Sources of Information Relevant to Development of Nunavut Land Use Plan

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Environment Canada (EC) has suggested that development should be discouraged in areas likely to experience permafrost loss. The rationale for this is that changes in permafrost conditions may lead to negative effects on infrastructure. This would be of concern for community planning and also for industrial developments including facilities such as mine waste management facilities that depend on frozen conditions for their operation. Nunavut Planning Commission (NPC) has requested that EC provide the location of these areas in the 'NPC Response to the Government of Canada Technical Priorities and Comments' document.

The Geological Survey of Canada (GSC) of Natural Resources Canada has considered the suggestions by EC and NPC and offers the following comments.

Permafrost is defined as a thermal condition, i.e. soil or rock that remains below a temperature of 0°C from one year to the next. However, this definition does not consider other properties of the ground that are relevant for infrastructure integrity. Warming and thawing of permafrost may not necessarily have impacts on infrastructure integrity. One needs to consider whether the ground will behave differently in a thawed condition compared to the frozen state.

Identification or mapping of areas where permafrost loss may be the greatest in response to climate change may not necessarily be the most useful approach. In terms of ground stability identification of areas with high or excess ground ice contents is a primary consideration as thawing in these areas would affect ground instability. These are the areas we may want to avoid when planning communities, linear transportation or other infrastructure as well as industrial/mining facilities (or at least design appropriately for those conditions). In these areas small changes with respect to permafrost thaw may mean large changes with respect to thaw settlement, ground stability and strength. Permafrost thaw in areas with little ground ice, including bedrock, may have little effect on ground stability.

Another issue related to permafrost loss is the impact that this may have on subsurface hydrology (groundwater pathways). This is an issue for mine waste containment for example. Groundwater movement is limited by frozen conditions and as thawing occurs mobility of subsurface water becomes more important. Whether permafrost loss will have a significant impact on groundwater will depend on whether the hydraulic conductivity of the unfrozen material is different (and greater) than for frozen material. In this case, how quickly permafrost degrades may be of concern.

GSC produced a national scale map of permafrost sensitivity to climate warming in 2004 (see Smith and Burgess 2004). The physical sensitivity in terms of thaw settlement was considered in this mapping. These maps provide an indication of broad areas where thawing of permafrost may have implications for ground stability but are not appropriate for local scale planning.

Mapping of surficial materials, permafrost conditions and landscape hazards has been done at a community scale for Clyde River (Smith et al. 2012a, 2012b), Pangnirtung (Leblanc et al. 2010, 2011; Carbonneau et al. 2012) and Iqaluit (Leblanc et al. 2012, 2013; Allard et al. 2012). These products can inform planning of community infrastructure. Reports and databases are also available that provide information on permafrost temperatures in Nunavut and can inform planning at local and regional scales (see Ednie and Smith 2010, 2011; Smith et al. 2010, 2013; Throop et al. 2010).

Ground ice and landscape stability mapping beyond the examples given is somewhat limited. A GSC study focussed on northern Ellesmere Island (Fosheim Peninsula) provides relevant information on permafrost dynamics, ground ice and slope instability (see Garneau and Alt 2000). There are a number of investigations conducted by university researchers which may also provide information on ground ice conditions at various locations in Nunavut.

Important sources of information on ground ice conditions are geotechnical reports associated with engineering design of resource development or community infrastructure. Compilation of information from these reports into accessible databases would facilitate identification of problematic areas with respect to ground ice and ground instability. The GSC has, for example, compiled information from geotechnical reports associated with proposed mines in the Kitikmeot region and is working to develop relationships between ground ice content and terrain types that can be utilized to inform infrastructure planning and land management decisions. It is suggested that geotechnical information from other regions and recent infrastructure/development projects could be compiled on an ongoing basis to build up regional knowledge on permafrost and land stability.

With respect to coastal stability issues, the GSC has characterized coastal sensitivity to climate change at a national scale (Shaw et al. 1998). The GSC is currently working to update these maps. Community and regional scale coastal sensitivity mapping is also being conducted (see for eg. James et al. 2011 and 2013).

Coastal vulnerability is a consequence of several factors. Important factors include the composition of the coastline (loose sediments, such as sand and silt, compared to weakly consolidated sediments, compared to crystalline bedrock), the presence and nature of permafrost, the relief (low elevation, gentle slope, vs. steep shorelines), the expected trend of sea-level change, tidal range (large tides generate large tidal currents, which move sediment around) and the wave and wind climate (an open coastline exposed to prevailing winds that generate large waves is much more vulnerable than a protected coastline). A final important factor is the extent and duration of sea-ice, which acts to protect shorelines. With reduced duration of sea ice, which is projected to occur in many parts of the Arctic, shorelines become more exposed to winds and waves, increasing erosion rates and vulnerability.

There are a number of other initiatives (some of which are still in progress) that may also provide information to support development and updating of land use plans. The Nunavut General Monitoring Program for example, has developed (or is developing) State of Knowledge reports for valued ecosystem components including permafrost. The ArcticNet Network of Centres of Expertise is conducting regional impact assessments, the components of which are in various stages of development.

Relevant Publications

National Scale Characterization of Sensitivity of Permafrost to Climate Warming

Smith, S.L., and Burgess, M.M. 2004. Sensitivity of permafrost to climate warming in Canada. Geological Survey of Canada Bulletin 579. http://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb?path=geoscan/shorte.web&search1=R=216137

Local/Community Scale Permafrost, Landscape Hazard Mapping (also surficial geology mapping)

Allard, M; Doyon, J; Mathon-Dufour, V; LeBlanc, A -M; L'Hérault, E; Mate, D; Oldenborger, G A; Sladen, W E. 2012. Surficial geology, Iqaluit, Nunavut. Geological Survey of Canada, Canadian Geoscience Map 64, (ed. prelim.), 1 sheet; 1 doi:10.4095/289503 http://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb?path=geoscan/downloade.web&search1=R=289503

Carbonneau, A -S; Allard, M; LeBlanc, A -M; L'Hérault, E; Mate, D; Oldenborger, G A; Gosselin, P; Sladen, W E. 2012. Surficial geology and periglacial features, Pangnirtung, Nunavut. Geological Survey of Canada, Canadian Geoscience Map 65, (ed. prelim.), 1 sheet; doi:10.4095/289504 http://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb?path=geoscan/downloade.web&search1=R=289504

Garneau, M., and Alt, B.T. 2000. Environmental response to climate change in the high Arctic. In Geological Survey of Canada Bulletin 529. http://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb?path=geoscan/shorte.web&search1=R=211887

Leblanc, A.-M., Mathon-Dufour, V., Allard, M., Oldenborger, G.A., Short, N., L'Hérault, and Sladen, W.E. 2013. Permafrost characterization at the Iqaluit International Airport, Nunavut, in support of decision-making and planning. Summary of Activities 2012, Canada-Nunavut Geoscience Office: 131-142. http://cngo.ca/summary-of-activities/2012/

Leblanc, A.-M., Short, N., Oldenborger, G., Mathon-Dufour, V., and Allard, M. 2012. Geophysical investigation and InSar mapping of permafrost and ground movement at the Iqaluit airport. *In* Cold Regions Engineering 2012, Sustainable Infrastructure Development in a Changing Cold Environment. *Edited by* G. Doré and B. Morse. Quebec. American Society of Civil Engineers, pp. 644-654.

Leblanc, A.-M., Allard, M., Carbonneau, A.-S., Oldenborger, G.A., L'Hérault, E., Sladen, W.E., Gosselin, P., and Mate, D. 2011. Assessing permafrost conditions and landscape hazards in support of climate change adaptation in Pangnirtung, Nunavut, Geological Survey of Canada Open File 6868.

http://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb?path=geoscan/shorte.web&search1=R=289548

Leblanc, A.-M., Oldenborger, G., Sladen, W., Mate, D., Carbonneau, A.-S., Gosselin, P., L'Hérault, E., and Allard, M. 2010. Assessing permafrost conditions in support of climate change adaptation in Pangnirtung, Nunavut. *In* GEO2010, 63rd Canadian Geotechnical Conference & 6th Canadian Permafrost Conference. Calgary, Sept. 2010. GEO2010 Calgary Organizing Committee, pp. 1242-1250.
http://www.aina.ucalgary.ca/scripts/minisa.dll/130/1/0?SEARCH

Smith, I R; Irvine, M L; Bell, T. 2012. Periglacial and permafrost geology, Clyde River, Baffin Island, Nunavut; Geological Survey of Canada, Canadian Geoscience Map 57, (ed. prelim.), 1 sheet; doi:10.4095/289602
http://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb?path=geoscan/downloade.web&search1=R=289602

Smith, I R; Irvine, M L; Bell, T. 2012. Surficial geology, Clyde River, Baffin Island, Nunavut; Geological Survey of Canada, Canadian Geoscience Map 58, (ed. prelim.), 1 sheet; doi:10.4095/289603
http://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb?path=geoscan/downloade.web&search1=R=289603

National Scale Coastal Sensitivity to Climate Change

Shaw, J., Taylor, R.B., Forbes, D.L., Ruz, M.H., Solomon, S. 1998. Sensitivity of the coasts of Canada to sea-level rise; Geological Survey of Canada, Bulletin 505, doi:10.4095/210075.
http://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb?path=geoscan/shorte.web&search1=R=210075

> *Please note that work is currently underway by the Geological Survey of Canada to update this.

Local/Community Scale Coastal Geoscience

James, T S; Simon, K M; Forbes, D L; Dyke, A S; Mate, D J. 2011. Sea-level projections for five pilot communities of the Nunavut climate change partnership; Geological Survey of Canada, Open File 6715, 27 pages, doi:10.4095/288019
http://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb?path=geoscan/downloade.web&search1=R=288019

> *Please note that work is currently underway by the Geological Survey of Canada to update sea-level projections for Arctic communities, though currently projections are only available for the five communities. This work indicates that the land is rising over much of Nunavut, and projected amounts of local relative sea-level rise will be smaller than projected global amounts of sea-level rise for most of Nunavut.

James, T.S., Whalen, D.J.R., Jenner, K.A., Hatcher, S.V., Ulmi, M., Forbes, D.L., Manson, G.K., Henton, J.A. and Craymer, M.R. 2013. Coastal geoscience for sustainable development in

Nunavut: 2012 activities; *in* Summary of Activities 2012, Canada-Nunavut Geoscience Office, p. 143–150. http://cngo.ca/summary-of-activities/2012/

Landscape Stability in Nunavut Communities
The following four articles can be found at http://cngo.ca/summary-of-activities/2013/ as of January 27, 2014:

Allard, M., Manson, G. K., Mate D. submitted. Reconnaissance Assessment of Landscape Hazards and Potential Impacts of Future Climate Change in Whale Cove, Nunavut, *in* Summary of Activities 2013, Canada-Nunavut Geoscience Office.

Reconnaissance assessment of landscape hazards and potential impacts of future climate change in Kugluktuk, NU (Smith)

Reconnaissance assessment of landscape hazards and potential impacts of future climate change in Cambridge Bay (Smith and Forbes)

Reconnaissance assessment of landscape hazards and potential impacts of future climate change in Arviat (Forbes et al.)

Coastal Hazards in Iqaluit
Hatcher, S.V. 2014. People at the Tidal Flats: Coastal Morphology and Hazards in Iqaluit, Nunavut. M.Sc. thesis, Memorial University, examination successful, in final revision.

Information on Permafrost Thermal State (permafrost temperature)
Ednie, M., and Smith, S.L. 2011. Establishment of community-based permafrost monitoring sites and initial ground thermal data Baffin Region, Nunavut, Geological Survey of Canada Open File 6727.
http://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb?path=geoscan/shorte.web&search1=R=287873

Ednie, M., and Smith, S.L. 2010. Establishment of community-based permafrost monitoring sites, Baffin region, Nunavut. In GEO2010, 63rd Canadian Geotechnical Conference & 6th Canadian Permafrost Conference Calgary. GEO2010 Calgary Organizing Committee, pp. 1205-1211. http://www.aina.ucalgary.ca/scripts/minisa.dll/130/1/0?SEARCH

Smith, S.L., Riseborough, D.W., Ednie, M., and Chartrand, J. 2013. A map and summary database of permafrost temperatures in Nunavut, Canada, Geological Survey of Canada Open File 7393.
http://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb?path=geoscan/shorte.web&search1=R=292615

Smith, S.L., Lewkowicz, A.G., Burn, C.R., Allard, M., and Throop, J. 2010. The thermal state of permafrost in Canada - Results from the International Polar Year. In GEO2010, 63rd Canadian Geotechnical Conference and the 6th Canadian Permafrost Conference. Calgary, Sept 2010.

GEO2010 Calgary Organizing Committee, pp. 1214-1221. 1211.
http://www.aina.ucalgary.ca/scripts/minisa.dll/130/1/0?SEARCH

Throop, J.L., Smith, S.L., and Lewkowicz, A.G. 2010. Observed recent changes in climate and permafrost temperatures at four sites in northern Canada. In GEO2010, 63rd Canadian Geotechnical Conference and the 6th Canadian Permafrost Conference. Calgary, Sept 2010. GEO2010 Calgary Organizing Committee, pp. 1265-1272.
http://www.aina.ucalgary.ca/scripts/minisa.dll/130/1/0?SEARCH