipelago, Hudson Bay Complex, and the Baffin Bay-Davis Strait to inform the implementation of protective measures (Arctic Monitoring and Assessment

Programme, Conservation of Arctic Flora and Fauna, and Sustainable Development Working Group, 2013).

- There is a need for increased and updated charting/hydrographic data and bottom-mapping that meets modern standards which are essential to support safe navigation for community re-supply and shipping associated with economic development (Wright, 2012).
- In terms of the impacts of shipping on marine mammals, further research is needed regarding the impacts of noise and of shipping routes and timing on the distribution and behaviour of marine mammals (Huntington, 2009).
- There is a need for further research to increase the efficiency, safety and reliability of marine shipping.
- Further research is needed to more precisely define issues pertaining to Arctic shipping to help decision makers develop targeted interventions.
- There is a need to update and enhance existing data regarding Arctic marine conditions such as ice quality/quantity and the relative utility of sea lanes at a given time of year, given that existing data is not comprehensive and is about 30 years out of date.
- Research is needed to further inform and ensure that regulations and standards pertaining to future shipping and marine operations appropriately correspond to the associated level of risk to human and environmental health (Chircop, 2009; Arctic Council, 2009).
- The 2012 *Oil Spills in Arctic Waters* white paper published by the US Arctic Research Commission highlights the need for additional research to improve oil spill preparedness, response effectiveness and damage assessment. The paper also provides recommendations for further research pertaining to spill delineation and mitigation; oil spill response technologies; data management tools; and the fate of oil and environmental effects (United States Arctic Research Commission, 2012).
- The 2011 report *Behaviour of oil and other hazardous and noxious substances (HNS) spilled in Arctic waters (BoHaSA)* released by the Arctic Council's Emergency Prevention, Preparedness and Response Working Group outlines a number of gaps regarding the behaviour of these substances in Arctic waters including the need for further development of oil spill response technologies, such as those which involve remote sensing (Singsass & Lewis, 2011).
- There is a need for further research to better understand the characteristics of multi-year ice.
- Further research is needed to determine the training that should be required for crews on ships in terms of evacuation and survival, the type and level of thermal protection that is needed for evacuees (Boileau et al., 2010). There is also a need to identify thermal regulatory responses and exposure times by geographic location until rescue.

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