Climate Change and Freshwater Fish in the Albany River Watershed

WILDLIFE CONSERVATION SOCIETY CANADA

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Table of Contents

About Wildlife Conservation Society Canada (WCS Canada)

WCS Canada's mission is to save wildlife and wildlands by improving our understanding of — and seeking solutions to — critical issues that threaten key species and large wild ecosystems throughout Canada. It both implements and supports comprehensive field studies that gather information on wildlife needs and seeks to resolve key conservation problems by working with a broad array of stakeholders, including local community members, conservation groups, regulatory agencies, and commercial interests. It also provides technical assistance and biological expertise to local groups and agencies that lack the resources to address complex conservation issues. Major issues addressed to date include protected-area design, conservation-based land use planning, monitoring and management of wildlife and fish populations, recovery of endangered species, and impacts of climate change upon wildlife. Since 2004, WCS Canada has been an independently registered and managed non-governmentl organization, while retaining a strong collaborative working relationship with sister WCS programs in more than 55 countries around the world.

About the Authors

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Dr. Erika Rowland works on climate change adaptation in natural resource management in landscapes across North America, assembling and generating climate science and other information to support planning and action.

Acknowledgements

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Introduction

This report was developed to support Fort Albany First Nation (FAFN) and their project entitled, "The Strength of Many: Integrating Adaptation into a Comprehensive Community Plan". Based on discussions with Lisa Hardess (Hardess Planning Inc.), this report supports activities under project objective 1 - *To identify the primary impacts of climate change affecting FAFN, drawing from climate change science, scenarios, and Traditional Knowledge*.

This report focuses on four main areas of work under this objective:

1) a scientific overview of climate change impacts on freshwater fish as well as the impacts from various land uses, mainly resource extraction and development;
2) a climate change scenario and a set of draft maps for three key variables relevant to freshwater fish;
3) a conceptual model of climate and non-climate impacts on freshwater fish; and,
4) preliminary scoping of impacts and vulnerabilities of freshwater fish.

This information, together with a set of distribution maps for freshwater fish in the watershed, can be used to support a process of assessing the vulnerability of freshwater fish, identify further research needs, and lend scientific support to Fort Albany First Nations' efforts in climate change adaptation planning and land use planning. Because the geographic scope for planning in the current proposal was not defined for the project at this stage, WCS Canada focused on the Albany (and primary tributary, the Kenogami River) watershed (Figure 1). The watershed consists of two major ecozones: the Boreal Shield and the Hudson Plains, which create very different aquatic habitats and environments for freshwater fish. For example, the glacial history and underlying geology of the Shield has resulted in tens of thousands of lakes, variations in elevation, and complex drainage patterns. The Lowland areas were once a submerged marine region and today are undergoing isostatic rebound. The aquatic environment is characterized by the largest wetland in North America, bogs and ponds, with few large lakes amongst long and fairly slow flowing river systems (Marshall & Jones 2011). At 982 km, the Albany river is one of the longest rivers in Ontario, draining an area of 135,200 km^2, with a mean annual discharge of 1,420 m^3 per second (Marshall & Jones 2011).

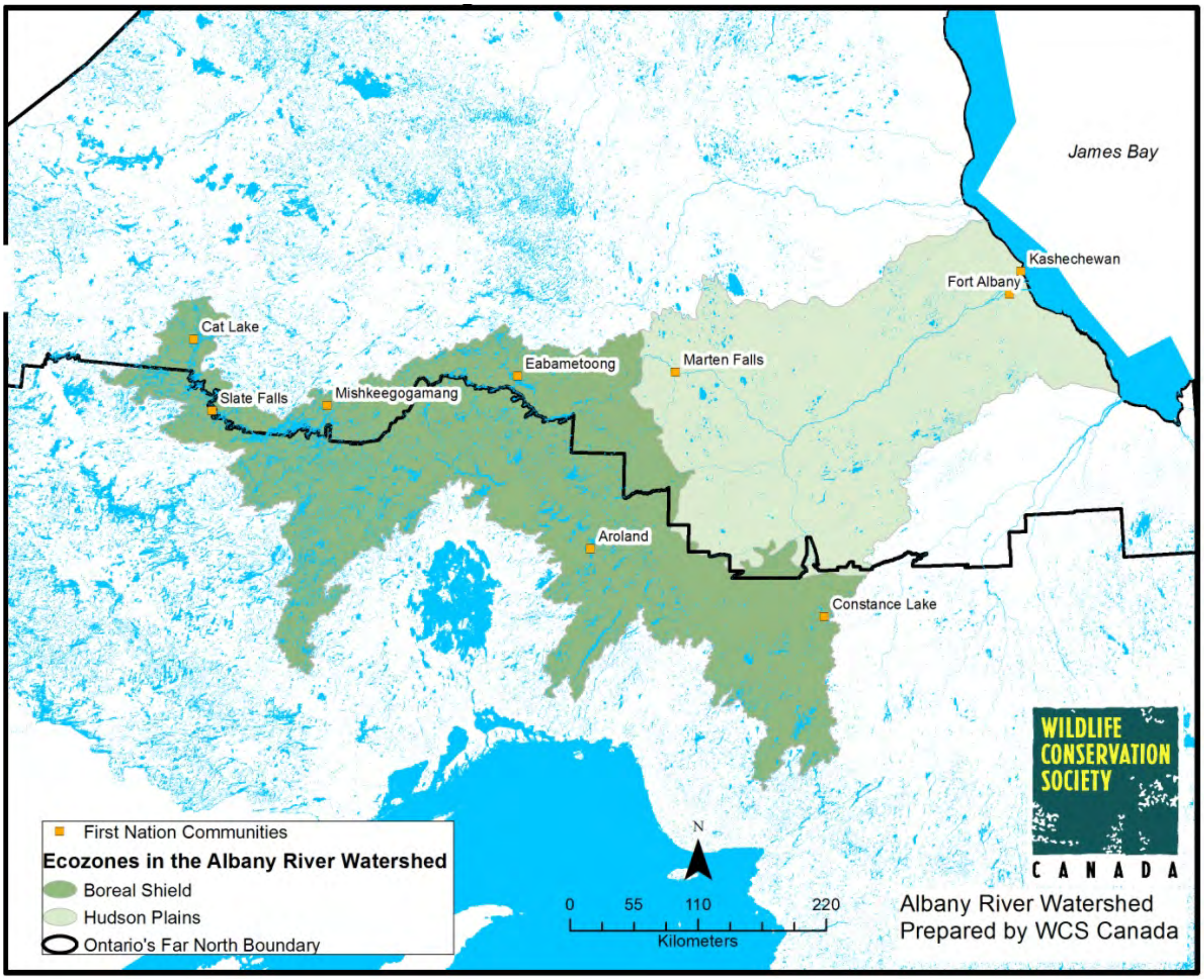

Figure 1. The Albany River watershed, including the Kenogami River.

WCS Canada selected freshwater fish because fish are directly affected by the temperature of their environment in various ways that can inform planning for climate change as well as land use planning (e.g., hydro-development) that may affect both the land and aquatic environment within the watershed. First Nations also rely and depend upon freshwater fish for food and cultural values as well as freshwater. Finally, Hori (2010) described fish die-offs in the Albany River during July 2005 that were attributed to climate change (warmer temperatures, reduced precipitation).

In general, freshwater fish can be grouped into three thermal guilds: 1) warm-water (e.g., smallmouth bass); 2) cool-water (e.g., northern pike, walleye, yellow perch); and 3) cold-water (e.g., brook trout, lake trout, lake whitefish). Climatic changes such as warming and changes in precipitation can affect freshwater fish within these guilds in numerous and complex ways regardless of human activities and other land uses. In addition, current and potential land uses, particularly industrial activities, can have single, multiple, and cumulative effects on freshwater fish regardless of climate change. WCS Canada has been conducting research on climate change impacts on freshwater fish, particularly lake trout and brook trout, in northern Ontario. WCS Canada recently conducted a workshop in December 2012 (report available) focused on assessing vulnerabilities, identifying adaptation options, and sharing scientific information about freshwater fish in the Attawapiskat, Ekwan, and Winisk watersheds where some of the information (e.g., climate models, vulnerability) may be similar for the Albany watershed.

Scientific Overview of Climate Change Impacts on Freshwater Fish[4]

A number of scientific studies have been conducted to assess and predict the consequences of climate change on freshwater habitats (lakes, rivers, streams, and wetlands) and the fish that depend on them. Climate change is predicted to affect freshwater ecosystems and fish in a variety of complex ways, particularly in northern hemispheres where a warming of 1.8°C has taken place over the last 150 years (Magnuson et al. 2000).

Climate change impacts on freshwater environments

Climate change influences: 1) ice cover; 2) water temperature profiles; 3) total water volumes; and 4) water quality of freshwater bodies (Schindler et al. 1990, Lofgren 2002). Climate change is predicted to increase surface water temperatures with increasing air temperature (Lofgren 2002); however the magnitude of response in freshwater ecosystems depends on characteristics of the waterbody, such as area, depth, latitude, and stratification (Gerten & Adrian 2001,Lofgren 2002). In the northern hemisphere, particularly boreal forests, lakes and rivers now freeze later, break-up earlier, and experience shorter ice cover periods (Magnuson et al. 2000, Benson et al. 2001).

Lakes in milder climates (e.g., temperate) generally undergo a process called thermal stratification as summer approaches. As air temperature increases, the surface waters warm whereas the bottom layer of water remains relatively cool. These two layers are separated by the thermocline — the transition layer between the mixed water layer near the surface and the deeper, colder water layer. During the summer, surface waters reach their maximum depth and stratification remains throughout the summer. Climate change may result in changes in length of seasonal stratification of lakes and the depth of thermoclines (i.e. the thickness of the surface water layer), both of which interact with a number of climate variables. For example, shallower thermocline depths result from rapid onset of spring stratification (Robertson & Ragotzkic 1990, Snucins and Gunn 2000), whereas deepening of thermoclines may be a consequence of warmer water and longer ice-free seasons (Schindler 2001).

Total water volumes are also predicted to change with climate. Warming is predicted to cause greater evaporation, which is expected to exceed anticipated increases in precipitation (Schindler 2001, Lofgren 2002). Mortsch et al. (2000) estimated that evaporation effects on watersheds would create an

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[4] From McDermid in Browne 2007.

approximately 1 m drop in water levels. Consequently, a disappearance of wetland surface area (Schindler 2001), decreases in river flow (Schindler 2001), and ultimately decreased connectivity among aquatic habitats can occur. Decreases in nutrient input and increases in water transparency are also expected to accompany climate change (Schindler et al. 1990). Changes in productivity and nutrient inputs in northern lakes are likely to lead to lower phytoplankton abundances (Lofgren 2002), which can have cascading effects throughout the food web with consequences for fisheries.

How can these changes in the freshwater environment affect freshwater fish in boreal lake environments?

Impacts on fish

Fish are directly influenced by the temperature of their environment, as it plays a role in the regulation of all physiological processes (Fry 1971). Freshwater fish can be grouped into three thermal guilds: 1) warm-water (e.g., smallmouth bass, sunfish); 2) cool-water (e.g. pike, walleye, yellow perch); and 3) cold-water (e.g. brook trout, whitefish, lake trout), with responses to climate change differing among them. Climate change can impact freshwater fish in two ways: 1) impacts on fish at specific locations, such as changes in productivity or health; and 2) impacts on the spatial distribution of fish populations, such as northward migrations (Shuter et al. 1998). Changes in ice cover patterns results in a lengthening of growing seasons and is generally predicted to increase growth and productivity of all guilds if suitable thermal habitat and nutrients are available. For example, Shuter et al. (2002) predicted an increase in yield and productivity of walleye north of 51° latitude as air temperature increases. However, increases in air temperature accompanied by decreasing water levels can result in declines in water quality that would negatively impact many fish species, especially at the egg and fry stages (Hunter et al. 1979, Williamson et al. 1997, Huff et al. 2004).

Impacts on fish habitat

Changes in water temperature profiles will alter the availability of habitat at or near the optimal or preferred temperature profiles for each fish species. Warm-water fish prefer temperatures greater than 25°C, cool-water fish prefer temperatures of 15-25°C, and cold-water fish prefer temperatures below 15°C. Thus as climate warms, the amount of thermal habitat available for warm-water species will increase, whereas we anticipate thermal habitat will decrease for cold-water species. For cool-water fish the response is more difficult to predict. Magnuson et al. (1990) suggested that climate change may expand thermal habitat for cool-water fish by extending the growing season. Casselman (2002) found that cool-water species were more negatively affected by colder than warmer temperatures. Cold-water fish, such as lake trout and brook trout, will be most adversely affected by climate change, and unable to inhabit lakes in the southern part of their current range, resulting in a reduced distribution as water temperatures increase (Snucins and Gunn 1995; Meisner 1990; Shuter et al. 2002). In addition, with increased evaporation and decreases in thermocline depth, subthermocline habitat available for cold-water species will decrease (Schindler 2001), leading to an overall decrease in productivity in lakes where cold-water species persist. Furthermore, unstratified and shallow northern lakes may warm beyond optimum temperatures for cold-water species (Schindler 2001).

Impacts on fish communities

Climate warming may accelerate the rate of spread of non-native species that flourish in warmer waters. A number of species are currently at the northern limit of their zoogeographic range south of 51° latitude, such as smallmouth bass, rockbass, fathead minnow, river and Iowa darters, and various *Notropis* species. These species have the potential for range expansion with climate warming and their abundance is predicted to increase as water temperatures increase and extend the growing season (Shuter et al. 2002). Smallmouth bass are currently held at their northern zoogeographic limit (south of 51° latitude) by climate (Shuter & Post 1990). It is, however, predicted that the northern limit for this species will advance 120 km north for every degree Celsius of air warming that occurs (Shuter & Post 1990, Sharma et al. 2009). Both cool and cold-water species are adversely affected by increases in both native and non-native warm-water species, through competition for resources (Shuter & Meisner 1992, Vander Zanden et al. 1999). Furthermore, this range expansion could also lead to the extirpation of over 20,000 cyprinid populations in Ontario (Jackson & Mandrak 2002).

Interactions with other human activities

Climate change impacts may also be exacerbated by overfishing (e.g., commercial, recreational, subsistence), and other land uses such as dams and mining that destroy habitat and fragment aquatic systems, as well as introduce non-native species, either deliberately through bait activities and stocking programs or as climate change creates new thermal habitat displacing native species (Schindler 2001).

Current Distribution of Freshwater Fish

The distribution of 11 freshwater species, based on sampling data in Ontario's Fish Distribution Data System and literature sources, were entered in a Geographic Information System (GIS) and clipped to the Albany watershed. Maps offer a preliminary snapshot of freshwater fish to discuss current distribution of various species, gaps and limitations in the data, connectivity within and between watersheds, variations in aquatic ecosystems across the watershed, and the role and value of traditional knowledge and local observations (see Draft Maps accompanying this report).

Overview of Land Use Impacts on Freshwater Fish and Their Habitats

McGovern and Vukelich (2009) and Browne (2007) provided comprehensive reviews of how land uses associated with resource extraction and development may impact aquatic ecosystems in Ontario's Far North. Resource development activities in the Albany watershed include hydro-development and mining and both are expected to expand in the future (Browne 2007, McGovern & Vukelich 2009). Forestry is also a significant land use in the Area of Undertaking (AOU) within the watershed. Current infrastructure includes seasonal winter roads from communities that tend to operate from January to March. The demand for all-weather roads is expected to increase with proposed mines in the Ring of Fire (e.g., Cliffs Chromite Project, Noront's Eagle's Nest Multi-metal Project) and existing mines outside of the watershed (e.g., De Beers Victor diamond mine). Remote communities also want all-weather roads as the viability of winter roads becomes increasingly unreliable due to warmer weather. Transmission corridors to supply energy to mining operations offer opportunities for extending transmission to some remote communities and may be more likely in the future. Status of these impacts as well as the typical impacts associated with these activities on aquatic ecosystems and freshwater fish are described briefly below.

The major form of fish harvest is fishing for food and sport by First Nations (McGovern & Vukelich 2009, Berkes et al. 1995a, b). Harvest data for the whole Hudson Plains Lowlands Ecozone, which includes Fort Albany, indicated that whitefish and cisco have been the principle species harvested over a number of survey periods for which data exist (1981-82, 1982-83, 1989-91). In addition, between 2,000 and 3,500 kg of sturgeon were harvested from all Ontario coastal communities, except Peawanuck, between 1981-1983 (McGovern & Vulkelich 2009). Sport fishing by residents and non-residents has been and continues to be less important than the First Nations food fishery (McGovern & Vukelich 2009). Ontario's management of fisheries in the Albany watershed is shared across five fish management zones.

Hydro-electric developments

Hydro-electric dams affect aquatic ecosystems in three primary ways: 1) they act as barriers to migration, blocking the movement of fish and other aquatic organisms; 2) they alter the flow, nutrient, sediment, and temperature regimes above and below the dams and possibly strand fish; and 3) the construction of reservoirs upstream of dams can result in erosion problems, loss of spawning areas, and increased methyl mercury uptake within the aquatic food chain which has health implications for First Nations who depend on fish for food and decreases marketability of fish (Stokes & Wren 1987, Browne 2007). The Albany River watershed is considered to be "moderately" fragmented by flow regulation and river channel fragmentation (Dynesius & Nilsson 1994). There are two first order diversions (Long Lac, Ogoki) and one second-order diversion (Lake St. Joseph) diverting flow away from the Albany watershed and James Bay for the purpose of hydro-electric projects elsewhere in the province (Figure 2). First-order diversion means water is transported from one basin to another basin across a continental divide and neither basin empties into the same ocean whereas second order diversions transfer freshwater from one freshwater basin to another freshwater basin (Noone 2006).

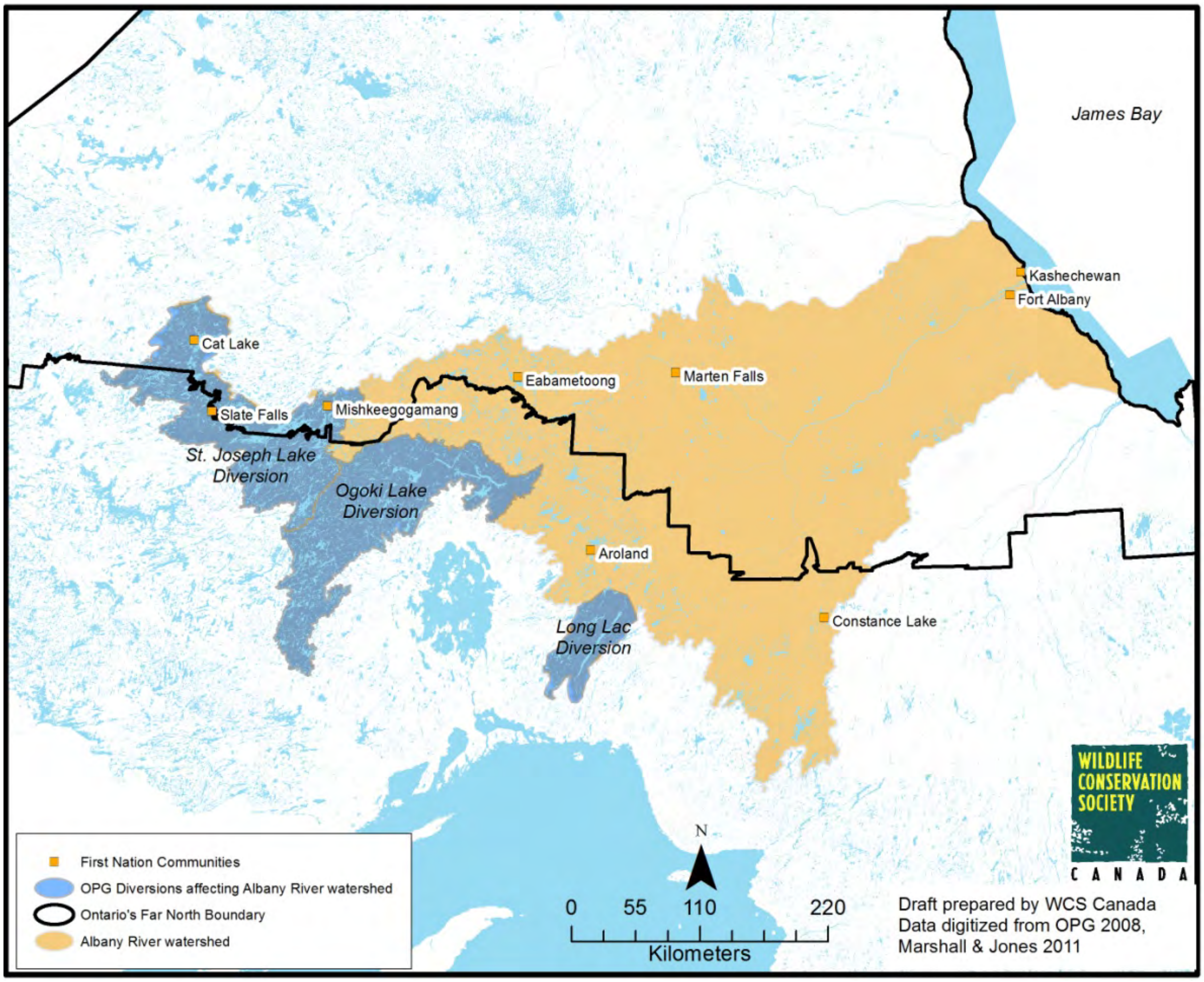

Figure 2. Diversions that affect the Albany River watershed (from OPG 2008; Marshall & Jones 2011).

The Long Lac diversion (built 1937-1938), now operated by Ontario Power Generation (OPG), diverts the Kenogami river headwaters away from the Albany River to empty through Long Lac and the Aguasabon River into Lake Superior. Long Lac diverts 45 m^3/sec from the Hudson Bay basin to the Great Lakes basin (Marshall & Jones 2011). Initially, the diversion supported forestry development (Long Lac Pulp and Paper Company)[5]. The Ogoki reservoir (completed in 1943), now operated by OPG, is the largest inter-Basin water transfer project ever built in the Great Lakes region, diverting flow through Little Jackfish River in the Hudson Bay basin toward Lake Nipigon, generating stations along the system, and out to Lake Superior in the Great Lakes basin. The diversion has shifted an average annual flow of 113 m^3/sec second from the Albany watershed to Lake Superior. The St. Joseph Lake diversion (completed in the 1950s) diverts water from St. Joseph Lake, in the Albany's headwaters, to Lac Seul via the Root River

[5] http://www.opg.com/power/hydro/northwest_plant_group/aguasabon.asp

system to feed generating stations at Ear Falls and several stations along the English/Winnipeg drainage before emptying into the Nelson River basin in Manitoba where it flows to the Hudson Bay (McGovern & Vukelich 2009, S. McGovern, personal communication). The diversion transfers an average annual flow of 86 m^3/sec away from the Albany watershed. Taken together, these diversions have reduced the mean annual discharge of the Albany River by 17% since their construction (Marshall & Jones 2011, OPG 2008).

Ontario's Ministry of Natural Resources (OMNR) has identified a number of potential water power sites in the Albany watershed (Figure 3). Existing hydro-development is the cheapest form of energy generation in Ontario and an integral part of Ontario's Long Term Energy Plan (OPA 2011). All new dams within the Albany watershed fall within the Northern Rivers Policy Area and are subject to the Northern Rivers Commitment restricting new developments to less than 25 MW and requiring First Nations support.[6]

[6] http://www.mnr.gov.on.ca/stdprodconsume/groups/lr/@mnr/@renewable/documents/document/290575.pdf

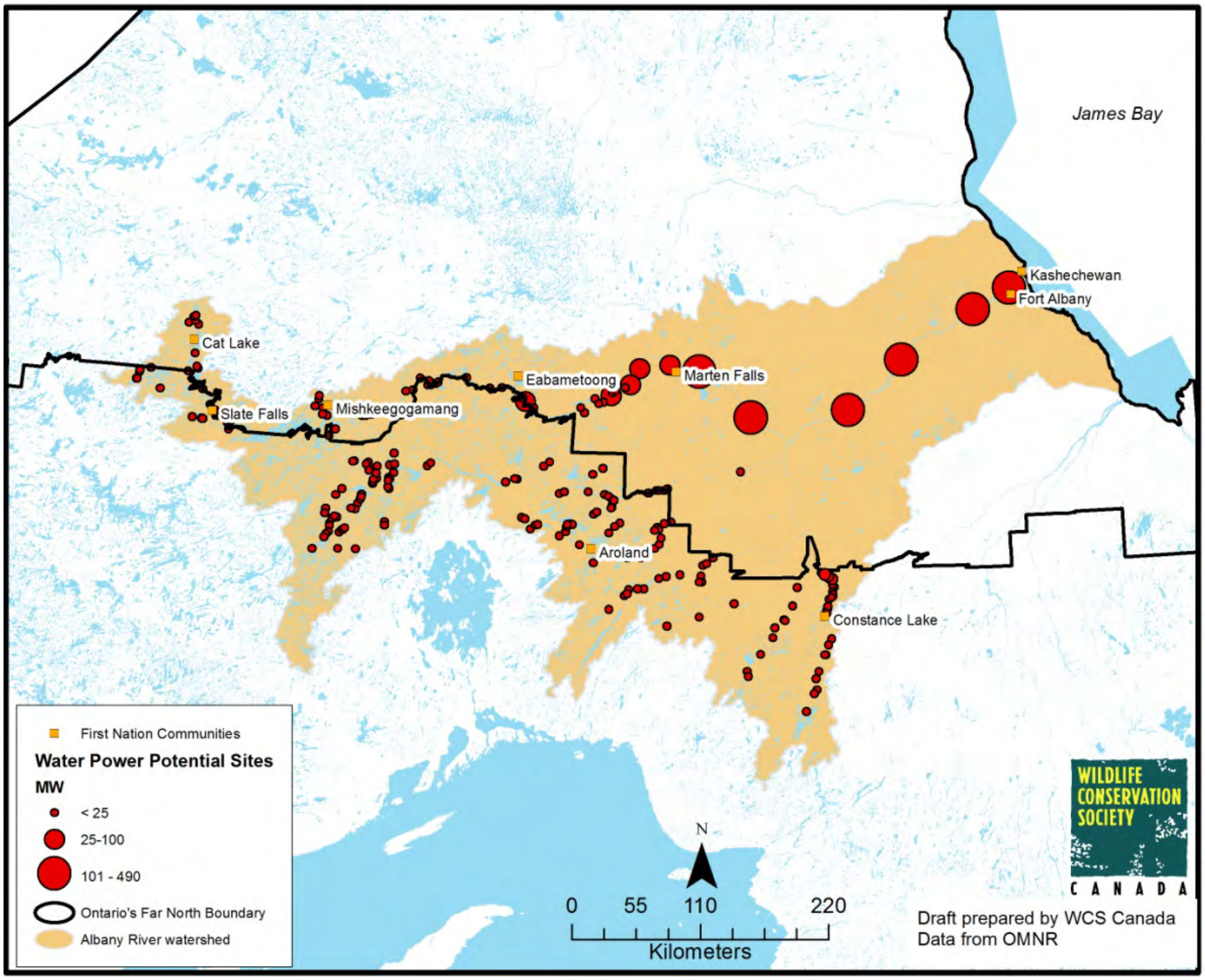

Figure 3. Waterpower potential identified in the Albany River watershed.

Mining

Mining construction and operation can affect aquatic environments by: 1) increasing human access to surrounding lakes and rivers; 2) physically altering or destroying aquatic habitats; 3) releasing effluents into lakes and rivers from the mine and/or the ore processing facility; and 4) creating mine tailings (piles of waste rock and processing waste) that weather and leach metals and other contaminants into adjacent surface water and groundwater (summarized in Browne 2007). In 2012, there were 3,557 mineral claims covering approximately 4% of the Albany River watershed (Figure 4). However, there are a number of activities developing outside the watershed that will have impacts on the Albany, specifically in the Ring of Fire where two mining companies are in federal and provincial environmental assessment processes for a chromite mine (Cliffs Chromite Project) and a multi-metal nickel mine

(Noront Resources Ltd.)[7] (Figure 4). Infrastructure associated with these projects will cross the Albany watershed (Figure 4). Expansion by De Beers Canada Ltd at the Victor Diamond mine may also have implications for increased infrastructure in the lowland region of the Albany watershed (Figure 4).

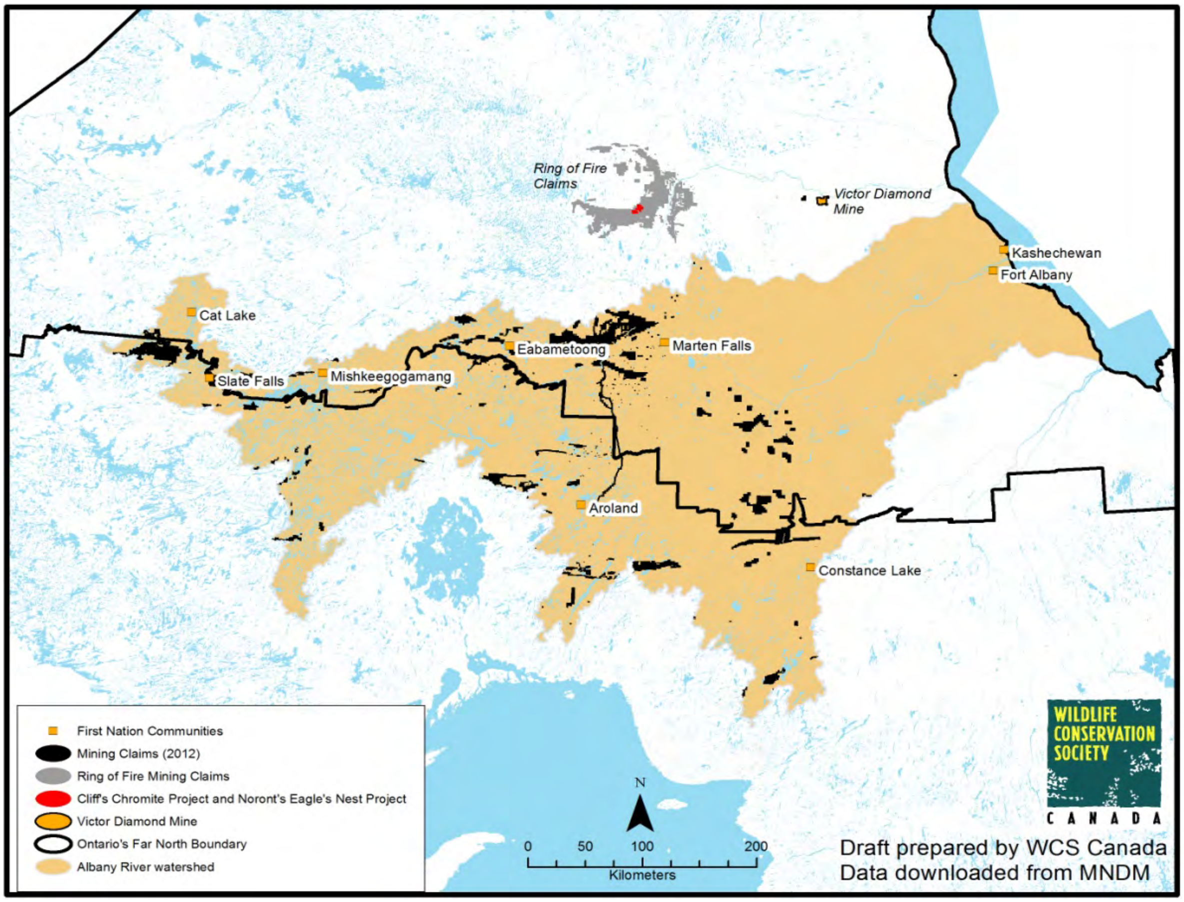

Figure 4. Active mineral claims in the Albany River watershed as of 2012.

Forestry

Logging activities expose soils, resulting in changes in water flow regimes, nutrient and sediment transfer, and increases in mercury levels in aquatic biota. Forestry also requires road development, which can result in fragmentation of aquatic habitat (e.g., poorly installed culverts), erosion and sedimentation, and increased fish harvest due to new road access (summarized in Browne 2007). There are 18 Forest Management Units (FMUs) within the portion of the Albany watershed managed as the AOU as defined by the *Class Environmental Assessment for Timber Management* (Figure 5). FMUs comprise 65% of the boreal shield ecozone within the watershed. Industrial forestry currently affects

[7] http://fourriversmatawa.ca/index.php/projects/environmental-assessment-information/

37% of the watershed (Figure 5). Forestry is governed and regulated through a variety of legal and policy tools created by OMNR under the *Crown Forest Sustainability Act*. North of the AOU, other than a small portion of the Whitefeather Forest (0.03% in the watershed), for which environmental assessment coverage was extended in 2009, the amount of industrial forestry that will be designated by communities in the Albany watershed is not known at this time.

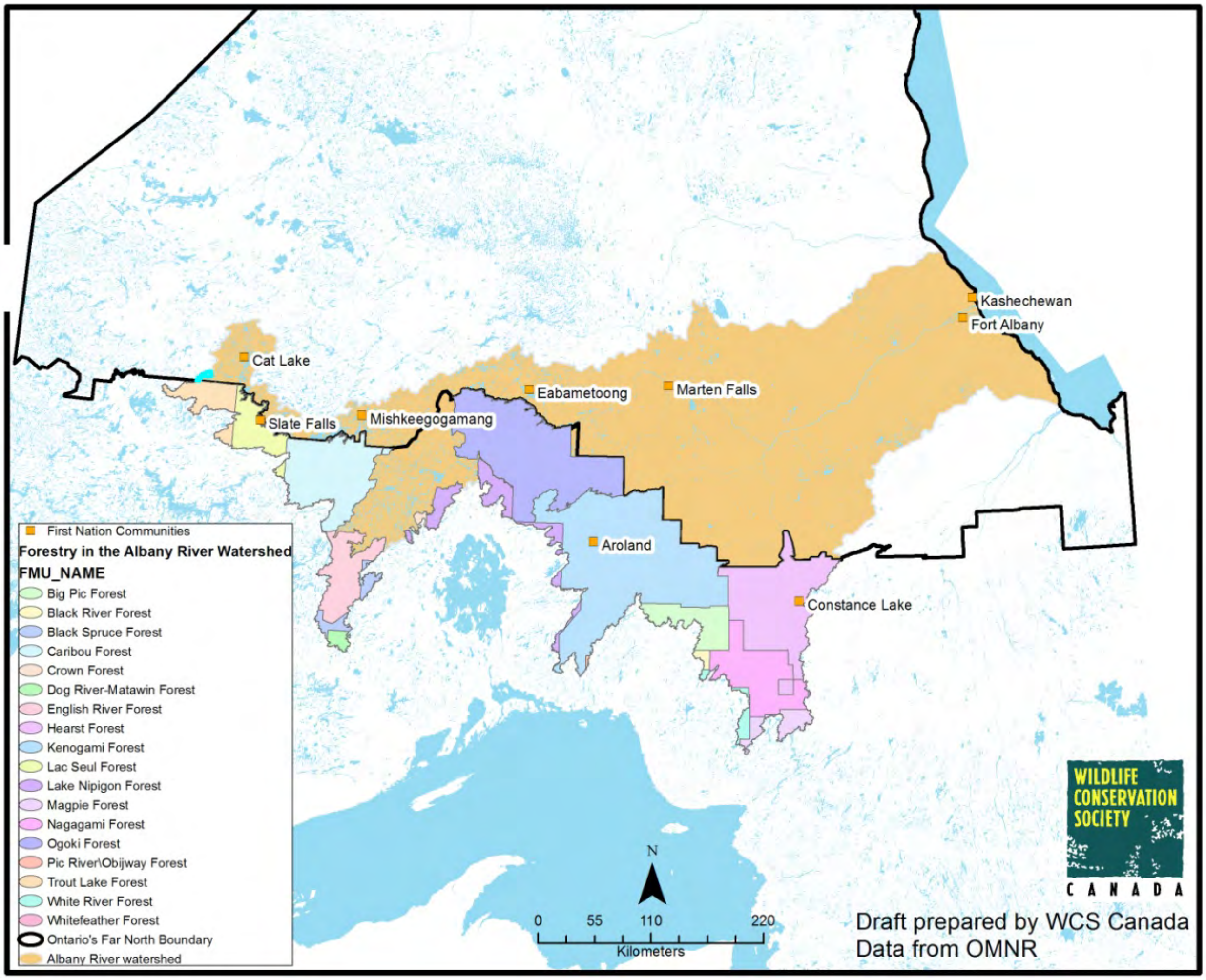

Figure 5. Forest Management Units in the Albany River watershed.

Infrastructure

Roads can change hydrological processes by interrupting or changing stream flow, decreasing connectivity for aquatic species, limiting nutrient cycling, changing disturbance regimes such as flood timing and duration, and introducing new contaminants into the air and water from road surfaces, vehicles, or spills (Browne 2007). New roads also enable fishing access to previously unexploited lakes in particular (Hunt et al. 2000, Gunn & Seinn 2000). At higher exploitation levels, removal of the majority of large, mature fish can have negative consequences for the long-term persistence of fish populations.

In addition to logging roads, winter roads in the Far North Planning Area of the watershed connect remote First Nations communities to provincial road networks south of the area (Figure 6). Winter roads in the Albany watershed are seasonal and managed by remote First Nations communities including Kashechewan, Fort Albany, Eabemetoong, and Marten Falls. Winter roads are important for First Nations because they significantly reduce transportation costs for food, fuel, including diesel for generators providing community electricity for heating and power infrastructure and homes, bulk commodities, including food, and heavy equipment. Winter roads may also be important for industrial users like De Beer's Victor Diamond mine in the Attawapiskat watershed, that uses the James Bay coastal winter roads in the Albany watershed to bring supplies to the mine site. New potential all-weather roads for industrial users are likely to increase in the future. Currently, routes proposed for all-weather roads to Ring of Fire mines, specifically Cliff's Chromite Project, cross a number of waterways and waterbodies in the Albany watershed to access rail and road networks near Nakina. Since the mid-2000s, there has been increasing calls from First Nations communities and organizations for all-weather access to communities due to the financial burden incurred to communities shipping fuel, food, materials and equipment on increasingly unpredictable winter roads.[8, 9] All-weather roads to communities in the Albany watershed have the potential to provide a number of positive benefits to remote First Nation communities and are increasingly being demanded given the unpredictable, but typically reduced winter road seaons because of changing climate.[10]

Energy infrastructure, such as transmission lines, is well established in the region of the watershed within the AOU (Figure 6). Infrastructure to support new industrial users within or outside of the watershed is likely to increase in the future. For example, both the Ring of Fire mines and the expansion of the Victor Diamond mine rely on infrastructure that may affect the Albany watershed. We assume that this infrastructure will parallel any road infrastructure. Energy infrastructure for remote communities in Ontario's Far North, including those in the watershed, is desired to reduce the

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[8] http://www.cbc.ca/news/canada/north/story/2013/03/28/tby-winter-roads-thunder-bay-remote-first-nations-communities.html
[9] http://www.afn.ca/index.php/en/news-media/latest-news/assembly-of-first-nations-national-chief-supports-calls-for-all-weathe
[10] http://www.mnr.gov.on.ca/en/Business/FarNorth/2ColumnSubPage/266512.html

dependency on diesel. First Nation communities in the northwest are involved in planning initiatives to supply energy to remote communities as a new upgrade from Pickle Lake to the Musselwhite Mine, under Ontario's Long Term Energy Plan, gets underway.[11,12]

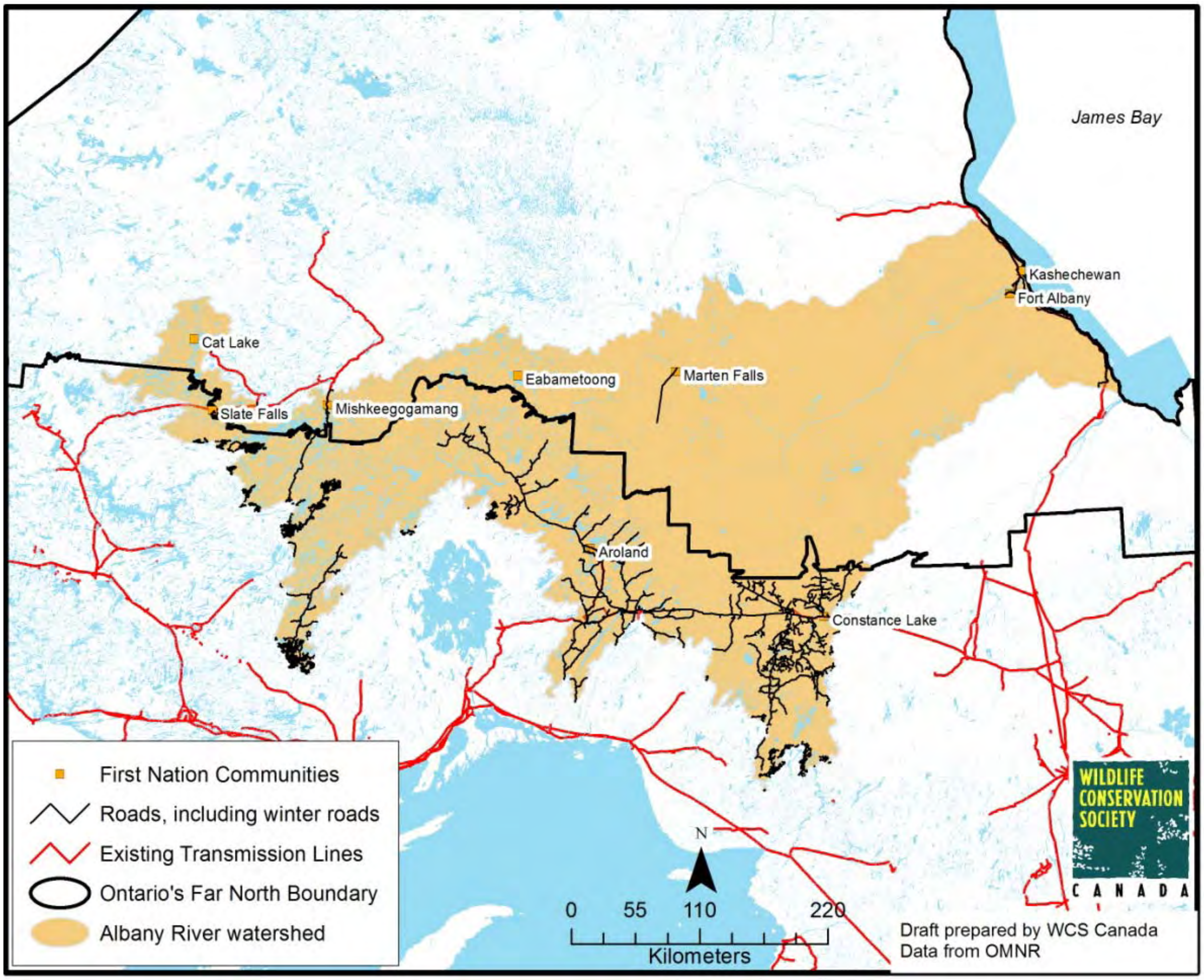

Figure 6. Current infrastructure (transmission, winter roads, roads) in the Albany watershed.

Assessing Climate Change Vulnerabilities

In most of the current literature on climate change adaption, the vulnerability of a species or ecosystem to climate change is a function of the amount of *exposure* to changes in climate conditions, the level of *sensitivity* to those changes in climate, and the *adaptive capacity* of the species or ecosystem to cope with that exposure and sensitivity. We define 'adaptation' as adjustments in ecological, social, and/or economic systems in response to observed or expected changes in climate to alleviate adverse impacts

[11] http://www.wataypower.ca/node/182
[12] http://www.sagatay.com/index-2.html

or take advantage of new opportunities. ‘Adaptation strategies’ are actions aimed at reducing vulnerabilities and/or taking advantage of opportunities related to climate change. A number of broad responses to climate change thought to support species or ecosystem adaptation have been described in the literature including:

- protect adequate and appropriate space for species, ecosystems, or processes;
- maintain or enhance connectivity;
- protect climate refugia[13];
- enhance resilience of species and systems to climate change;
- reduce non-climate stressors;
- use adaptive management approaches.

Understanding which of these concepts may be particularly applicable for planning purposes in the Albany watershed depends to a large extent on the community goals for conservation of freshwater fish. During the workshop we hosted in December 2012, we followed key steps from two similar and complementary adaptation planning processes – the process developed by Ontario and described in the “Practitioner’s Guide to Climate Change Adaptation in Ontario’s Ecosystems” (Gleeson et al. 2011) and the Adaptation for Conservation Targets (ACT) Framework (Cross et al. 2012) (Figure 7). Those steps include: 1) selecting a conservation feature; 2) identifying key drivers and current vulnerabilities; 3) developing and assessing future climate scenarios; and 4) identifying intervention points for climate and non-climate stressors.

[13] Climate refugia are generally defined as places where suitable climate/habitat conditions for a given species, ecosystem, or process will be found in the future. They can be in-situ refugia (places that are currently suitable and that will likely remain suitable in the future) or ex-situ refugia (places that are not currently suitable but may become so in the future).

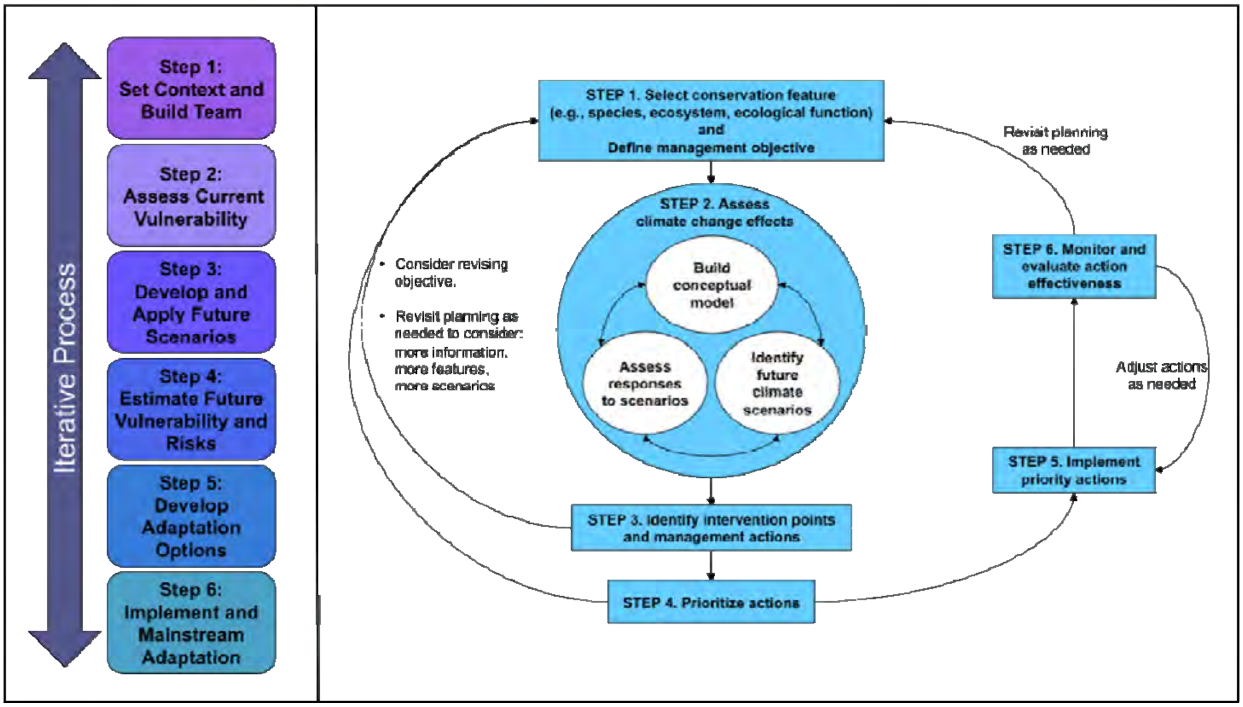

Figure 7. Adaptation planning processes that informed this assessment. Left: Modified from Gleeson et al. (2011). Right: The Adaptation for Conservation Targets (ACT) Framework (Cross et al. 2012).

Set Context and Select Feature(s)

We focused on a regional scale - the Albany watershed - which we consider to be an appropriate scale for preliminary adaption planning to address both climate and non-climate impacts on freshwater fish and aquatic ecosystems. In general, climate change impacts will occur beyond the watershed scale, however invasion dynamics, impacts on fish communities, loss of fish species, and effects on fish habitat due to climate change are relevant at this scale. Non-climate impacts, including contaminants and cumulative effects, are generally measured and assessed at the watershed scale. We *a priori* focused on freshwater fish and their aquatic habitats because of their ecological values as described above. We know they have important social and cultural values, but did not have this kind of information for this report. Our preliminary assessment is based on information from the scientific literature (described above in Sections 1 and 2), feedback received from experts at the December workshop, and expert opinion based on research on freshwater fish in northern Ontario (Jenni McDermid).

Assess Climate Change Effects

In order to assess climate change effects, we built a conceptual model for freshwater fish, identified a future climate change scenario, and developed a preliminary assessment of the responses based on expert opinion, literature review, and the feedback we gained at the workshop in December. These steps are described below.

A Conceptual Model for Freshwater Fish

Graphic conceptual models are used to illustrate and understand physical, ecological, social and climate drivers and how these may change under different climate scenarios. They are meant to be a simplified vision of the complex nature of the relationships between freshwater fish and their aquatic environments. For freshwater fish in the watershed, we identified a number of climate and non-climate stressors and the relationships to freshwater fish were determined based on the literature review in Sections 1 and 2 above (Figure 8).

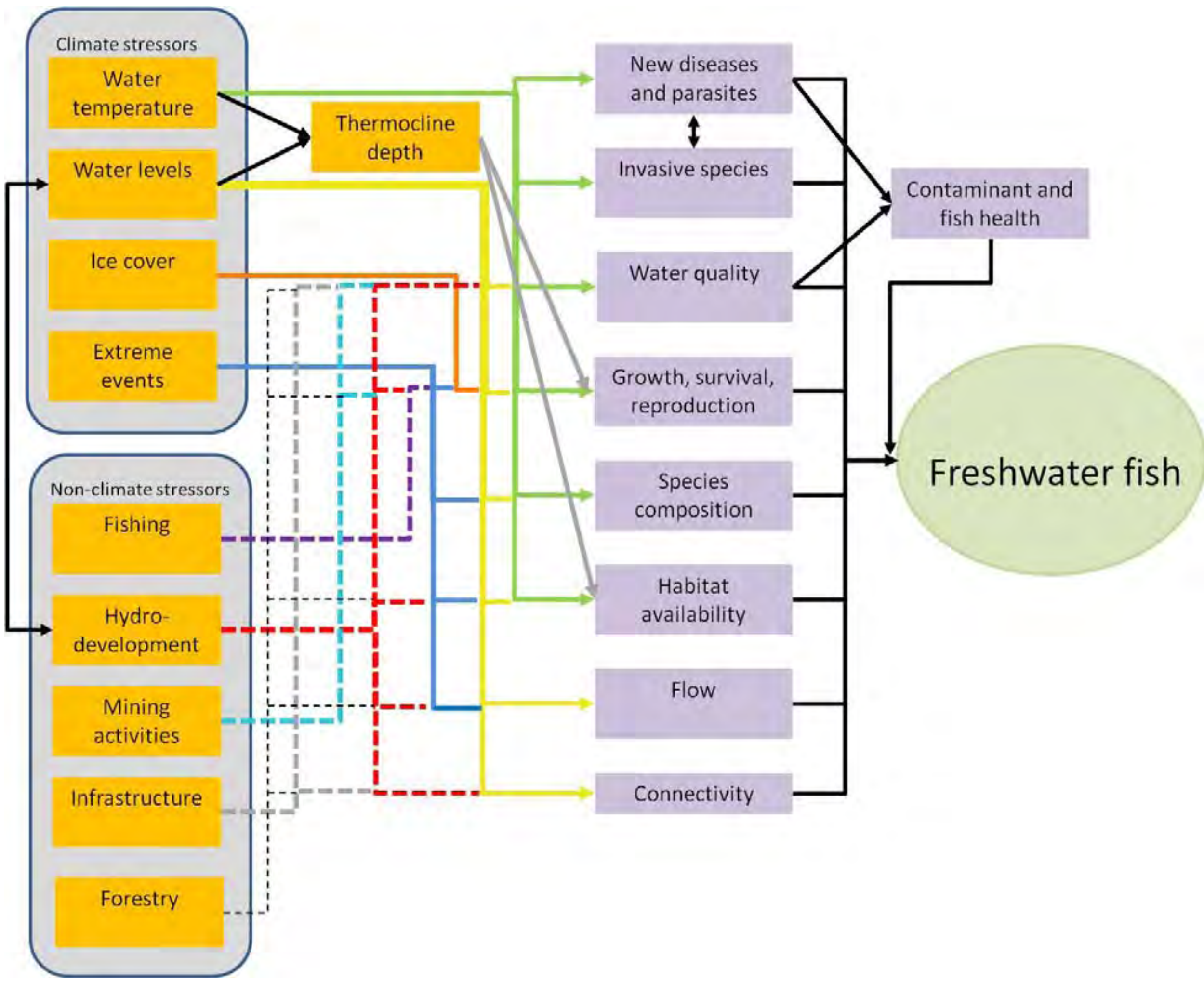

Figure 8. Graphical conceptual model of the key climate and non-climate stressors of potential influence to freshwater fish in the Albany watershed.

Based on feedback at the December workshop, there are a number of knowledge gaps associated with climate drivers:

- Permafrost;
- Watershed chemistry;
- Wind, especially extreme wind events;
- Marine environment dynamics such as saltwater intrusion;
- Fire regimes (frequency/magnitude/location in shield vs. lowlands).

Develop a Climate Change Scenario

Climate models are scientific tools that have been developed at a global scale to help us think about the future climate given what we know about the past climate. Often we want to know about what is happening in the regions where we live and work. Spatial climate models can be used to help us map the changes in regions and areas we are interested in to help understand impacts and support planning, adaptation options, research, monitoring, etc. They are not used to predict the weather, but to describe the slow mean change of average weather or variables we are interested in. All the data for climate models comes from weather stations, as well as summer fire weather stations, and is managed by Environment Canada. One general limitation to climate models in Canada is that we don't have a lot of historical data and this information is not evenly available across Canada. For example, there were few weather stations before 1930 and northern regions tend to be underrepresented (McKenney et al. 2011). In Ontario, there are 246 meteorological stations used to calculate Ontario climate norms, but only three of these are located in the Far North making the region one of the weakest meteorological networks in Canada[14]. While these data undergo testing for errors, they are, at best, an approximation of actual climate and we need to be cautious if we are using the maps to make decisions. Some of these models have been useful in indicating where climate change effects may be most pronounced (e.g., Arctic and Subarctic regions). Many of the model projections are supported by local observations, particularly in the Arctic (Krupnik & Jolly 2002, Berkes & Jolly 2002).

The other important aspect of climate modeling is simulating what the future may look like (e.g., scenarios). In its last report in 2007, the Intergovernmental Panel on Climate Change (IPCC) created different narrative "storylines" to describe consistently the relationships between the forces driving emissions (e.g., release of greenhouse gases like carbon dioxide and methane) and their trajectories. The most well known scenarios are called A1, A2, B1, and B2 (Table 1).

[14] http://www.mnr.gov.on.ca/en/Business/FarNorth/2ColumnSubPage/266512.html

Table 1. The Emissions Scenarios of the Special Report on Emissions Scenarios (SRES) (available at http://www.grida.no/publications/other/ipcc_tar/?src=/climate/ipcc_tar/wg1/029.htm)

A1. The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system.
A2. The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.
B1. The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.
B2. The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the A1 and B1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

The scenario considered in this report was developed by WCS climate change scientists Drs. Erika Rowland and Molly Cross using data from Natural Resources Canada, Canadian Forest Service (McKenney et al. 2011). The climatic and bioclimatic variables included in the scenario were based on projections from four general circulation models (GCMs) generated using the A2 emissions scenario and downscaled to 10 km resolution. These were the same data used for the December workshop.

We examined a variety of data in developing the scenario including annual temperature, annual precipitation, seasonal temperature and precipitation, maximum summer temperature, and growing season length for both the historical baseline (1961-1990) and future (2041-2070) time periods (Table 2). We selected three variables – maximum summer temperature, total annual precipitation, and growing season length - that addressed some of the key sources of climate change exposure for freshwater fish (Figures 9-12; see Appendix A for maps of baseline/historic outputs). The main scenario considered in this assessment reflects the projected changes in these variables between the historical baseline (1961-1990) and future (2041-2070) for the watershed. The changes represent increases for all variables: +3.5°C in summer maximum temperature, a 9 % increase in total annual precipitation, and an additional 23 days in growing season length (Table 2).

Table 2. Summaries of the projections from four different global circulation models for the Albany watershed developed by Dr. Erika Rowland, WCS. Model output is based on the relatively high IPCC A2 greenhouse gas emissions scenario for the period 2041-2070 and downscaled from 50 km to 10 km resolution by the Canadian Forest Service.

Model/Hist	**Annual Mean Temp (°C)**	**Annual Total Precipitation (mm)**	**Summer Max Temp (°C)***	**Grow Season Length (ave/max)**
Historic	*-0.7*	*671.0*	*22.9*	*156.0*
CGCM3.1	2.9	740.0	25.7	179.0
CSIRO-MK35	2.6	761.0	26.6	176.0
MIROC-32MR	3.0	697.0	26.9	181.0
NCAR-CCSM3	3.2	727.0	26.4	190.0
4-model average	*+ 2.9*	*731.3*	*26.4*	*181.5*
Albany scenario	*+ 3.7*	*+ 60*	*+ 3.5*	*+ 23*

[a]Data available upon request from the Canadian Forest Service. See McKenney et al. 2011 and http://cfs.nrcan.gc.ca/projects/3/8

[b]**CGCM3.1**-Canadian Centre for Climate Modelling and Analysis; **CSIRO-MK35**- *Commonwealth Scientific and Industrial Research Organisation (*CSIRO) Atmospheric Research, Australia; **MIROC-32MR**- National Institute for Environmental Studies, and Frontier Research Center for Global Change, Japan; **NCAR-CCSM3**-National Center for Atmospheric Research, USA-Climate System Model, Version 3.0.

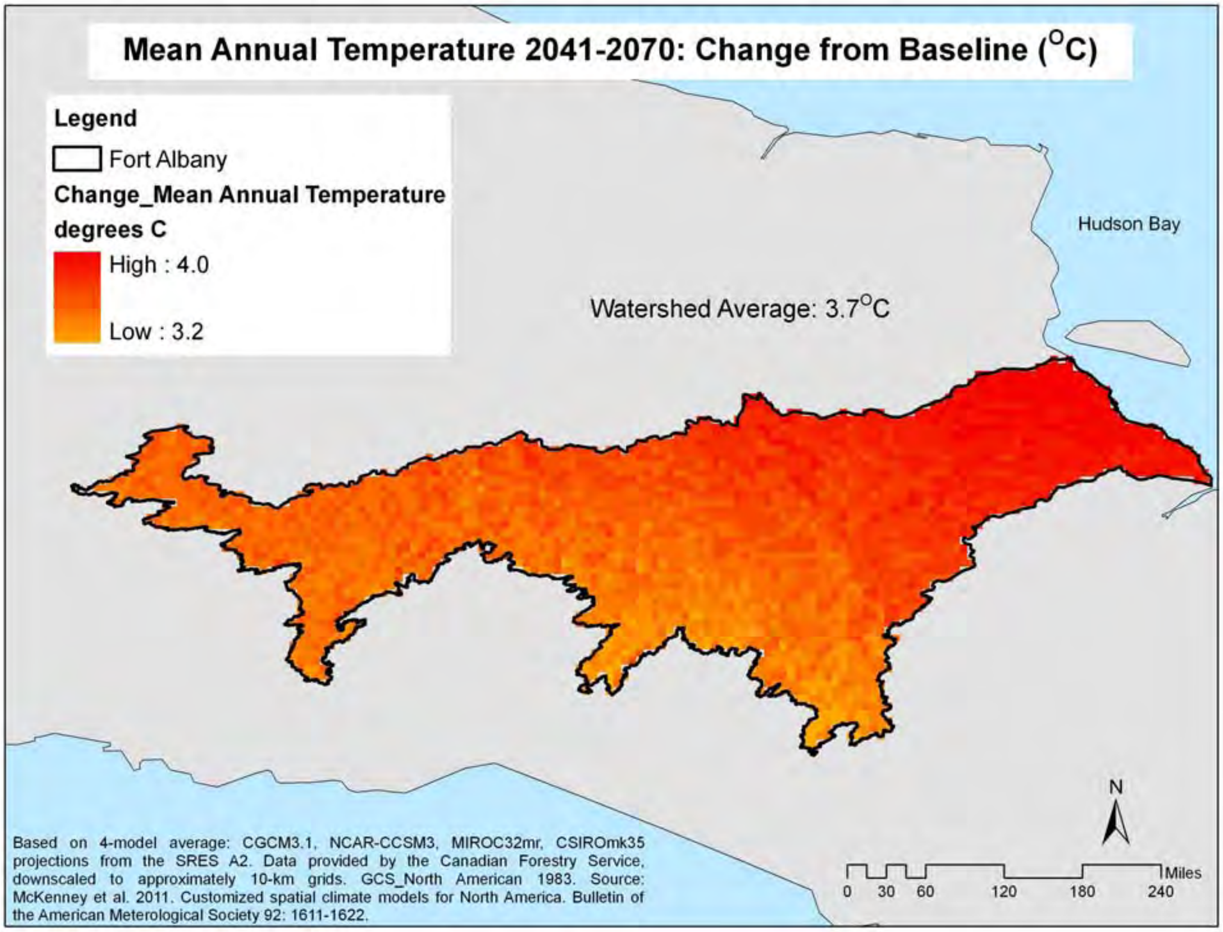

Figure 9. Map depicting the spatial heterogeneity across the Albany River watershed of the change in annual mean temperature between the baseline (1961-1990) and future (2041-2070).

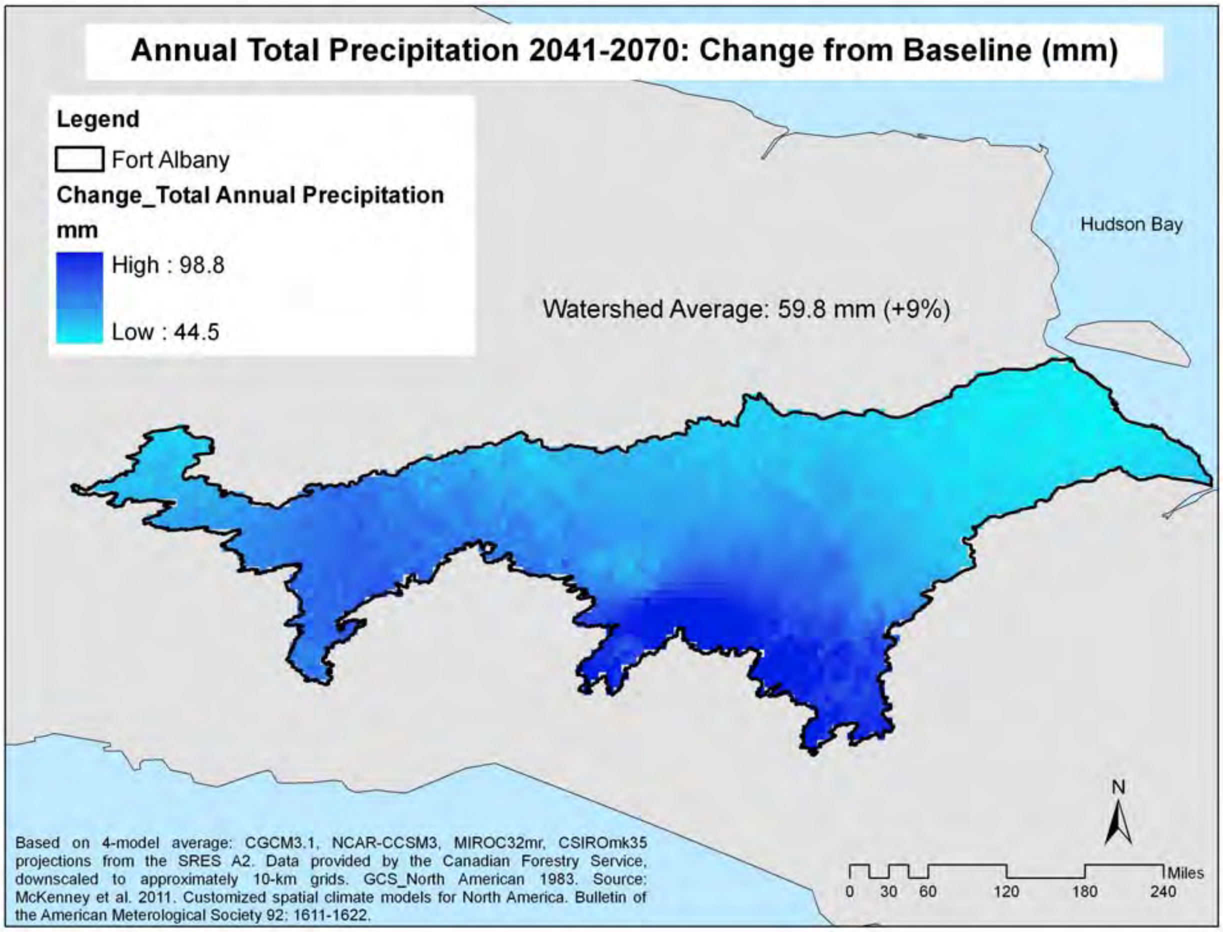

Figure 10. Map depicting the spatial heterogeneity across the Albany River watershed of the change in annual total precipitation between the baseline (1961-1990) and future (2041-2070).

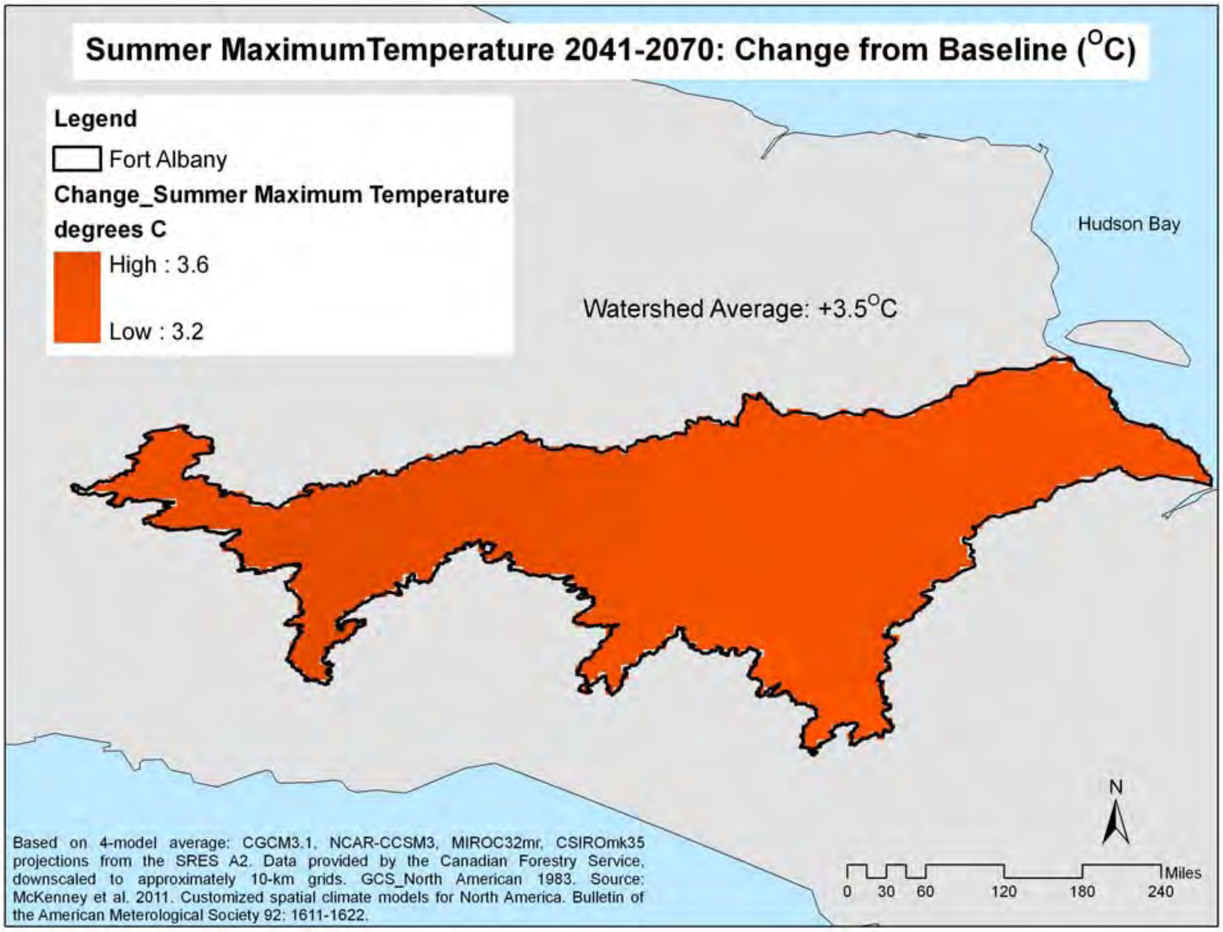

Figure 11. Map depicting the spatial heterogeneity across the Albany River watershed of the change in summer maximum temperature between the baseline (1961-1990) and future (2041-2070).

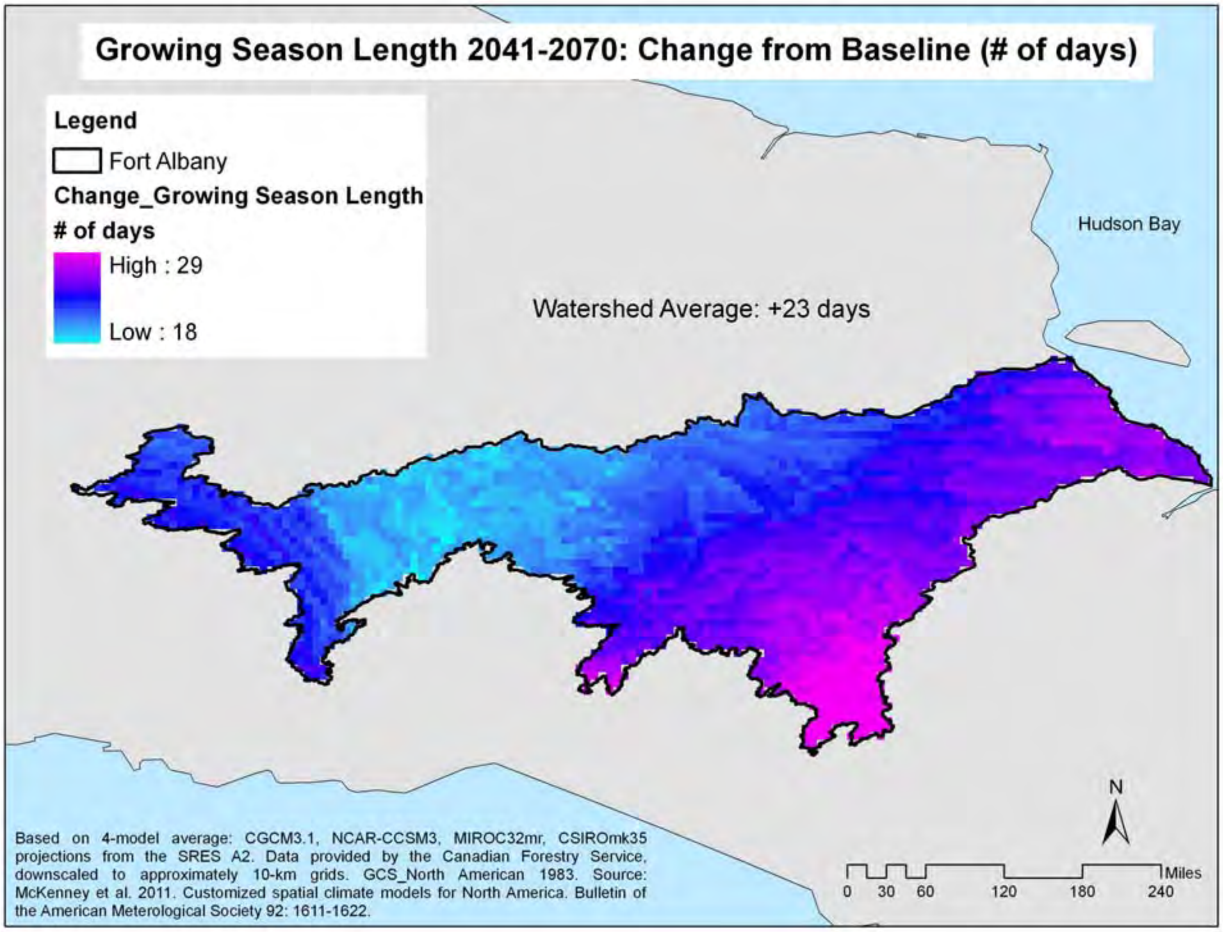

Figure 12. Map depicting the spatial heterogeneity across the Albany River watershed of the change in growing season length between the baseline (1961-1990) and future (2041-2070).

Models and the maps based on the models do have limitations. They are only as good as the data and information on which they are built. Based on feedback at the December workshop, we are aware of two general, but important limitations, with the climate change models used that are relevant for the Albany watershed:

- Some important hydrological processes are not captured in the models including:
    - Feedback mechanisms between freshwater and marine ecosystems in the lowlands, particularly ice dynamics. Consequently, the magnitude of future temperature change in particular is likely greater than described in our scenario.
    - Dynamics in hydrological cycles between surface and groundwater.
- Seasonal variation may be more important than annual means in northern systems.
    - 80% of river flow comes from spring melt, which is in turn affected by storage of water in ice during winter.

- Four calendar seasons may not be the appropriate timing for aquatics. Local observations identify six seasons [Spring: May-June; Summer: July-Aug; Fall: Sept-Oct; Freeze: Nov-Dec; Winter: Jan-Feb; Thaw: March-April].
- Seasonal or annual extremes in northern systems may be critical drivers in adaptation that are generally not captured in average projected trends.

Local observations of change could provide more explanatory power to these models, which tend not to deal effectively with uncertainty. Because the models are generally based on measures of average change, they may not be able to address social and ecological impacts associated with extreme events e.g., flooding and wildfires (Berkes 2002).

Apply Future Scenarios

Using the conceptual model as a guide, we considered the direct and indirect effects on freshwater fish and their habitats given the plausible scenario of future climate (2041-2070) for the watershed as described above (Table 2).

- Some of the key outcomes based on assessment of climate stressors include:
  - Cold-water fish will experience losses in habitat and certain cold-water fish (e.g., lake trout) will be more vulnerable than other cold-water fish species.
  - Adaptive capacity within guilds may make some species less vulnerable than others. Research has shown that lake trout have a more fixed physiological limit and cannot tolerate warmer temperatures whereas brook trout may have greater adaptive capacity.
  - Cold-water species will be more vulnerable in shallow lakes and rivers and areas without groundwater input and less vulnerable in aquatic ecosystems in the watersheds that are deeper and have groundwater input.
  - Cool-water species may benefit or decline due to competition and predation with warm-water species as they expand their range.
  - Warm-water fish will benefit from increased thermal habitats in the north.
- All guilds will be equally susceptible to certain impacts due to climate change. All thermal guilds could experience salt incursion in the lowland regions of the watershed, increased mobilization of sediment, and the loss of flow and droughts.

- Vulnerability of fish in aquatic ecosystems varies between ecozones (e.g., Boreal Shield, Hudson Plains Lowlands), but there are some unknowns.
    - Availability of thermal refugia may vary between ecozones. In the lowlands, thermal refugia could be moderated by groundwater and connectivity.
    - Populations in the lowlands may be more homogenous genetically because of the flat topography allowing mixing between systems when spring melt or flooding occurs.
- "Ecohydrological zones" as well as watersheds may be more relevant for climate change planning.
- Vulnerability within watersheds may depend on what is happening in other watersheds. In general, lowland areas of the watershed may be more susceptible to climate stressors due to proximity to James Bay and sea dynamics, isostatic rebound along the coast, and permafrost.

Some of the key outcomes based on assessment of non-climate stressors include:

- Generally, changes associated with land use such as forestry, mining, and hydrodevelopment exacerbate climate change impacts on freshwater fish.
    - Land uses increase levels of contaminants through both accidents and mobilizing materials in sediment.
    - Land use changes like roads and increased connectivity increase opportunities to introduce species (e.g., through live bait) to northern watersheds.
    - Inputs that increase oxygen stress and eutrophication in aquatic systems will reduce the resilience of freshwater fish against other stressors e.g., parasites, invasive species, etc.
    - Adaptation planning should set goals/visions/objectives for the desired conditions in watersheds or ecohydrological zones, given current and potential land use.
    - Pathway of effect diagrams could be useful to help understand and communicate how various land use scenarios and plans could affect freshwater fish guilds within a watershed.
- Cumulative effects assessment for aquatic systems needs to be proactive and applied at the watershed scale because rivers in particular and their associated wetlands have longitudinal, lateral, and vertical connections that present special challenges to planning for conservation of freshwater fish and their habitats (e.g., jurisdiction, human demands, connectivity). Most management of fish and freshwater systems in practice is focused on single species, single types of waterbodies like lakes, etc. even though there are multiple impacts. In addition, conservation

planning for freshwater systems has lagged behind terrestrial and marine planning and expecting protected areas to conserve freshwater biodiversity is widely seen as a failure due to ineffective design and management (Abell et al. 2011). Multiple land uses and climate change impacts demand more proactive and effective approaches for addressing cumulative effects on aquatic systems (Schindler 2001).

- Each land use has varying degrees of impact on the aquatic ecosystems. Single, multiple and cumulative effects of land uses on aquatic systems should be considered in light of climate change.
- Harvest needs to be managed and monitored with attention to access management associated with new infrastructure and land uses.

Identify Adaptation Options

Adaptation options are usually thought about as ways in which we can reduce vulnerabilities, take advantage of opportunities, and cope with changing conditions. Can we moderate exposure of sensitive species, or address the natural ability of species to adapt to these changes? Are there existing strategies that could be modified to accommodate changes in this region? With respect to the conceptual model, could we identify specific intervention points?

Based on the feedback from the December workshop, we developed a preliminary set of intervention points for climate and non-climate (land use) stressors that may be equally relevant for this watershed. These include: climate refugia, stewardship and education, climate change mitigation, land use planning and documentation, and environmental assessment. The points require both discussion and input with community and other experts to address risks for freshwater fish and aquatic ecosystems in the watershed.

Baseline Research

In Ontario’s Far North, there is a dearth of scientific information to address changes and impacts due to climate change and land uses, which supports the need for baseline research and monitoring. Based on the December workshop, there are a number of general research needs identified that are generally relevant for adaptation planning and vulnerability assessment and could be considered in this watershed. Addressing these research questions would support decision-making for freshwater fish given climate and non-climate stressors in the watershed (Table 3).

Table 3. Preliminary research needs.

Hydrology
What are the feedback mechanisms between freshwater and marine ecosystems in the lowlands, particularly the effects of ice dynamics on the Bays?
What are the dynamics of groundwater cycles in the lowland systems in particular?
Freshwater fish and habitats
What fish communities currently occur in wetland and spring bogs?
What is the adaptive capacity of species in these thermal guilds?
How will connectivity affect anadromous fish?
How does change in scouring and ice activity in streams and rivers affect eggs and spawning habitat?
Permafrost
How does permafrost melt affect mercury levels and dissolved organic carbon?
Mapping
Mapping of permafrost needed as national dataset and maps are not current.
Invasive Species
Map the risk of invasive species in the watershed e.g., access, connectivity
Fish health and disease
How might increased temperatures affect health of fish from a disease perspective?
How do other stresses affect fish health and immunity?
Extreme events
How do these impacts vary based on boreal shield vs. lowland regions in the watershed?

Monitoring

At present, there are two scales of scientific monitoring occurring in the Far North that may inform Fort Albany planning processes: 1) baseline studies and monitoring programs that may be associated with current or new development projects developed in Ontario's environmental assessment processes; and, 2) lakes being sampled under OMNR's broad-scale monitoring program for freshwater fish and aquatic ecosystems (see overview in Marshall & Jones 2011). While the scope and extent of information available varies among watersheds, one of the main recommendations from our December workshop was the need for proactive multi-scale monitoring of numerous system components to understand impacts on freshwater fish in the face of change due to climate and emerging land uses. We selected some of the monitoring options that may be relevant to Albany watershed (Table 4).

Table 4. Preliminary monitoring recommendations.

Monitoring for baseline Review existing systems of monitoring and protocols e.g., BSM, Alberta Monitoring for aquatics should include: Temperature, precipitation, stream flow, water quality Fish health e.g., parasites Fish contaminant loads e.g., mercury A diversity of fish, not just game species Attention to multiple scales for monitoring Regional scales are most relevant for cumulative effects
Monitoring for industrial land uses. Develop before and after control impact (BACI) monitoring systems for new developments. Point source contamination in watersheds demands more intensive monitoring e.g., government, industry Share information from other contaminated sites e.g., military sites, to support better monitoring programs

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APPENDIX A. Baseline maps for selected climate variables relevant to Freshwater Fish across the Albany watershed.

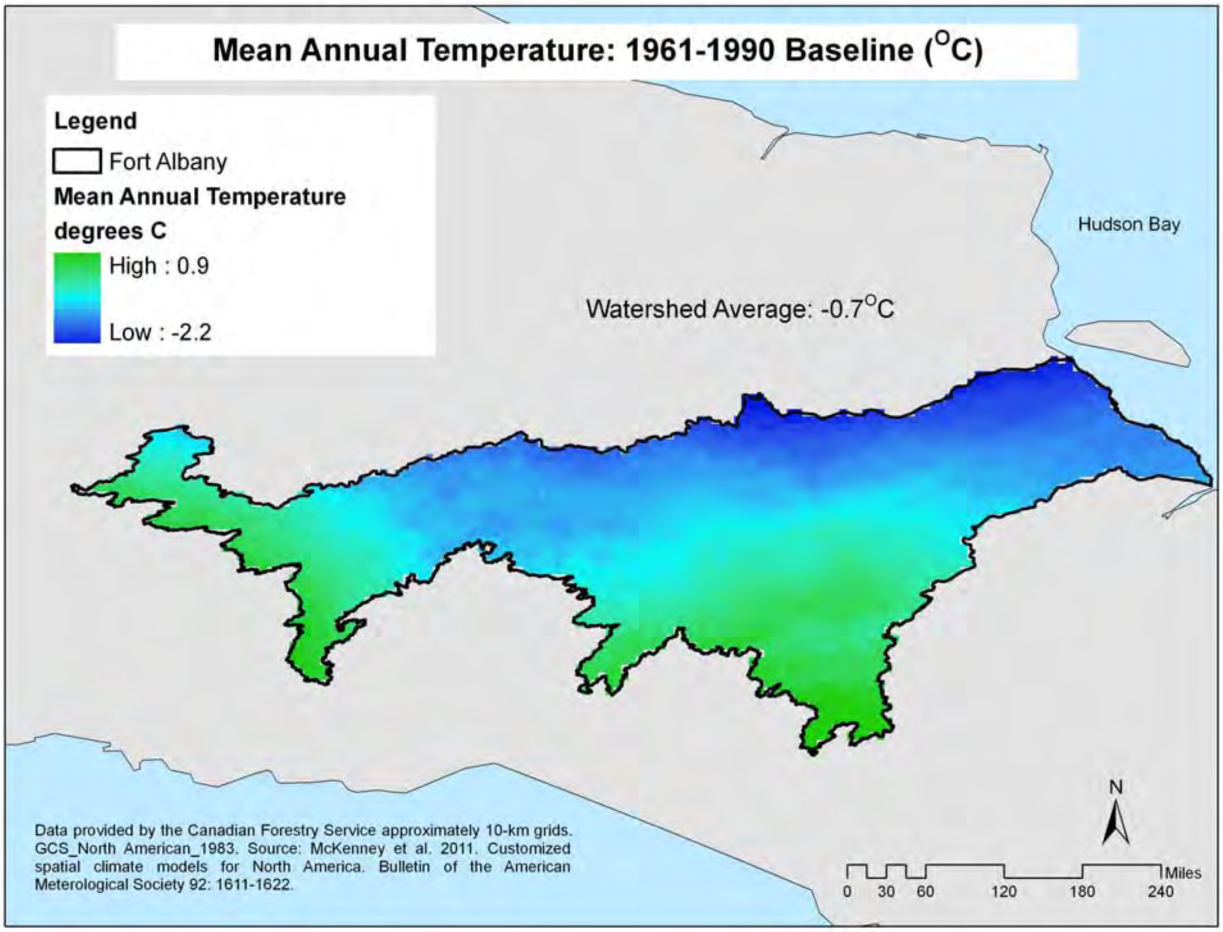

Figure 13. Map of the baseline (1961-1990) annual mean temperature across the Albany watershed.

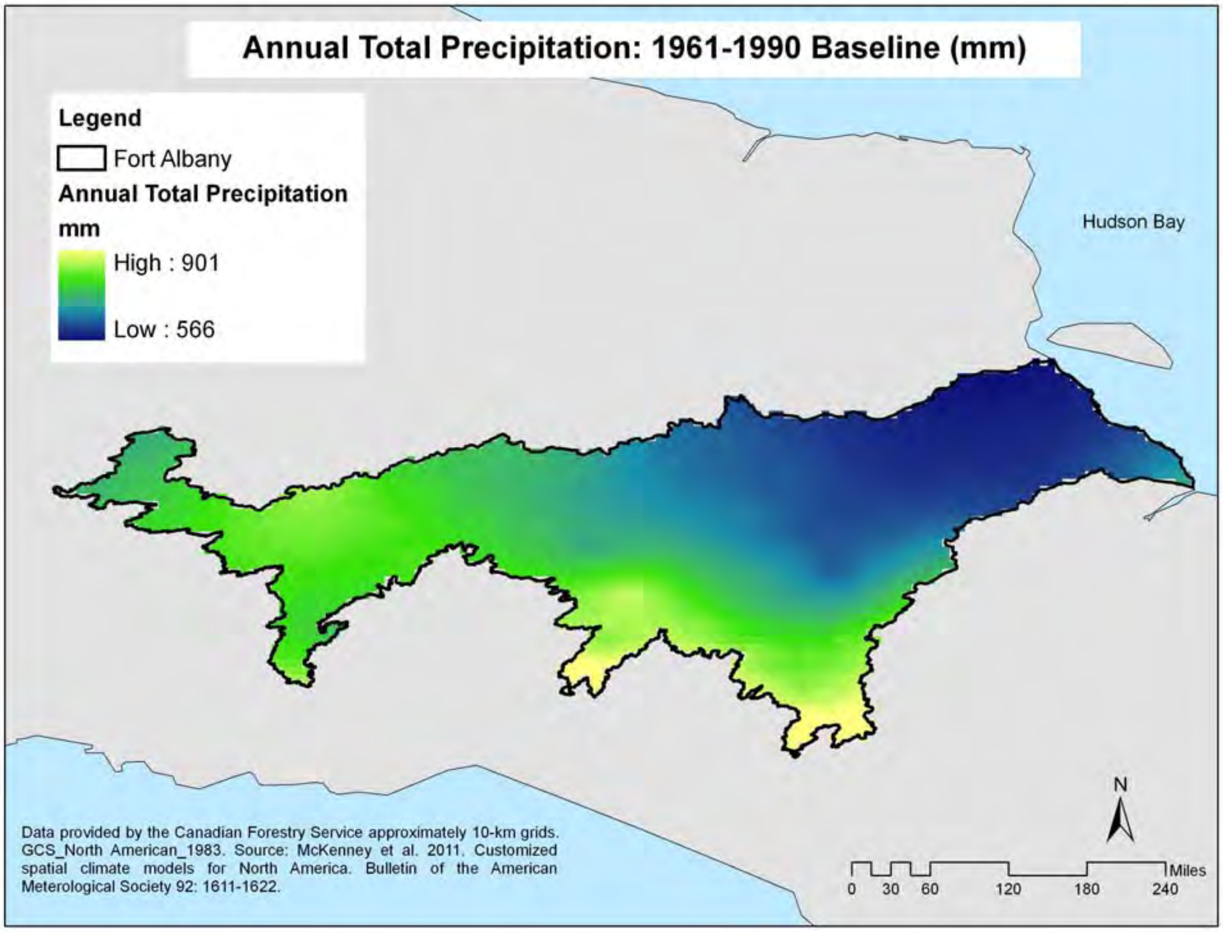

Figure 14. Map of the baseline (1961-1990) total annual precipitation across the Albany watershed.

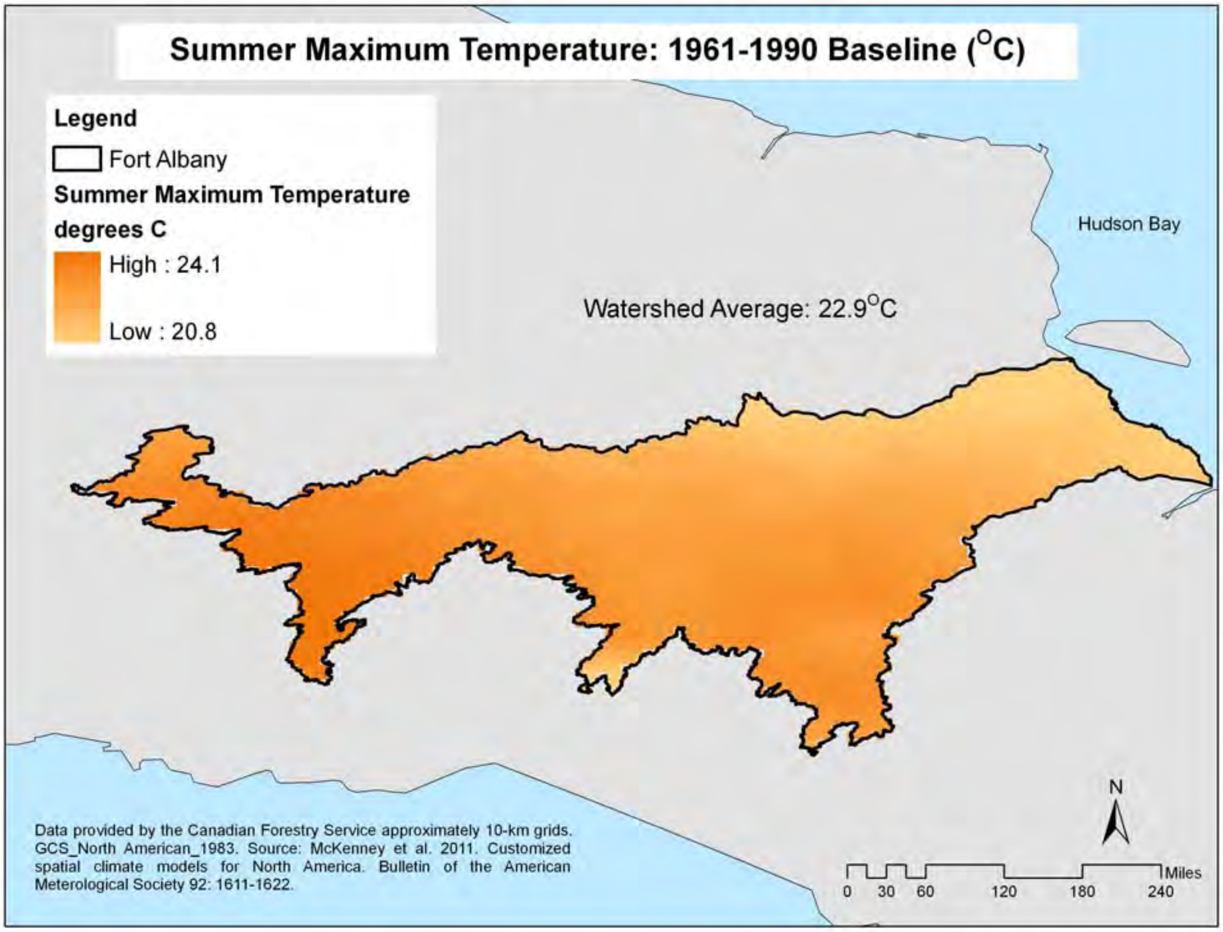

Figure 15. Map of the baseline (1961-1990) summer maximum temperature across the Albany watershed.

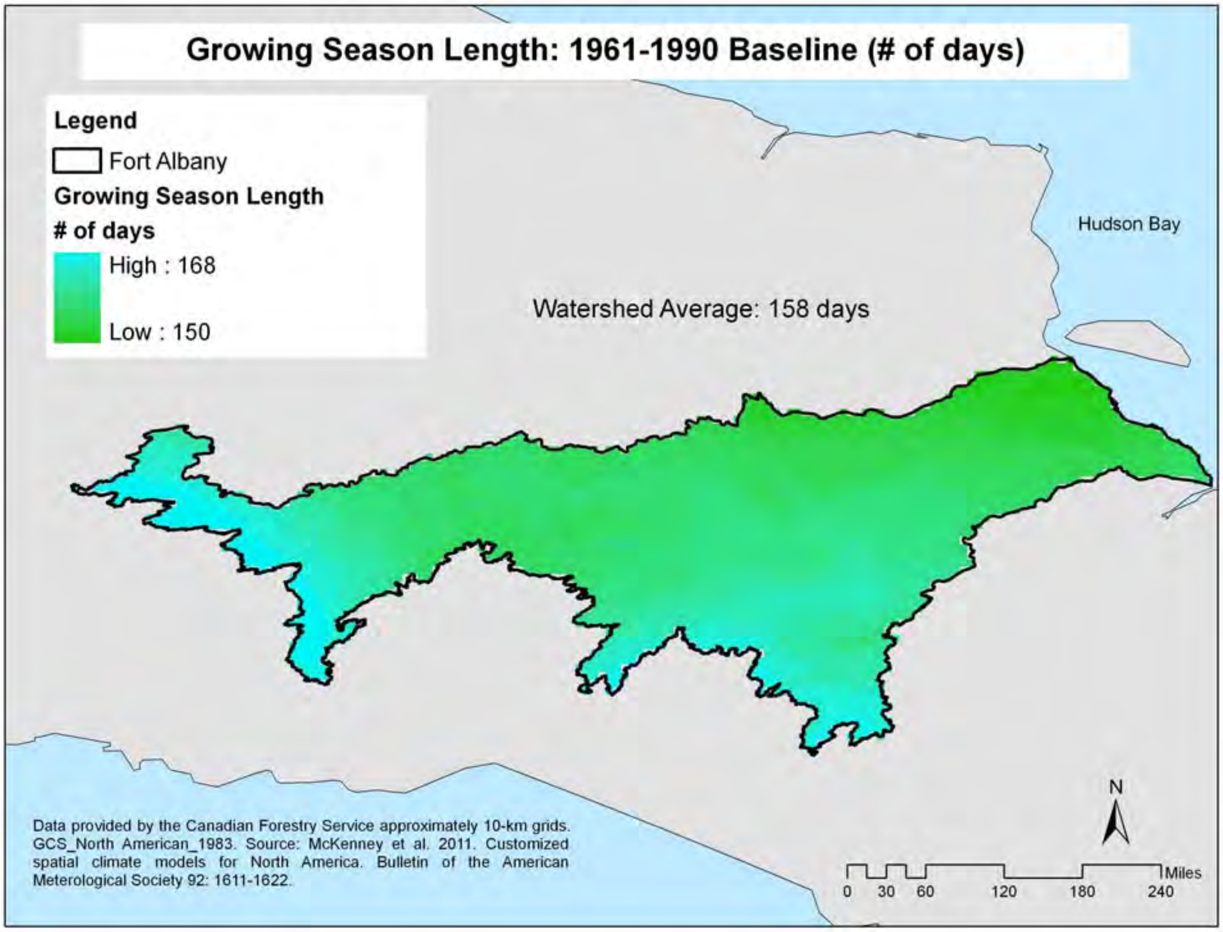

Figure 16. Map of the baseline (1961-1990) growing season across the Albany watershed.