Yukon Water

An Assessment of Climate Change Vulnerabilities

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Copies available from:

Environment Yukon
Water Resources Branch, V-310
Box 2703, Whitehorse, Yukon, Y1A 2C6
Email: water.resources@gov.yk.ca
www.environmentyukon.gov.yk.ca

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Executive Summary

Executive Summary

The need to monitor and respond to climate change—including its impacts on water—is an emerging national and territorial priority. Climate change is already altering, and will continue to alter, the hydrologic cycle in Yukon, affecting not only water-course flows, volumes, and timing, but also the quality of the water. These changes will inevitably affect every aspect of Yukon life, from day-to-day household practices to industrial development and energy generation.

This report provides a snapshot of current and forecasted water resource issues in Yukon related to climate change. It documents current and future Yukon water uses and practices, reviews our knowledge about possible climate change impacts on Yukon water, and provides a list of existing programs that collect water-related data. The report was produced through the Adaptive Management for Water Users Responding to Climate Change project (the Water Adaptation Project), led by Environment Yukon's Water Resources Branch and funded by Indian and Northern Affairs Canada.

Yukoners have many water needs. Some industries, such as agriculture and placer mining, depend entirely on the availability of water. Hydro power plants need reliable river flows, as well as water storage, in order to meet energy demands. Hard rock mines often have too much water and have to manage it carefully to minimize impacts on surrounding water quality. Groundwater is our main source of drinking water. And we use water bodies and waterways for travel, firefighting, recreation, and harvesting. Water also has great cultural significance for many Yukoners.

Climate change is intrinsically linked with hydrological changes. However, determining the effects of climate change on water resources at the scale of a region—even a region the size of Yukon—is difficult. Trends analyses are sensitive to time scales and to natural variability, such as interannual to decadal climate oscillations. Projections of possible futures for climate and hydrology are affected by the chosen emission scenarios, global climate models, downscaling techniques, model runs, and hydrologic parameterizations. While some studies have examined climate change impacts on water resources in Yukon, many gaps remain.

It is clear, however, that Yukon's climate is changing, and so is its hydrologic regime. Over the last several decades, winter and summer temperatures have increased in all regions, and the forecast is for continued warming. Most projections for precipitation suggest increases, particularly in winter. Snowmelt has been starting earlier, particularly in Yukon's mountain streams. The period of snow cover is decreasing, and a continued trend of earlier snowmelt and associated earlier peak flows can be expected. An analysis of global evaporation trends found that higher temperatures could result in greater evaporation, particularly in the North.

The cryosphere—snow and ice in all their forms—is important to Yukon water resources. It is also particularly vulnerable to climate change. Increasing air temperatures are already leading to permafrost warming and degradation. Yukon has lost 22% of its glacial cover over the last 50 years, and continued decline could have a profound influence on glacier-dominated basins. The timing of break-up on the Yukon River at Dawson has advanced by at least five days a century since records were first kept in 1896, and a similar trend is noted for the Porcupine River at Old Crow. Changes in break-up and spring freshet timing could lead to new problems with ice-jam floods.

Streamflow patterns, both above and below ground, are changing. The changes in surface streamflow vary by hydrologic regime and season, with increases in some times and places and decreases elsewhere. Generally, increased river flow is projected for high-latitude rivers, such as the Yukon and Mackenzie, to the end of the 21^{st} century. How climate change will affect groundwater is not well understood at present. However, the Yukon River Basin is experiencing significant increases in estimated groundwater flow. Within Yukon, the largest increases were detected in the Yukon headwaters and the Porcupine River watershed.

Water quality is an issue, as well as water quantity. Lower water levels tend to increase concentrations of ions (e.g., dissolved metals) in water. High flows and flooding flush sediment and contaminants, both natural and anthropogenic, into the water system. Higher water temperatures affect ecosystems, human health, and community water systems.

Climate change is also linked to some extreme events. There appears to be an upward trend in the number of heavy snowfalls in autumn and winter over northern Canada. The Klondike River mid-winter break-up and flood in 2003, rapid lake drainage in Old Crow Flats, and flooding in the Southern Lakes all happened in the last decade.

In the face of this level of change, information is vital. A great many governments, departments, and organizations are engaged in water monitoring and data collection in Yukon. While the majority of these programs are not collecting data for the purpose of climate change detection and adaptation monitoring, their spatial, temporal, and parameter coverage are invaluable to climate change planning. A high-level investigation of spatial coverage indicates that hydrometric, meteorological, and snow networks provide good regional coverage in the territory, although a large gap is apparent in the coverage of water quality in northern Yukon, with no active stations in the Peel Watershed.

This report draws several high-level links between water use needs and changing hydrological and water quality regimes, based on the identification of key water use vulnerabilities and the assessment of general trends and projections available for Yukon water resources. Much work remains in order to address the vulnerabilities identified for Yukon water use and to inform both users and decision makers about how to adapt their actions in response to the impacts of climate change. From this first step, several areas for further consideration are identified, many of which rely on continued collection, use, and dissemination of water monitoring data.

These include:

- A progression toward monitoring and managing on a watershed basis, rather than stream by stream.
- The incorporation of water valuation principles and a more formalized approach to environmental flow assessments into water management.
- The consideration of projected hydrologic changes in near- and long-term planning for hydro power production.
- The accounting of future changes to water flow and quality when assessing future agriculture growth areas, and associated water supply options.
- The regular review and revision of minesite water balance and water management plans to respond to climate and hydrologic changes.
- The consideration of climate change implications for mine closure planning, including on-going monitoring.
- The development of community risk evaluations and adaptive management plans for water needs of Yukon communities.
- Improved understanding of groundwater resources, and ensuring the information is communicated from researchers and monitoring agencies to decision makers.
- The review and adjustment of water monitoring networks to take into consideration future needs, climate change, and adaptation measures.
- The support of watershed modelling research that could help decision makers ensure projects affecting water are sustainable.
- The increased dissemination of water monitoring data and information.
- The recurring review of the different facets of water management to ensure that decision making is informed by and responsive to changing climatic conditions.

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Prepared by:

Holly Goulding, Water Adaptation Analyst, Water Resources Branch, Environment Yukon

Consultant:

Claire Eamer, Writer

Reviewers:

Heather Jirousek, Program Advisor, Water Resources Branch, Environment Yukon

Kevin McDonnell, Director, Water Resources Branch, Environment Yukon

Tim Sellars, Manager, Environmental Planning, Environment Yukon

Ric Janowicz, Manager, Hydrology Unit, Water Resources Branch, Environment Yukon

Bob Truelson, Manager, Water Quality Unit, Water Resources Branch, Environment Yukon

We would like to acknowledge contributors who provided information about their programs and activities:

Environment Yukon

Kevin McDonnell

Heather Jirousek

Ric Janowicz

Glenn Ford,

Bob Truelson

Jean Beckerton

Wayne Kettley

Julia Ahlgren

Pat Paslowski

Bryan Levia

Bethany Peters

Matthew Nefstead

Nathan Millar

Energy, Mines and Resources

Mark Nowosad

Tanya Gates

Angele LeDuc

Panya Lipovsky

Sarah Laxton

Kaori Torgai

Frank Patch

Matt Ball

Richard Corbet

Bob Holmes

Erin Dowd

Lyle Dinn

Community Services

Don Green

Peter Zurachenko

Rodney D'Abramo

Health and Social Services

Dianna Hayden

Pat Brooks

Benton Foster

Highways and Public Works

Nick Barnett

Catherine Harwood

Executive Council Office

Kelly Boutelier

Jennifer Logan

Environment Canada

Wade Hanna

Andrew Muir

Denis LaCroix

Doug Davidge

Bob More

Bev McNaughton

Andrea Ryan

Fisheries and Oceans Canada

Sean Collins

Indian & Northern Affairs Canada

Kevin Rumsey

Yukon River Inter-Tribal Watershed Council

Bryan Maracle

Leah Mackey

Ta'an Kwäch'än Council

Rosa Brown

Tr'ondek Hwech'in

Bill Kendrick

Kwanlin Dun First Nation

Dave Sembsmoen

Carcross Tagish First Nation

Mike Baerg

Mike Wark

Randy Clarkson

Dale Eftoda

Kai Woloshyn

Niels Jacobson

Rick Nielsen

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1 Introduction

1 Introduction

Water resources is one of the highest priority issues with respect to climate change impacts and adaptation in Canada. A clean reliable water supply is crucial for domestic use, food and energy production, transportation, recreation and maintenance of natural ecosystems. Water related problems, such as droughts, floods and assorted water quality issues are expected to become more common as a result of climate change.

Lemmen and Warren, 2004

The need to monitor and respond to climate change—including its impacts on water—is an emerging national and territorial priority. Climate change is already altering, and will continue to alter, the hydrologic cycle in Yukon. Precipitation, snowpack, permafrost, glaciers, and streamflow are changing as a result of climate change. This affects not only water-course flows, volumes, and timing, but also the quality of the water. As part of adaptation planning, decision makers strive to develop adaptation measures that will position the jurisdiction to handle the changes.

Yukoners use water for a variety of purposes: drinking water, electrical generation, industrial water supply and waste disposal, irrigation, and recreation. Yukoners value the ecosystem services that water provides, such as habitat, waste assimilation, and productive capacity, as well as cultural and spiritual services.

Yukoners will have to adapt their use of water in response to the impacts of climate change on the territory's water resources. Action is needed, equally, to ensure that water management decisions (e.g., water licensing) take into account discrepancies between the needs of water users and the current and future supply. The challenge planners and resource managers face is the limited current understanding of the effects of climate change on Yukon's hydrology and water quality at local and regional scales. The availability of reliable long-term data is a constraint to climate change projections and watershed modelling across Canada's North, and uncertainty and sometimes-contradictory conclusions inherently underly any predictions of climate change effects on water resources.

At the very least, governments and water managers can use water monitoring networks to gather the information needed to assess and plan for possible adaptations to a changing climate. Whatever the approach used to plan for climate change adaptation, it is vital to have access to accurate, sufficient, and relevant data on hydrological conditions and water quality. We need monitoring data to reduce the uncertainties related to the hydrological impacts of climate change and to calibrate and validate climate and hydrologic models. We also need to forecast future water uses, to the extent possible, in order to identify and prepare for areas that may be under threat from the combined pressures of climate change and water use.

This information will aid in the identification of vulnerable water resource systems, and allow managers and decision makers to pursue "no regrets" adaptation actions—that is, actions that generate net benefits under all future scenarios of climate change and impacts. We also need monitoring to determine the effectiveness of adaptation measures.

This report attempts to summarize the vulnerability of Yukon water resources to climate change by documenting existing and forecasted uses of water and practices throughout Yukon, current knowledge and modelling related to climate change impacts on Yukon's water quantity and quality regimes, and existing water quantity and quality data collection programs. It ultimately provides a snapshot of current and forecasted water resource issues in Yukon related to climate change.

It is hoped that communities, First Nations, other government agencies, municipalities, researchers, academia, and non-profit organizations will benefit from the collation of water resources information in this report, whether to assist in watershed stewardship initiatives or to help facilitate better decision making and community planning. It is also anticipated that the information will set the groundwork for further work on the development of regional climate change scenarios and community information and needs assessments.

1.1 Background

This report has been produced through the Adaptive Management for Water Users Responding to Climate Change project (the Water Adaptation Project), led by Environment Yukon's Water Resources Branch and funded by Indian and Northern Affairs Canada. This two-year project sought to address gaps in knowledge, collection, amalgamation, and dissemination of all sources of water information in order to guide adaptive actions by water users and to assist decision makers in responding to climate change.

The report builds on the following needs, identified through the Water Management Framework initiative led by the six Yukon Government departments with responsibilities for territorial waters (see section 2.3):

- More water quality and quantity data availability to support baseline determination, impact assessment, modelling for water supply, cumulative effects, land use planning and climate change.
- The need to improve the utility and accessibility of research results for use by decision makers.

The report addresses these needs by summarizing and disseminating climate change research related to water resources and base information on water monitoring networks. A website, yukonwater.ca, created in parallel with the report, further delivers on these goals.

The report is also intended to meet the water-related adaptation goal, set out in the Yukon Government Climate Change Action Plan, of completing a Yukon water resources risk and vulnerability assessment.

1.2 Objectives

The primary objective of the Water Adaptation Project is to ensure that water programs meet the needs of water users as they respond to the effects of climate change. This report is intended to help fill the gaps in knowledge and in the dissemination of data related to water use, the impacts of climate change on water resources, and water quantity and quality for the use of those engaged in project planning, decision making, and community understanding.

By assembling all available information on existing and forecasted uses of water throughout Yukon, water quantity and quality data collection, and predicted water flow and quality changes arising from climate change, the report provides a foundation that will help territorial, federal, municipal, and First Nation government water managers take effective adaptive actions, particularly with regard to water quality and quantity collection programs.

1.3 Scope

This report includes:

- A high-level description of water use in Yukon, including public and industry consumptive and non-consumptive water users.
- A high-level summary of research on climate change impacts on water resources.
- An inventory of water monitoring networks.
- A discussion of key stresses and knowledge gaps.
- Priorities moving forward.

The report considers the water regime for the entire Yukon Territory, without going into deeper regional analysis. It identifies high-level gaps, but does not look at distinct hazards or use risk matrices.

1.4 Methodology

Data and information collected for this report include:

- Quantitative data, gathered from reports, peer-reviewed literature, territorial and national statistics, water licences, and other environmental permits.
- Qualitative data, gathered through initial consultations with government resource and water managers, focus groups, and through broader outreach with Yukon Government, federal government, municipalities, First Nations, boards and councils, and academia.

2 Yukon Water Landscape

Yukon, with only a small population, is rich in water resources. Many agencies manage and advocate for the protection of water resources in the territory, including federal, territorial, municipal, and First Nation government departments, boards and councils, and non-governmental organizations. This section provides the physical and cultural context for water resources and their use in Yukon, in addition to outlining Yukon water governance and management.

2.1 Physical Setting

Yukon occupies the northwestern corner of Canada. Its southern border with British Columbia lies at 60°N, and its western border, with the state of Alaska, is at 141°W. Its eastern border, with the Northwest Territories, roughly follows the Yukon/ Mackenzie watershed. On the north, the territory is bounded by the Beaufort Sea.

Most of Yukon falls within the northern part of the Canadian Cordillera, or the Western Canadian Sedimentary Basin. Much of the land surface is relatively high elevation—either mountainous or high inland plateau—and soil cover is thin, leaving bedrock at or near the surface through much of the territory (Smith *et al.*, 2004, Bedrock Geology).

The territory is drained by six major watersheds, each with several tributaries (Figure 1). The watersheds are the Alsek, Yukon, Porcupine (Yukon), Peel (Mackenzie), Liard (Mackenzie), and North Slope.

2.2 Cultural Setting

As of June 2010, the population of Yukon was 34,984. Roughly two-thirds live in the capital city, Whitehorse. The other larger communities—all much smaller than Whitehorse—are Dawson City, Watson Lake, and Haines Junction. Only one Yukon community, Old Crow, is without all-season road access.

Of the territory's 14 First Nations, 11 are self-governing. First Nation governments play a large and growing role in Yukon, and renewable resource councils and other multi-party advisory bodies established through the land claims process are an important part of the management regime for natural resources, including water resources.

Historically, mining was a major component of the Yukon economy. Through the last years of the 20th century and the first decade of the 21st century, however, the industry was in decline. In 2008, mining, quarrying, and oil and gas extraction totalled just over 5% of Yukon's Gross Domestic Product (Nelitz *et al.*, 2010). With several large mines in various stages of development and strong gold prices, that percentage could climb in the near future.

Based on Yukon Bureau of Statistics monthly employment reports, the territory's largest employer is the public sector (all levels of government services), employing more than 40% of working people in 2009. The retail trade, tourism, and related service industries also employed substantial numbers (Nelitz *et al.*, 2010). Agriculture, forestry, and trapping and hunting are very small components of the territorial economy but locally important in some communities.

Figure 1: Yukon drainages

2.3 Water Governance and Management

Water governance and management are central to ensuring sustainable water use. Water governance provides the context for the decision-making process we follow, while water management refers to the operational approaches we adopt. Governance includes how we make decisions and who gets to decide. Management includes the policies, models, principles, and information used to make those decisions (Bakker, 2007) and the procedures used to implement them.

2.3.1 Yukon Government

Within the territorial government, there are six departments with responsibilities for Yukon waters:

- Environment (Water Resources Branch) develops water-related strategic plans and policies, monitors, analyzes, and reports on water quality (e.g., aquatic health) and quantity (e.g., flood forecasting), and provides expert technical advice in these areas. It enforces the *Waters Act* and ensures compliance with water licences and for water-retaining structures. Other Environment responsibilities with respect to statutes and programs with mandates for protecting various components of the environment include surface and groundwater (e.g., fisheries management, monitoring of permittee groundwater sampling requirements for solid waste disposal sites).

- Energy, Mines and Resources (Client Services & Inspections and Minerals Branch) is directly responsible for protecting water resources in relation to placer mining and one large quartz mining project. It is also indirectly accountable through its mandate for managing minerals, abandoned mines, lands, oil and gas, energy, agriculture, forest resources, and regional land use planning.

- Community Services (Community Infrastructure Branch) builds and manages water, sewerage, road works, flood and erosion control, and solid waste disposal projects for unincorporated Yukon communities. It also provides advice and project assistance to municipalities and Yukon First Nations.

- Health and Social Services (Environmental Health Services) regulates drinking water in Yukon through the *Drinking Water Regulation* under the *Public Health and Safety Act*. It provides information and advice, and performs inspection and enforcement in a variety of areas, including drinking water quality, sewage disposal, food service, institutions, and child care facilities.

- Executive Council Office houses the Yukon Water Board Secretariat, which is responsible for administering the water licensing process and supporting the Yukon Water Board.

- Highways and Public Works (Property Management Agency) has a mandate to ensure safety and comfort in Yukon government buildings and, as such, provides potable water and sewage disposal.

2.3.2 Federal Government

Within the federal government, there are several departments with responsibilities for Yukon waters:

- Environment Canada focuses on hydrometric monitoring, pollution abatement, environmental contaminants, environmental emergency response, and wildlife monitoring, and participates in environmental assessments of project proposals.

- Indian and Northern Affairs Canada provides safe water and effective wastewater systems for First Nations. This includes supporting and training First Nation water operators.

- Fisheries and Oceans Canada reviews projects and proposals with the goal of protecting fish and fish habitat.

- Transport Canada is responsible for navigable waters, as well as waters in contact with transportation corridors. It is also active in northern Yukon coastal waters through its Coast Guard operations.

2.3.3 Yukon First Nations

Yukon First Nations have rights in relation to water that are set out in Final Agreements. These include use and protection of water on Settlement Lands, and use of water in Yukon for trapping, non-commercial harvesting, and traditional heritage, cultural, and spiritual purposes. In addition, the Council of Yukon First Nations nominates one-third of the members of the Yukon Water Board. Many First Nations own and operate their own drinking water systems.

2.3.4 Municipalities

Incorporated Yukon communities build and manage water and wastewater systems and solid waste facilities.

2.3.5 Boards and Councils

The Yukon Environmental and Socio-economic Assessment Board (YESAB), Regional Planning Commissions, Renewable Resource Councils, and the Yukon Water Board all play important roles with respect to Yukon waters. The Yukon Water Board, for example, issues water rights and regulates water use and waste disposal to water through its licensing process. Licences are required for undertakings using water or depositing waste to water, such as mining, municipal use, power generation, agriculture, recreation, and conservation.

2.3.6 Other Stakeholders

Non-government organizations such as the Yukon River Inter-Tribal Watershed Council, the Yukon Conservation Society, and the Yukon Water and Waste Association advocate and act to protect and conserve water. Industry (from large mining companies to local water-well drillers), community organizations, and even ordinary citizens are responsible for protecting Yukon source waters. All are stakeholders in managing Yukon's water resources.

2.3.7 Interjurisdictional Initiatives

Yukon participates in a number of regional and national water initiatives:

- The Mackenzie River Basin Board was created in 1997 by the Transboundary Waters Master Agreement between the governments of Canada, Saskatchewan, Alberta, British Columbia, Yukon, and the Northwest Territories. The agreement commits all six governments to working together to manage the water resources of the whole Mackenzie River Basin, including through the negotiation of bilateral water management agreements and the development of basin-wide aquatic ecosystem reporting.

- The Canadian Council of Ministers of the Environment (CCME) is a federal/provincial/territorial council established to help its members meet their mandate of protecting Canada's environment. Water is one of CCME's key areas, and the council has enabled jurisdictions to enhance coordination on water issues such as wastewater effluent and water quality guidelines, as well as on water policy issues such as water valuation, water monitoring and climate change, and groundwater.

- The Council of the Federation Water Stewardship Council was created in August, 2010, when Canada's Premiers endorsed the Council of the Federation Water Charter, which recognizes the collective obligation of Canadians and their governments to be responsible stewards. One immediate outcome of this Charter is for jurisdictions to promote World Water Day/Canada Water Week.

- The Federal-Provincial-Territorial Committee on Drinking Water develops the *Guidelines for Canadian Drinking Water Quality* which are used as a standard for safe drinking water in many jurisdictions. The guidelines set maximum concentrations that are protective of health for many contaminants that can be found in drinking water.

3 Water Use

3 Water Use

Water uses in Yukon fall into several categories, including ecosystem services, natural resource sectors, and municipal use. Water bodies and waterways are also used for travel (ferries, ice roads, etc.), safety (forest fire management), recreation, and harvesting. In addition, they have cultural significance for Yukon residents (Figure 2).

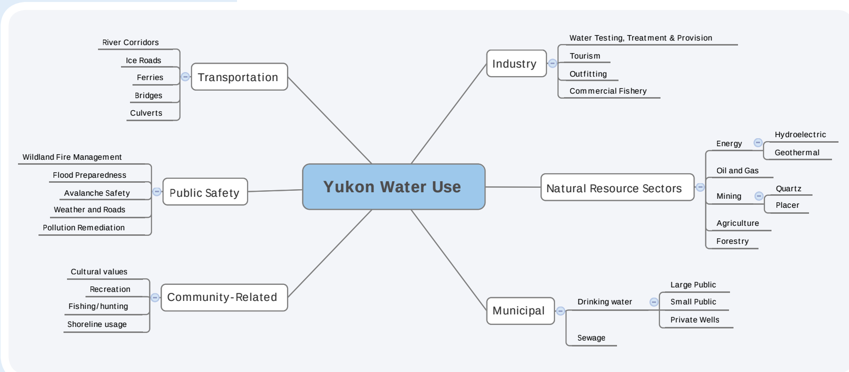


Figure 2: Framing Yukon water use

In this report, we focus on consumptive water use. This section outlines Yukon's water use licensing regime and describes natural resource and municipal water use, including the growth of these sectors and sector vulnerabilities. The section starts with a summary of the ecosystem services provided by freshwater systems and how they are incorporated into resource use decisions.

3.1 Ecosystem Services

Ecosystem services are the benefits people draw from natural ecosystems. Generally, they are broken into the following categories:

- Provisioning services: These services include food, water, and fundamental materials such as wood and fibre.
- Regulating services: Functioning ecosystems affect climate, flooding, disease, waste disposal, and water quality.
- Cultural services: These provide recreation, as well as aesthetic and spiritual benefits.
- Supporting services: Healthy ecosystems are vital to such fundamental natural processes as soil formation, nutrient cycling, and photosynthesis (NRTEE, 2010).

Aquatic ecosystems play a vital role in providing all of these services, either directly or through the role they play in the health of larger ecosystems. The sustainable use of water means much more than keeping enough water available for human use. Sustainability cannot be achieved without maintaining the integrity and health of natural aquatic ecosystems and the services they provide.

Table 1: Ecosystem services provided by freshwater (adapted from NRTEE, 2010 and CCME, 2011)

Ecosystem Service	Examples
Provisioning services	drinking water, food, timber, fibre
Regulating services	climatic control, waste assimilation, flood protection, water purification, fire regulation
Cultural services	recreation, spiritual nourishment
Supporting services	photosynthesis, soil formation, nutrient cycling

3.1.1 Freshwater Ecosystem Services

Water moves constantly through the hydrologic cycle. It condenses in the atmosphere and falls to earth as precipitation. Then it drains across, through, and beneath the land, pooling in lakes and oceans. Eventually it evaporates back into the atmosphere where the cycle begins again. Water's location and availability are never static, and each phase of the cycle plays an important role in supporting ecosystems. Aquatic ecosystems derive their stability, despite this constant change, from the complex interactions within them, driven by chemical, biological, and physical fluctuations. It is this ability of ecosystems to change and adapt that makes them resilient.

Humans rely heavily on the ecosystem services provided by the freshwater system (Table 1). Stresses on watersheds from increased development pressure and climate change, however, can compromise the health and productivity of aquatic ecosystems and put at risk their ability to provide a full range of ecosystem services. Among the human activities that have impacts on aquatic ecosystems are dams, dikes/levees, diversions, wetland draining, deforestation, land use change, and waste disposal. Climate change adds another dimension of impact. Climate change manifests itself in changes in air and water temperature, in the timing, intensity, and type (i.e., snow vs. rain) of precipitation, and in the amount and timing of runoff in watersheds influenced by glaciers, snow, and permafrost, which lead to changes in streamflow and groundwater. These changes, in turn, impact aquatic ecosystems.

To maintain our freshwater systems and the ecosystem services they provide, experts say Canada needs to move towards a new water ethic, based on the principle of "water for nature first." Without adequate water—more than we realized in the past—natural systems cannot sustain both themselves and us. Therefore, nature's water needs must be satisfied before we allocate water to our own direct needs (Sandford, 2010).

Managing water effectively, for both natural and human use, requires an understanding of how much water is available and how it moves through the environment. It also requires knowledge of how much water is needed to maintain healthy and sustainable ecosystems. Sound information is also needed about hydrology, physical habitat, water quality, and biological function in order to inform management decisions and monitor changes in the system (NRTEE, 2010). All of that information comes from monitoring and research.

The Canadian Council of Ministers of the Environment published a Water Valuation Guidance Document in 2010 as a Canada-wide reference source for water resource decision makers in federal, provincial, and territorial governments, Aboriginal groups, and local municipalities and boards. The document is intended to help establish how water valuation can assist in addressing water management issues, particularly in relation to conservation actions, infrastructure investment, setting water quality standards, water pricing, water allocation, and compensation for use and damage (CCME, 2010).

3.1.2 Recognition of Freshwater Ecosystem Services in Yukon

The *Yukon Environmental and Socio-Economic Assessment Act* (YESAA), the *Waters Act*, and the *Fisheries Act* are the main pieces of legislation pertaining to water use activities. The environmental assessment and water licensing processes are the mechanisms by which freshwater ecosystem requirements are assessed and addressed. Following are specific examples illustrating ways that environmental flows are mitigated and regulated to ensure the preservation of freshwater ecosystem services:

- Agricultural *Water Licence AG06-029*, for crop irrigation from Flat Creek, sets a withdrawal limit based on the percent of flow taken to ensure minimum base flows ("No more than 10% of the flow in Flat Creek shall be withdrawn at any time. The Licensee shall not withdraw water from Flat Creek when the flow of Flat Creek is equal to or less than 0.11 cubic metres per second immediately downstream of the intake point").
- In agricultural *Water Licence AG06-030*, for crop irrigation from a beaver pond, the rate of withdrawal is required to be "less than 22% of the median natural flow available in the water course" as determined by a set monitoring schedule.
- In *YESAA Review of file 2009-0040*, for the Mayo 'B' Hydro Enhancement Project, minimum allowable flows for distinct river reaches are established to minimize impacts on fish and fish habitat ("To eliminate, reduce or control significant adverse effects on fish and fish habitat associated with changes to the water flow management regime, the following mitigative measures are required: The proponent shall maintain a minimum flow rate of 6 cms through zone 2 during the chinook salmon rearing season, May 1 to September 30, and minimum flow rates of 5 cms during the remainder of the year. The proponent shall maintain a minimum flow rate of 11 cms through zone 1 during for the chinook salmon rearing season, May 1 to September 30.").

The Umbrella Final Agreement has a condition regarding the maintenance of water flows, which will also serve to maintain environmental flows on and adjacent to Settlement Land. Section 14.8.1 states:

Subject to the rights of Water users authorized in accordance with this chapter and Laws of General Application, a Yukon First Nation has the right to have Water which is on or flowing through or adjacent to its Settlement Land remain substantially unaltered as to quantity, quality and rate of flow, including seasonal rate of flow.

3.2 Water Use Licensing Regime

Water licences are currently required for water use above criteria in the regulations for various undertakings. Undertakings fall into nine categories: Agricultural, Conservation, Hydro, Industrial, Municipal, Miscellaneous, Placer, Quartz,and Recreational. Active licences as of March 2010 are shown in Appendix A. These licences follow a *First in Time, First in Right* framework—meaning that water licencees are granted rights to use water based on the age and order of licences granted. Other activities that can trigger the requirement for a water licence under the *Waters Regulation* include watercourse crossings, diversions, and the deposit of waste. Table 2 shows the minimum water use that triggers the requirement for each type of licence and the associated annual fees. For reference, both Minto and Bellekeno mines pay a $30 licence fee for their annual water use. Licensees are required to report yearly (or with greater frequency, depending on the licence) on water use operations and deposit of water.

Under the *Waters Act*, industrial, placer mining, and quartz mining projects that use water or deposit waste without a licence are still required to submit a notice of water use to the Yukon Water Board. Many other forms of water use do not require a licence. Among them are homeowners or businesses that have no access to municipal water services and use a well (drilled, dug, or surface) or trucked water delivery for domestic potable water. Waste disposal systems that entail septic systems are required to operate under the *Public Health and Safety Act's Sewage Disposal Systems Regulation.*

Table 2:
Threshold to licence requirement for water licence types*

Licence Type	Water use threshold to licence requirement (m^3/day)	Fee
Agricultural	300	Greater of $30 and $0.15/1000m^3
Conservation	300	--
Hydro Power	None	Class 1 - $1500; Class 2 - $4000; Class 3 - $10,000; Class 4 - $30,000; Class 5 - $80,000; Class 6 - $90,000 up to 100,000 kW and $1000 per additional 1000kW
Industrial	100	Greater of $30 and the sum of $1/100m^3 up to 2000m^3/day; $1.5/100m^3 from 2000 - 4000m^3/day; and $2/100m^3 above 4000m^3/day
Municipal	100	--
Miscellaneous	100	Greater of $30 and the sum of $1/100m^3 up to 2000m^3/day; $1.5/100m^3 from 2000-4000m^3/day; and $2/100m^3 above 4000m^3/day
Placer Mining	300	Greater of $30 and the sum of $0.5/100m^3 up to 2000m^3/day; $0.75/100m^3 from 2000-4000m^3/day; and $1/100m^3 above 4000m^3/day
Quartz Mining	300	Greater of $30 and the sum of $1/100m^3 up to 2000m^3/day; $1.5/100m^3 from 2000-4000m^3/day; and $2/100m^3 above 4000m^3/day
Recreation	300	--

** Adapted from the Waters Regulation, Yukon Waters Act 2003*

3.3 Natural Resource Sectors

According to Statistics Canada, an estimated 42 km^3 of water were withdrawn from the environment and used in household and economic activities in Canada in 2005. About 9% was used directly by the residential sector, but the overwhelming majority—more than 90%—went to support economic activity (Figure 3). Arriving at such an estimate can be challenging, as evidence suggests "that accurate, reliable data and information regarding actual water use by the various resource sectors is quite variable" (NRTEE, 2010).

Natural resource sectors account for the largest share of water use in Canada, responsible for approximately 84% of all water withdrawn in 2005. Although reporting requirements vary significantly across the country, making it difficult to acquire a clear picture of water use, it is likely that water usage by the natural resources sectors will continue to grow. Forecasting organizations project that natural resource sectors in Canada will grow about 50% to 65% between now and 2030 (NRTEE, 2010).

Water use in Yukon presents a very different picture. Mining dominates the allowable use under Yukon water licences by a substantial margin. In September 2010, placer mining led the way, accounting for 93% of the gross allowable water use (Figure 4).

Total allowable water use under all active licences, as of September 2010, was 2,844,000 m^3/day. Totals by licence type vary widely, from less than 2,000 m^3/day for conservation to over 2,600,000 m^3/day for placer mining (Figure 5).

These values represent only the amount of water that could be used by licensees, following the terms of their water licence. Actual water use varies by year, given, for example, the extent of activities (i.e., for placer mining), climatic conditions (i.e., for agriculture irrigation), and population size (i.e., for municipal). Annual reporting of water use is required for licensees, however these data are not currently collated for all undertakings or on a watershed basis due, in part, to relatively low pressures in most large watersheds.

3.3.1 Hydro Power

Hydro power is the main form of electricity production in Yukon. The scale of hydroelectric installations in the territory ranges from the large four-turbine plant at Whitehorse Rapids to small, in-stream micro-hydro installations serving only one principal user. Hydro generation stations are supplemented, as necessary, by diesel and by a small amount of wind generation at Haeckel Hill near Whitehorse.

Yukon Energy Corporation

Yukon Energy Corporation is the primary generator of electricity in the territory. The utility runs three hydro plants: Whitehorse Rapids on the Yukon River, Aishihik Lake, and Mayo. Combined, they are able to generate 75 MW of power.

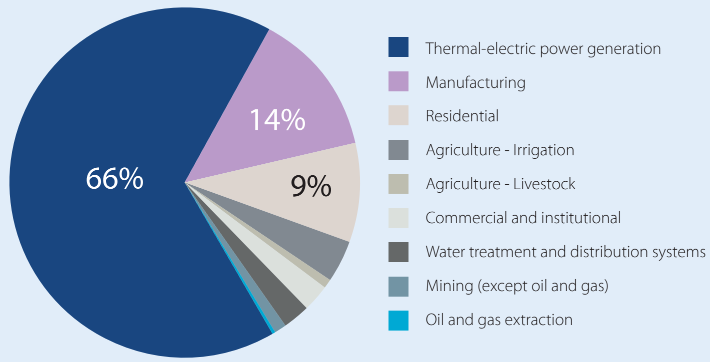


Figure 3: Water use in Canada, by sector, 2005 (Statistics Canada, 2010)

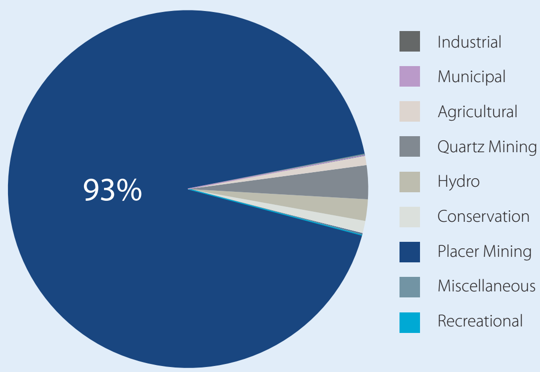


Figure 4: Yukon water licence use allowances by licence type percent, September 2010

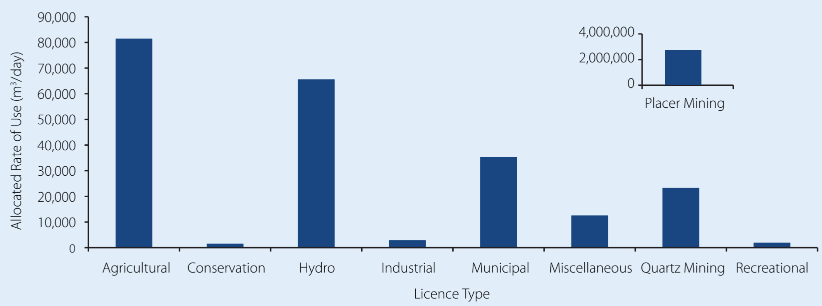


Figure 5: Yukon water licence use allowances by licence type amount, September 2010

The Whitehorse Rapids Plant is a run-of-river facility that holds back Yukon River water in Schwatka Lake. This plant includes two hydro turbines built in 1958, plus a third (1969) and fourth (1985) added since then. The facility can produce 40 MW of power, but is limited to 25 MW in winter. Water Use Licence HY99-010 (expiring in 2025) requires a minimum instantaneous flow of 85 m^3/s in the channels downstream from Lewes Dam (just below Marsh Lake) and from the Whitehorse Rapids Powerhouse. Maximum and minimum levels of Schwatka and Marsh lakes are also specified.

Concern has been expressed about water levels on Marsh and Tagish lakes, particularly after the 2007 floods, but no water is held back in summer. The gates are open after May 15th each year.

The Aishihik Hydro Plant has been operating since 1975 and can produce 30 MW of power. Water from the East Aishihik River is stored in Aishihik and Canyon lakes and diverted through the Aishihik Generating Station. This plant is the only hydroelectric facility in Yukon that can store energy in summer, when demand is low, to be used during high-demand periods in winter. It can also store energy during wet years, to be used in dry years when the water levels of the lake are lower (YEC, 2010). Water Use Licence HY99-011 (expiring in 2019) sets minimum flows from 0.142 m^3/s to 0.708 m^3/s to be maintained over Otter Falls at different times of the year.

The Mayo Hydro Facility was built in 1951 and produces 5 MW. The addition of Mayo B by 2012 will add another 10 MW of power. Water Use Licence HY99-012 (expiring in 2025) requires a minimum flow of 2.8 m^3/s to pass through the Mayo and Wareham dams.

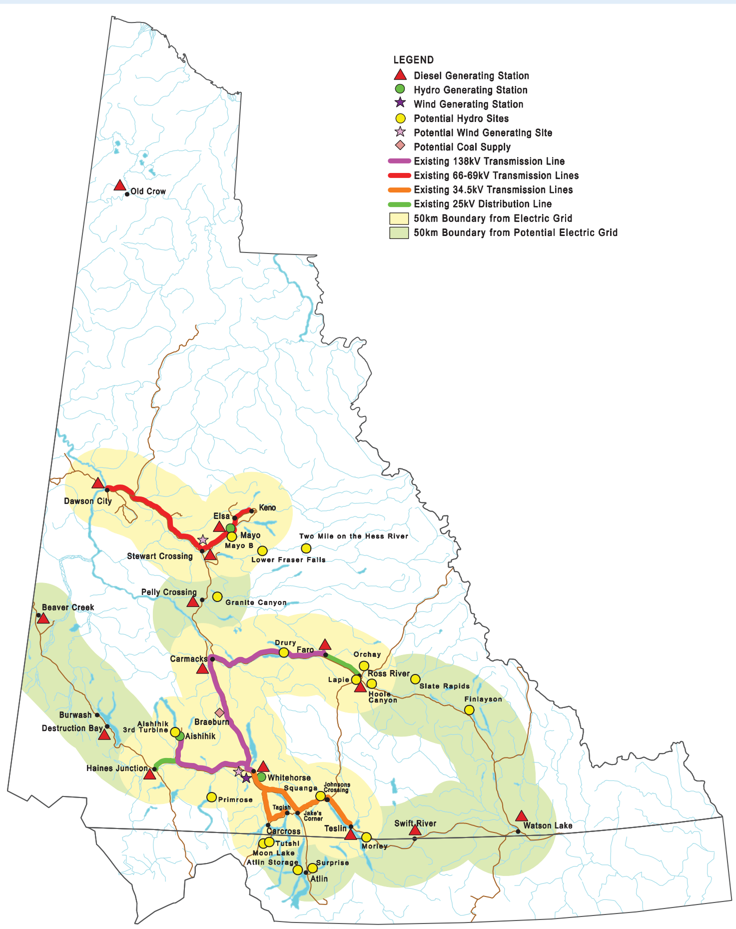


Figure 6: Potential hydro options in Yukon (Yukon Energy Corporation, 2006)

Yukon Electrical Company

Although the Yukon Electrical Company is primarily the distributor of electricity in Yukon, it operates one small hydro facility on Fish Lake, near Whitehorse, resulting in the production of 1.3 MW of power. The operation of the Fish Lake Generating Station is regulated under Water Use Licence HY07-018 (expiring in 2011), which sets required water surface elevations for Fish Lake, Louise Lake, and Head Pond #2, and minimum instantaneous flows of 0.15 m^3/s and 0.10 m^3/s through the Fish Lake and Louise Lake Control Structures, respectively.

Micro-hydro

Several micro-hydro producers supply electricity to off-grid locations in the territory. These systems are set up on small creeks and range in size from 1.0 to 150 kW (Class 0 operations).

Growth

Far more hydroelectric potential exists in Yukon than is currently being used. Studies undertaken by the Northern Canada Power Commission before 1987 identified 82 potential hydro sites, and subsequent work by Yukon Energy and the Yukon Development Corporation identified additional sites. The potential capacity of the sites ranges from very small (1-4 MW) to very large (100+ MW).

Yukon Energy's January 2006 20-Year Resource Plan submission to the Yukon Utilities Board assesses 19 of the potential hydro project options on the basis of site location, as well as rough qualitative and quantitative factors addressed in the initial NCPC and Yukon Energy studies, but does not recommend any particular options (Kishchuk, 2007). These longer-term potential hydro generation supply options include the expansion of existing facilities and a range of projects from very small to very large (Figure 6).

Vulnerabilities

Secure access to water for hydroelectric power generation is a critical issue in Yukon. Here and elsewhere, the sector is particularly interested in how extreme events will affect systems in the future. Nationally, utilities have already noticed increasing variability in weather and water, but they are unsure about how to incorporate this knowledge into planning. They are concerned that long-term climate change impacts could pose threats beyond what has been experienced in the past. Currently, the sector is undertaking its own research and vulnerability assessments regarding the impacts of climate change on operations (NRTEE, 2010).

3.3.2 Oil and Gas

Very little development of oil and gas resources has occurred in Yukon to date. There are currently two producing wells in the Kotaneelee Field, while 75 exploration wells have been drilled in Yukon, most within the Liard Plateau, Peel Plateau, or Eagle Plain basins (Kishchuk, 2007).

There are three areas of water use for oil and gas operations in Yukon (Corbet, 2010):

- Drilling muds: Water-based drilling muds are used for oil and gas drilling. These are composed of 92% water, 7% bentonite clay, and 1% polymers and bactericides. In permafrost regions, such as the Mackenzie Delta and Yukon's North Slope, salts (calcium or gypsum) are added to reduce the risk of freezing. A typical Eagle Plains well would require 200-500 m^3 of water per month. Water use can be reduced by replacing the water with mineral oil in drilling mud. The disposal of drilling mud to meet industry standard involves mixing the mud with soil in a sump and capping it; alternatively, the drilling mud is removed from the territory.
- Water flooding: The secondary recovery of oil requires the addition of water. For every litre/barrel of oil extracted, the equivalent amount of water must be reinjected. Water extracted along with the oil can be reinjected as flood water.
- Ice roads: The construction of ice roads to gain access to oil and gas wells requires approximately 1 million gallons/mile or 2,352 m^3/km. It would require 100-300 m^3/day to build an ice road in the Eagle Plains area. One road, built in 2005 by Devon Canada, was 15 km long.

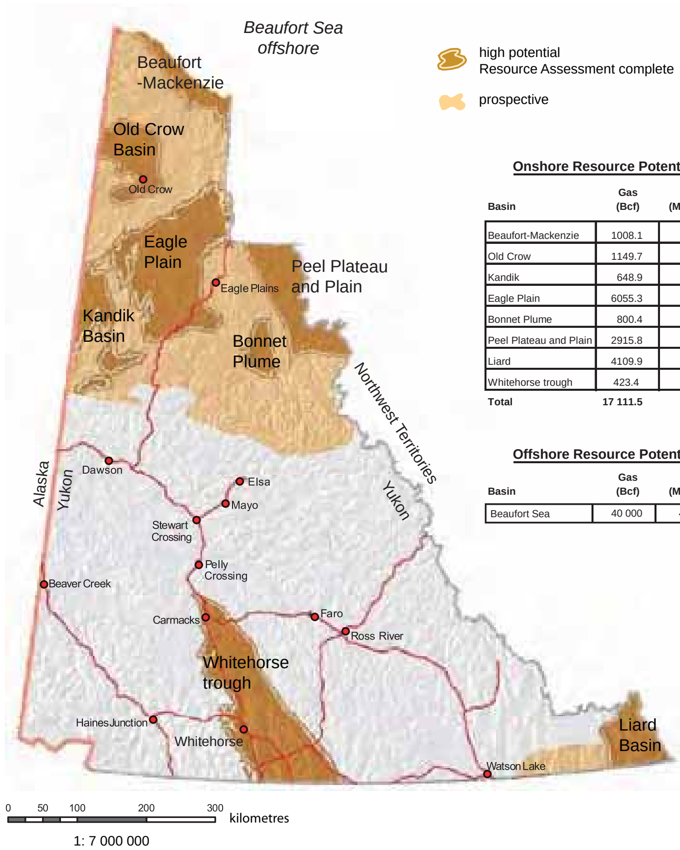
Water use in oil and gas production (excluding the construction of ice roads) is consumptive, as the water is injected into sub-surface formations and not returned to the source.

Kotaneelee

The only producing oil and gas wells in the territory are in the Kotaneelee Field in southeastern Yukon. The field was discovered in 1977 by the Columbia Gas Development Company of Canada Ltd. and its partners. The Kotaneelee Field produced gas briefly in 1979 after being tied in to the Westcoast Transmission system. Production resumed in 1990 (Morrow, 2005). In 2010, 190,000 m^3 of natural gas were produced daily in the field, while 6,000 m^3 of water are extracted per month and subsequently reinjected (Kotaneelee Gas Production Report at www.emr.gov.yk.ca/oilandgas/exploration.html).

Growth

The National Energy Board predicts oil production growth in Canada will be moderate over the medium term, with larger increases over the longer term. This agrees, in general, with forecasts by the Canadian Association of Petroleum Producers (NRTEE, 2010). Growth potential exists for oil and gas in Yukon (Figure 7). Active exploration is underway in several areas. However, future production is difficult to predict,



Onshore Resource Potential

Basin	Gas (Bcf)	Oil (MMbbls)
Beaufort-Mackenzie	1008.1	216.7
Old Crow	1149.7	0
Kandik	648.9	99.3
Eagle Plain	6055.3	436.7
Bonnet Plume	800.4	0
Peel Plateau and Plain	2915.8	0
Liard	4109.9	0.1
Whitehorse trough	423.4	19.2
Total	17 111.5	772.0

Offshore Resource Potential

Basin	Gas (Bcf)	Oil (MMbbls)
Beaufort Sea	40 000	4500

Figure 7: Yukon oil and gas regions (YGS, 2010)

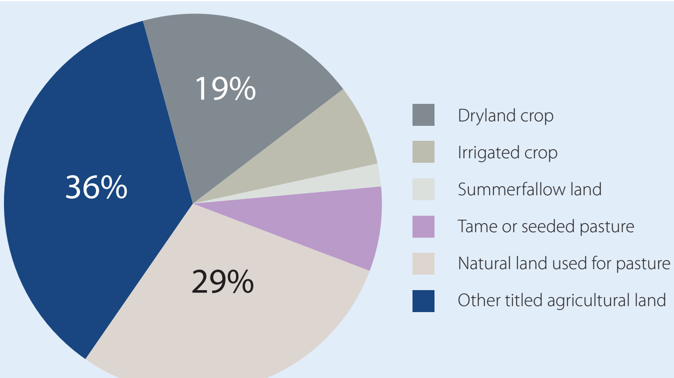


Figure 8: Agricultural land use types in Yukon (Statistics Canada, 2007)

dependent as it is on the size of reserves, the price of oil, the cost of production, and the cost and accessibility of transportation, particularly in more remote parts of the territory such as Eagle Plains. In southeastern Yukon, the absence of settled land claims has limited the granting of new oil and gas dispositions.

Vulnerabilities

Nationally, water quality is of more concern than water availability in the oil and gas sector (NRTEE, 2010). However, industry concern about water availability in Yukon centres around the large water-use requirement for ice roads in the Eagle Plains area. To this end, the industry has developed best practices to limit water use, in addition to considering summer access where this is an option.

3.3.3 Agriculture

Less than 2% of Yukon lands are suitable for agricultural development, due to limitations of geography, climate, and soils. Because of the territory's mountainous terrain, agriculture is largely restricted to the major river valleys: Yukon, Takhini, Pelly, Stewart, and Liard. Major crop types are shown in Figure 8. As of 2010, the Yukon government had issued 311 agriculture land dispositions, the majority in the Whitehorse region, although not all dispositions are actively farmed. The 2006 Census reported 148 farms in the territory.

Although the frost-free period in Yukon is less than 100 days per year and summer temperatures are cool, long daylight hours in summer promote rapid crop growth. Most agricultural production occurs in southwest Yukon, where droughts between April and July are common, so access to water is important for reliable production (Agriculture Branch, 2008).

Clean freshwater is vital to the production of fruits, vegetables, cereals, grains, meat, crop-derived fuel, and animal by-products. Nationally, water use in the agriculture sector represents 10% of the total water used. However, the industry accounts for 66% of national consumption, where the water is not fed directly back into the hydrologic cycle (NRTEE, 2010). The high consumption level results from irrigation, the largest water use in the sector, where water is absorbed through plant uptake, deep percolation, and evaporation (Figure 9). Regional usage and consumption vary, depending on the farming practices and climatic and regional characteristics.

In Yukon, the agricultural community needs water for four principal uses (Ball, 2010):

- Irrigation water for various crops.
- Potable water for crop washing.
- Potable water for livestock.
- Potable water for home use.

As elsewhere in Canada, irrigation of crops represents the largest water use by the agriculture sector. The 2006 census found that approximately 2,000 acres are under irrigation in Yukon. There are currently 19 active agricultural water licences held by users requiring more than 300 m^3/day. Those using less than that threshold amount are not captured through the licensing system. The majority of licences are in the Whitehorse area, predominantly in the Takhini Valley. Other areas where licences are held include Tagish, Mayo, and Dawson. The combined total of current licensed water use allowances is more than 80,000 m^3/day. While this value is high, daily water use is concentrated over the short growing season.

The amount of water required for irrigation ranges from 100 m^3/acre/year to 1,700 m^3/acre/year. At the low end are hay crops, which account for the majority of irrigated acres. Water is applied from late May to the middle or end of July, depending on the year. At the high end are vegetable crops. They require more water, more consistently, from the middle of May until the middle of August. Given an average of around 400 m^3/acre/year over the 2,000 cultivated acres in Yukon, irrigation currently uses 800,000 m^3/year of water (Ball, 2010).

Nationally, water quality concerns associated with agriculture arise mostly from non-point-source pollution resulting from various agricultural practices and from precipitation runoff. This is a major concern in regions with substantial precipitation. In response, more and more farmers are adopting water protection practices, such as growing buffer strips of vegetation around waterways and wetlands (NRTEE, 2010). Similar concerns do not register in Yukon's agriculture sector, given the semi-arid climate and limited summer precipitation. In addition, testing has, to date, shown that intensively used agricultural areas are not impacting waterways, due in part to the riparian setbacks (Ball, 2010).

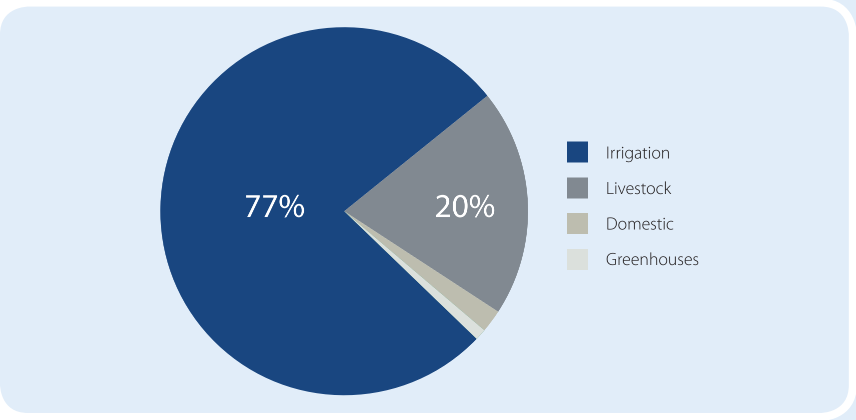


Figure 9: Distribution of agricultural water use in Canada (adapted from NRTEE, 2010)

Growth

There is likely to be more demand in the future for local vegetables and locally grown foods, with demand for hay crops remaining strong for the foreseeable future. One of the biggest constraints on growth of the agricultural sector in Yukon is the accessibility of water. For example, the yield increase from dryland cropping to irrigation is ten-fold for hay in the Yukon River Valley (10 bales/acre to 100 respectively) (Local Farmer, pers. comm., 2010).

The amount of agricultural land adjacent to water courses is limited. For prospective farmers purchasing existing property or applying for Crown land, river access or the availability of surface water in nearby creeks or ponds is the biggest consideration, since it directly influences the crops that can be grown. Many current agriculture leases are under-utilized, at least in part because of lack of access to water or limited irrigation infrastructure.

The Prairie Farm Rehabilitation Administration (PFRA) has undertaken investigations in the feasibility of centralized irrigation systems in the Yukon River Valley. A rural irrigation program similar to the Rural Electrification Program or Rural Domestic Well Water Program might help owners finance their access to water. The Yukon Government's Agriculture Branch is currently developing an irrigation strategy that will address water needs and accessibility issues.

Vulnerabilities

Nationally, the increase in extreme weather events, such as drought, as a result of climate change is the biggest concern for the agricultural sector (NRTEE, 2010). In the semi-arid southwestern Yukon, however, where most of the territory's farming takes place, drought conditions and constant irrigation during the growing season are part of normal operations. In this setting, the integrity of irrigation systems is the largest vulnerability. Breakdowns and the associated impact of missed water application on crops can quickly result in significantly lower yields. Changing temperature and precipitation conditions will impact Yukon agriculture through the amount of irrigation water required to produce a crop.

As farming becomes progressively more focused on higher-value crops, it is likely that water demand will increase and competition for scarce water resources will arise. This pattern has been observed in the South Saskatchewan River Basin, where water allocations exceed environmental flow requirements in much of the basin (NRTEE, 2010). While this is not likely to become a concern in Yukon on major rivers such as the Yukon and Takhini, competition could arise on small creeks. Given the high cost of pumping water for irrigation, however, water efficiency is a major focus in the sector.

3.3.4 Fisheries and Aquaculture

Yukon's freshwater fishery is dominated by recreational angling, although commercial, domestic, and First Nations fisheries made up 5%, 2%, and ~7%, respectively, in 2007. Lake trout and lake whitefish are the primary target species for the commercial fishery. Lake-wide quotas and individual licensee quotas for lake trout have been established to ensure the sustainability of stocks. Since the late 1990s, however, only a small portion of the annual allotted quota is taken in the commercial harvest (Environment Yukon, 2010b). The aquaculture industry in Yukon includes pothole-lake fish farm operations, where fish are stocked and grown in closed-system pothole lakes with no native game fish, and two tank farm operations, raising and exporting Arctic char and Arctic char eggs.

The health of fish and fish stocks is inextricably linked to a healthy aquatic ecosystem. Through the management, licensing, and regulation of all aspects of freshwater fisheries and through its work with First Nations in the management of the subsistence fishery, Yukon Environment strives to protect and maintain healthy aquatic ecosystems. Aquaculture operations can affect natural fish occurrence through the escape of farmed species or diseases into creek systems where they do not naturally occur. There is also the potential to introduce surplus nutrients to the downstream aquatic environment. Additions of phosphorus are of particular concern since phosphorus is a limiting nutrient for aquatic plant growth, and the impacts of phosphorus in the aquatic environment have become a familiar concern across Canada. The phosphorus comes primarily from anthropogenic sources (e.g., municipal wastewater, agricultural runoff, industry). The Yukon government licenses and manages all aquaculture in the territory, but federal regulations regarding food safety and animal health also govern this industry. Nutrient concerns related to aquaculture operations have recently been explored through the water licensing process for one of the local hatcheries.

Growth

Participation in the freshwater fishery is expected to decline due to lack of participation by youth. The commercial fishery is tightly managed on six waterbodies, although there is still room for growth in this area. Of the aquaculture operations, not all fish farm licences issued on pothole lakes are currently active. These, together with tank farms and hatcheries, can produce significant quantities of fish products for local markets and export (Environment Yukon, 2010b).

Vulnerabilities

Many stressors affect this sector, and several could be compounded by changing hydrological or water quality regimes caused by climate change. These include the spread of fish diseases and invasive species, and stresses on fish habitat through impacts such as residential development, forestry, hydro projects, roads, and mining (Environment Yukon, 2010b).

3.3.5 Mining

Mining has been a significant industry in Yukon since the late 19th century. Both hard rock mining (also called quartz mining) and placer mining operations are currently active in the territory. There are currently two mines in production in Yukon—Minto (copper/gold) and Bellekeno (silver)—with the Wolverine mine close to production. Many others are currently moving through the exploration and regulatory processes. On the placer side, there are approximately 300 active water licences for placer mining operations, although this number does not capture operations that do not meet the licensing threshold (300 m^3/day). While the hard rock mining sector is not a significant water user nationally or in the territory, water availability is critical to placer mining.

Hard Rock Mining

Mining activities can affect water resources during all phases of mining: exploration, planning, development and commissioning, operations, and closure. Important water considerations for a mine site include the management of inflows of storm water, mine water, and groundwater; process water; tailings pond containment; and contact water. Water that comes in contact with ore or waste rock requires treatment before being discharged, so the sector is particularly concerned with keeping clean water clean and managing wastewater. The site water balance is an important tool for water management in mining operations and refers to the need to account for all water in and out of the site. Water is also actively used in mining for drilling and dust control, ore excavation, and production, including the milling process.

While water quality is often the most important management consideration in hard rock mining, water supply can also be significant. To the extent possible, mining operations maximize recycling of water in order to minimize both their freshwater make-up requirements from surface or groundwater sources and their water treatment requirements. From an operational perspective, it is important to segregate clean and contact water by upstream diversion of clean runoff, which keeps the clean water clean.

In Yukon, water use and protection are considered during the assessment and regulatory process. After going through YESAA review and obtaining a quartz mining licence, proponents apply for a water licence. This licence contains operating conditions, discharge standards, and required monitoring, sampling, and reporting. Proponents are required to prepare a mine-site water balance and provide details of their water management plan for operation and closure, including the storage, conveyance, diversion, treatment, and monitoring of water. Significant review of these plans is undertaken through the process. The continued review and update of water balance plans, based upon site specific data and changes in operational conditions by proponents, is also crucial to sound mining water management.

Placer Mining

The majority of active placer mining operations in Yukon are in the Dawson Mining District, which encompasses the Klondike River, Indian River, west Yukon (Fortymile and Sixtymile rivers and the Moosehorn Range), and lower Stewart River watersheds. Some mining also occurs in the Whitehorse and Mayo Mining Districts (Figure 10).

Water is critical to placer mining and required through every stage of the extraction process. Placer mining operations excavate soil and gravel, typically in creek and river valley bottoms, to uncover the gold-bearing gravels concentrated just above bedrock. This process may require the diversion of existing water courses while mining takes place. If permafrost overlies the deposit,

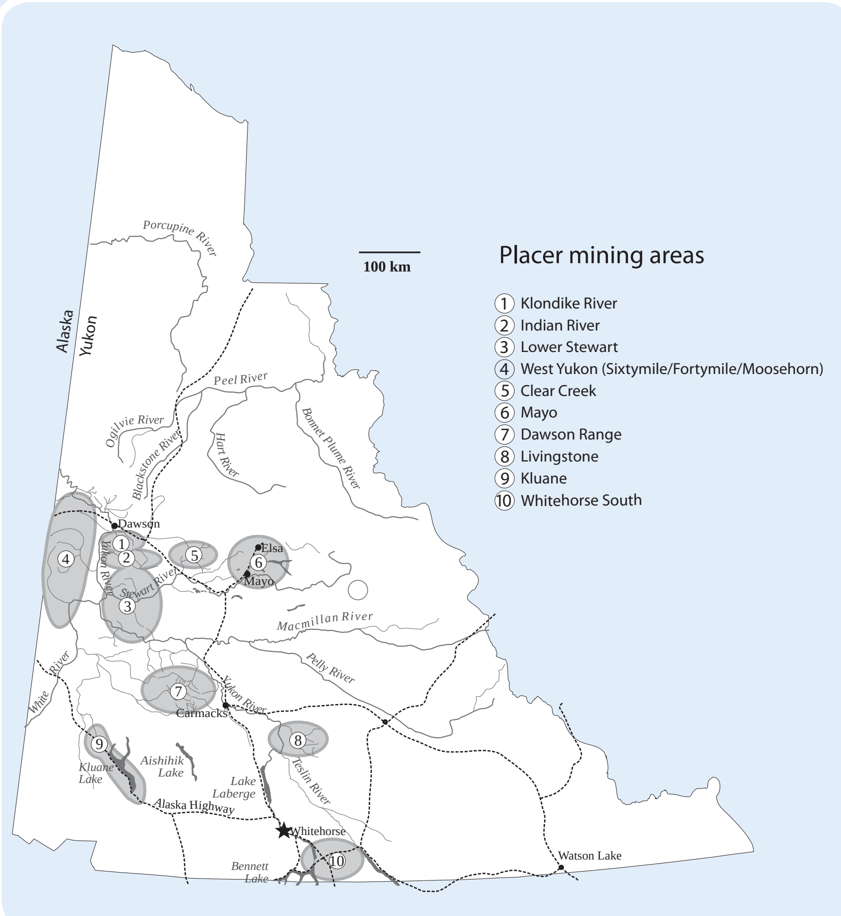


Figure 10: Placer mining areas in Yukon (YGS, 2010)

water is used to thaw the frozen ground, wash the gold loose, and carry the slurry of gold, sand and gravel to the sluice box. The placer gold is recovered through sluicing, where gravels are washed in flowing water and the heaviest particles, including gold, settle to the bottom of the sluice box. In the sluicing process, many other fine materials are washed away, resulting in high concentrations of suspended sediments in the sluicing water. Settling ponds are used to settle these particles and reduce the turbidity of the water so it can be discharged back into the stream (Yukon Placer Secretariat, 2010).

Water licences granted for placer operations outline allowable water use, deposit of waste, and mining activities, including the construction of dams and diversions. Sediment discharge standards are determined by the relevant watershed authorization under *The Fish Habitat Management System for Yukon Placer Mining*. In addition to the sampling required for licensee reporting, monitoring of water quality objectives and aquatic health is carried out in key watersheds through the Placer Secretariat (in partnership with Energy, Mines and Resources, Environment Yukon, and Fisheries and Oceans Canada) to assess the effectiveness of the standards and support regular reviews of the adaptive management system.

Growth

Considerable growth is projected in the Yukon mining sector. Table 3 highlights the status of major hard rock mines and their development. For placer mining, the increased price of gold in recent years has not yet been echoed by an equivalent increase in mining activity. There has been a gradual increase in active operations, from 131 in 2009 to 140 in 2010 (YGS, 2010), but new exploration beyond the most accessible and well-mined streams has thus far been limited. A sustained high in gold prices could help the industry overcome accessibility, geological, and regulatory constraints to frontier exploration, and encourage greater growth in the sector (LeBarge, pers. comm., 2011).

Vulnerabilities

At the national level, climate change concerns in the sector include implications for water supply and managing water on mine sites, given potential changes in precipitation, its timing, and an increase in the frequency of extreme events. For most hard rock mining operations the key issue is too much water rather than a scarcity of it. Given the potential under climate change for greater precipitation inputs and general water availability, on-site water management could become more challenging. Challenges exist in accounting for extreme events, annual snow melt, and understanding site hydrology and meteorology (NRTEE, 2010). In addition, permafrost degradation is a concern for tailings impoundment facilities. The changes might require the review of current site water balances, continued efforts to divert clean water, and, potentially, increased treatment (Hartley, 2010).

There is currently limited adaptation planning happening in the sector. Some recent initiatives addressing climate change include Environment Canada's 2009 *Environmental Code of Practice for Metal Mines*, the Canadian Dam Association's *Dam Safety Guidelines*, and the Mining Association of Canada's *Guide to the Management of Tailings Facilities* (NRTEE, 2010).

In Yukon, climate change could have both positive and negative impacts on placer mining. The availability of water is critical, since without access to water, there can be no mining. Reduced permafrost cover could facilitate the removal of overburden. However, shorter ice-road seasons could limit access to both mining and exploration sites (Hartley, 2010).

Downstream turbidity is a concern with placer mining, although sediment discharge standards are meant to provide a means to maintain effluent quality that is safe for the receiving aquatic ecosystem. The ongoing review of the *Fish Habitat Management System for Yukon Placer Mining*, through water quality objectives and aquatic health monitoring, aims to minimize water quality impacts on aquatic organisms while ensuring the industry can continue to thrive.

With minimal baseline data available in the territory, it is difficult to assess and limit the impact of mining activity on the aquatic environment under changing or uncertain background conditions. In addition, there is the challenge of extrapolating from a small monitoring snapshot to longer periods of time for the purposes of long-term planning, including mine closure. Given the longer horizon of closure planning, a current sector concern is how to incorporate climate change concerns into project design, including both infrastructure and ongoing monitoring.

3.3.6 Forestry

While the forestry sector is a significant component of the national economy (NRTEE, 2010), Yukon's forestry sector is small and largely opportunistic (i.e., burns, deadwood, beetle kill). There are approximately 70 commercial forestry operators in the territory at present, with most commercial harvesting associated with fuelwood for domestic heating. In addition, there are two operating mills that produce rough lumber for local markets (Dinn, pers. comm., 2010).

Sustainable forest management has a critical influence on the hydrology and water quality of watersheds. Forests play an important role in regulating water quantity, and forest land management can have a critical impact on the timing of surface flows, water quality, groundwater recharge, and floodplain maintenance (NRTEE, 2010). The main forest management activities affecting water resources include construction of access roads, harvesting, replanting, and pesticide application. While forest

Project	Company	Current status
Minto - copper/gold	Minto Explorations Ltd./ Capstone Mining	In production (Fall 2007) In assessment for a mine expansion
Bellekeno - silver	Alexco Keno Hill Mining Corp.	In production (Fall 2010) Interest in a mine expansion
Wolverine - zinc/lead	Yukon Zinc	Soon to be in production (Spring 2011)
Carmacks Copper - copper	Western Copper	Quartz Mining Licence (Spring 2010) Requires a Water Licence
MacTung - tungsten	North American Tungsten	Under YESAA review for a Quartz Mining Licence
Eagle Gold Project (old Dublin Gulch)	Victoria Gold	Advanced exploration Submitted YESAA proposal for a Quartz Mining Licence
Selwyn Project-Howard's Pass - lead/zinc	Selwyn Chihong Mining Ltd.	Advanced exploration Preparing YESAA submission for a Quartz Mining Licence
Silverhart - silver	CMC Metals	Advanced exploration
Ketza River - gold	Yukon Nevada Gold	Advanced exploration Preparing YESAA submission for a Quartz Mining Licence
Whitehorse Copper Tailings - reprocessing and remediation project	Brian Scott/Eagle Whitehorse	In feasibility stage
Brewery Creek	Alexco Resources	In closure
Sa Dena Hes	Teck Cominco	In temporary closure
Faro	Deloitte & Touche	In closure planning

Table 3: Status of major mines (Minerals, 2010)

management activities use limited amounts of water, they can have significant effects on the water quality within watersheds. In addition, replanting or fire management can change forest-water interactions, with resulting impacts on forest hydrology (NRTEE, 2010).

Given the small scale of Yukon forestry, its impact on water resources is limited. The *Forest Resources Act* requires the preparation of timber harvest plans for all harvesting greater than 20 m^3 per year. In addition harvesting greater than 1,000 m^3 requires additional environmental screening. Harvest plans include descriptions of environmental conditions, appropriate timber harvesting methods, objectives for controlling and managing roads, and strategies to reduce adverse impacts. First Nation participation in development of the plan is a requirement. Thresholds for limiting development within a given watershed have been set in certain cases, although this is not an established standard in the permitting process.

Growth

The Yukon forestry sector's growth is likely limited, given the small interest in the available forest resource. There is a potential growth opportunity in the use of forest products as fuel other than firewood, such as the use of wood chips or pellets in central heating.

Vulnerabilities

Climate change might lead to increased prevalence of forest fires, insect disturbances, and changes to forest species, which could in turn have dramatic effects on water resources in forested watersheds (NRTEE, 2010).

3.4 Municipal

We use water in our communities for drinking, cooking, toilets, bathing or showering, laundry, cleaning, and other household needs including lawn and garden watering, and car washing. In 2006, Canadians used 327 litres of water per person per day for residential uses, on average. Yukoners used an average of 647 litres per person per day—the highest in the country (Environment Canada, 2010a). Our high rate of water use is due in part to the use of bleeders in some buildings to prevent the freezing of pipes.

Environment Canada Municipal Water and Wastewater surveys, conducted since 1991, indicate that Canadians who are charged a volume-based rate for water use less of it. However, several other factors could also affect the differences in water use between metered and unmetered communities, including location, climate, and socio-economic variables (Environment Canada, 2010a).

Understanding how Canadian communities use water is a prerequisite to gauging Canada's progress toward the sustainable use of its water resources, and to understanding the sector's vulnerabilities to climate change.

Canadian communities are increasingly concerned about having enough fresh water to meet present and future needs, given rising demand for clean water, growing urban populations, and the anticipated impacts of climate change (Environment Canada, 2010a).

Problems with water availability are mainly (84%) caused by problems at the source (water shortages). Across Canada, larger municipalities rely heavily on surface water, while groundwater is important in smaller communities. This pattern holds true for lightly-populated Yukon, where more than 97% of people rely on groundwater for their domestic needs (Yukon Bureau of Statistics population statistics and Community Services and Environmental Health Services distribution information).

Supply and distribution in Yukon communities is undertaken by the Yukon Government, municipalities, and First Nations, and varies by community (Table 4). Many Yukoners have private wells. For rural residents outside of municipal boundaries, the Rural Domestic Well Water Program offers financing on a 100% cost-recovery basis.

Bacteriological sampling requirements are outlined in Schedule C of the Yukon *Drinking Water Regulation* and depend on the number of users of the system. The Regulation requires that Environmental Health Services (EHS) be

Opposite page:

Table 4: Drinking water in Yukon communities (with input from Community Services, Environmental Health Services, Property Management Division, and Indian and Northern Affairs Canada)

Community	Population, June 2010	GW/ SW[1]	Drinking Water System/ Water Source[2]	Distribution[3]	Owner
Beaver Creek	99	GW GW	2 SPDWS Private wells	Piped	WRFN Property Management, WRFN, Other
Burwash Landing	101	GW GW	LPDWS Private wells	Trucked	KFN Other
Carcross	430	SW GW GW	LPDWS LPDWS Private wells	Trucked Trucked	Community Services CTFN Property Management, Other
Carmacks	500	GW GW	LPDWS Private wells	Trucked	LSCFN LSCFN, Property Management, Other
Champagne & Takhini Subdivision		GW	LPDWS	Trucked	CAFN
Dawson City	1,891	GW GW	LPDWS Private wells	Piped + Trucked	City of Dawson Property Management, Other
Destruction Bay	48	GW GW	Delivered water from KFN LPDWS Private wells		 Property Management, Other
Faro	413	GW	LPDWS	Piped	Town of Faro
Haines Junction	856	GW GW GW	LPDWS Trucked dist. system (source HJ LPDWS) Private wells	Piped Trucked	Village of Haines Junction CAFN Other
Keno City	23	GW	LPDWS	Trucked	Community Services
Klondike		GW	SPDWS	Self-serve	Community Services
Marsh Lake	454	SW GW GW SW/GW	Army Beach WTP SPDWS Private wells Delivered water from AB or WH LPDWS	Self-serve Self-serve	Community Services Community Services Property Management, Other Other
Mayo	452	GW GW	LPDWS Trucked dist. system (source Mayo LPDWS)	Piped Trucked	Town of Mayo NNDFN
Mendenhall		GW	SPDWS	Self-serve (no treatment)	Community Association of Mendenhall
Old Crow	235	GW	LPDWS	Trucked	Community Services
Pelly Crossing	346	GW GW	LPDWS Private wells	Piped + Trucked	SFN Property Management, Other
Rock Creek		GW	SPDWS	Self-serve	Community Services
Ross River	361	GW GW	LPDWS Private wells	Trucked	Community Services Property Management, Other
Stewart Crossing	24	GW	Private wells		Property Management, Other
Tagish	245	GW	SPDWS	Self-serve	Community Services
Teslin	475	GW GW	LPDWS Private wells	Trucked	Village of Teslin Property Management
Watson Lake	1,569	GW GW GW	LPDWS Delivered from LFN Lower Post WTP (DWS regulated in BC) Private wells	Piped	Town of Watson Lake Property Management, LFN, Other
Whitehorse	26,418	GW GW GW GW	LPDWS 2 Trucked dist. systems (source WH LPDWS) LPDWS Trucked dist. system (source WH LPDWS)	Piped Trucked Piped Trucked	City of WH Commercial Private trailer court KDFN

[1] **GW –** groundwater source,
SW – surface water source

[2] **Drinking Water System in community or source of water provision:**
LPDWS – Large Public Drinking Water System
SPDWS – Small Public Drinking Water System
Private Wells – Private wells with closed distribution
Delivered water – No local source, delivered from a drinking water system in another community
Trucked Distribution System – Registered trucked system, delivering water from another drinking water system in the same community

[3] **Distribution:**
Piped – Distributed to users through a piped system
Trucked – Distributed to users through
Self-serve – Location where the public can access drinking water

notified immediately of any result that exceeds the acceptable concentration for any health-related parameter set out in the *Guidelines for Canadian Drinking Water Quality*. Currently all large public drinking water systems operating in Yukon submit their bacteriological samples directly to the EHS water quality laboratory, which is accredited for bacteriological testing. Water can be tested for total coliforms and E. coli at no cost to drinking water operators and private owners. There is not yet an obligation to report on sampling results for small public drinking water systems, private systems, or private wells, but many of these operators and owners still submit samples to the EHS lab for bacteriological testing.

Growth

Yukon has had small incremental population growth for some years, but an influx of immigrants or mining could have an impact on small communities. Some communities have significant tourism during part of the year. Increased tourism could have a large impact on water provision and sewage services in those communities (Hartley, 2010).

Vulnerabilities

While changes to municipal water sources have not been widely reported in Yukon, researchers suggest that changes to groundwater resources are occurring, particularly around groundwater-surface water interactions (Walvoord and Stiegl, 2007). A challenge that climate change poses to planning for the future is that planners can no longer rely on historical data to predict the future. They are trying to be more conservative to account for the expected increase in variability in flow conditions. Each community will need to evaluate its risk and develop flexible adaptive management plans to meet its specific needs. Ideally, organizations working in the same area should start or enhance data-sharing partnerships to utilize their resources better (Hartley, 2010).

In the municipal sector, there is already significant concern about protecting groundwater from contamination. Changes have been made in drinking water regulations and related water quality monitoring requirements in the wake of the disease outbreak in Walkerton, Ontario. Changing permafrost conditions could pose further threats to the quality of Yukon groundwater supplies if buried sewage systems and landfills are impacted (Hartley, 2010). Better source-water protection of drinking water should include:

- A more systematic approach to monitoring and tracking aquifer quality.
- Better enforcement to limit the potential for contamination, including industrial impacts.
- Better public education about the potential risks of well contamination.

Yukoners take water for granted and view it as an endless and pristine resource in the territory. Changes in lifestyle and ease of access have dramatically increased people's water consumption patterns. As citizens do not pay the true cost of water, they may not be using the resource wisely. In reality, we still know very little about our groundwater resources, which supply the vast majority of drinking water in Yukon. Also, communities will need significant and very costly upgrades to their water systems in the coming years due to aging infrastructure (Hartley, 2010).

4 Climate Change Impacts on Water Resources

Water resources and the hydrologic cycle are linked inextricably with climate and, therefore, with climate change. Water is involved in every component of the climate system: atmosphere, hydrosphere, cryosphere, land surface, and biosphere. Climate change, such as the warming trend recorded over the past decades, goes hand in hand with hydrological changes, including changing precipitation patterns, widespread melting of snow and ice, increases in atmospheric water vapour through increasing evaporation, and changes in soil moisture and runoff.

Determining exactly how climate change is affecting the hydrologic cycle at a local scale remains challenging. There is significant natural variability in both systems, on interannual to decadal time-scales at least, which often masks long-term trends. Even where trends are observed, recorded, and monitored, understanding the process of change and its causes is far from easy (Bates, 2008).

This section provides a summary of observed and projected climate change impacts on water resources. Some scientific and modeling studies have examined climate change impacts on water resources in Yukon, but many gaps exist. Where possible, for purposes of this report, North American, Canadian, Arctic, or regional studies have been studied to extract Yukon-relevant trends, projections, or implications.

4.1 Changing Climate

In its 2007 report, the International Panel on Climate Change (IPCC) stated: "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level." Of the 12 years preceding the report (1995-2006), 11 ranked among the 12 warmest years since 1850, when the instrumental record of global surface temperature begins. The string of warm years has continued unabated since the report. The IPCC also reported that observations from all continents and most oceans show that many natural systems are being affected (IPCC, 2007).

While the temperature increase is widespread over the globe, it is greater at the higher northern latitudes. Both the Arctic Climate Impact Assessment (ACIA) in 2005 and the IPCC assessment in 2007 reported that surface air temperatures in the Arctic have increased at almost twice the rate of the global mean increase over the past few decades (Sommerkron and Hamilton, 2008). Moreover, the rate of increase in North America is faster in the western Arctic than in the east.

The natural variability of the arctic climate and the relative paucity of long-term data make it difficult to separate the influence of climate change from other factors in observed environmental trends (McBean *et al*., 2005). Data prior to 1950 are particularly sparse. However, for the period 1950 to 1998, the western Arctic, including northern Yukon, shows significant warming of 1.5°C to 2.0°C (Zhang *et al*., 2000), while temperatures in the eastern Arctic actually cooled. During more recent periods, all regions show warming, with trends strongest in winter and spring. Annual and winter temperature anomalies and annual precipitation departures over four northern regions from 1948 to 2005 show the greatest warming in Yukon and the Mackenzie District (2.2°C and 2.0°C, respectively). Over the same period, temperatures throughout Canada as a whole increased by 1.2°C (Lemmen *et al*., 2008).

Although the general warming trend extends back to the end of the Little Ice Age in the second half of the 19th century, the long-term trend is overlaid by shorter-term climate fluctuations associated with cyclic climate patterns such as the El Niño Southern Oscillation and the Pacific Decadal Oscillation. Despite the shorter-term variations, general circulation models (GCMs) consistently indicate that the warming trend will continue and likely increase in magnitude over the next century (IPCC, 2007).

In Yukon, air temperature and precipitation have fluctuated significantly over the last century. Recent data suggest the fluctuations could be outside the natural range of variability. Dawson City, which has the longest data record in northern Canada, has experienced record warm winters in the first decade of the 21st century (Janowicz 2003). Over the last several decades, winter and summer temperatures have increased in all regions, with greater winter temperature increases in northern Yukon, and greater summer increases in southwestern Yukon (Janowicz, 2001).

The forecast is for continued warming over the coming decades. The IPCC projects a probable warming of about 0.2°C per decade over the next two decades. Depending on emission levels, the warming could occur quickly. Even if the concentrations of all greenhouse gases and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1°C per decade would be expected (IPCC, 2007).

Likely impacts in Yukon vary from region to region. For example, projected increases in temperature for Whitehorse indicate that warming will differ seasonally and that winter warming will be most significant, increasing 3.3°C to 5.4°C (NCE, 2010). A relatively uniform increase in annual temperature of 2.5°C to 3.5°C is projected for Dawson for the 30-year period to the 2050s (NCE, 2009). Trends and projections in precipitation are less consistent, both globally and regionally. They are discussed with changing hydrology in section 4.2.4.

4.2 Changing Hydrology

A recent jurisdictional overview of anticipated impacts of climate change on water resources and the hydrologic cycle identified the following potential climate change impacts anticipated in Yukon, from a review of scientific articles (Marbek, 2009):

- Earlier lake/river/sea break-up date (2)*
- Increased mean annual precipitation (3)
- Decreased winter precipitation (2)
- Increased summer precipitation (2)
- Increased annual runoff (3)
- Earlier spring freshet (3)
- Decreased (5) and increased (7) annual streamflow
- Increased winter streamflow (3)
- Increased spring streamflow (2)
- Increased fall streamflow (2)
- Decreased (7) and increased (3) maximum annual streamflow
- Decreased (2) and increased (8) minimum summer streamflow
- Earlier spring peak flow (3)
- Increased evaporation and evapotranspiration (3)

** Numbers in parentheses indicate the number of articles referencing each subject.*

While this list summarizes studies that include basins in Yukon, the direction (increase or decrease) and magnitude of change vary in different basins. Factors affecting the degree and nature of change include local climate, hydrologic regime, topography, and contributing area, among many others. The complexity of interactions explains the seemingly conflicting results in some cases (e.g., both decreased and increased annual streamflow).

The climate change impacts of greatest concern, most of them already observed, include increased magnitude of low flows related to permafrost warming (see section 4.2.4), decreased peak flows in permafrost areas (see section 4.2.4), increased peak flows in glacial areas (see section 4.2.5), greater frequency of ice jams, and earlier ice break-ups (see section 4.2.6).

4.2.1 Precipitation

Annual precipitation increased during the 1950–1998 period across Canada, with substantial spatial variability (Zhang *et al*., 2001a). From this analysis, all regions in Yukon appeared to experience slightly increasing winter precipitation. In summer, decreases were noted in the north, while precipitation increased in the south. The ratio of snow to total precipitation decreased in all regions in spring, in conjunction with increased spring temperatures that caused a greater amount of precipitation to fall as rain. A more recent trend analysis of long-term Meteorological Service of Canada stations in Yukon showed that winter precipitation has generally increased in northern regions and decreased in southern regions. Summer precipitation has generally increased slightly throughout the territory, with greater increases in southeast and central areas (Janowicz, 2010). The observed precipitation trends are somewhat outside the range of developed projections that suggest annual precipitation will increase in all Yukon regions by 5–15% (Janowicz, 2010).

Many general circulation models project increased mean annual precipitation at high latitudes of North America for the end of the 21st century, based on an emission scenario of rapid economic growth and increased globalization (Nohara *et al*., 2006). An Environment Canada assessment of the potential impacts of future climate change on the probable maximum precipitation in Yukon, using the Coupled Global Climate Model, found maximum increases of precipitation from 5% to nearly 20% by the end of the century, depending on the locations of the watersheds in the territory (Whitfield, 2006). Local scenarios produced for community adaptation projects in Whitehorse (NCE, 2010) and Dawson (NCE, 2009) also project increased mean annual and seasonal precipitation for their respective regions, particularly in winter.

Additional scenario results for projected Yukon precipitation can be found through the high-resolution climate change scenarios for North America produced by Natural Resources Canada's Canadian Forest Services (McKenney *et al*., 2006) or the Canadian Climate Change Scenarios Network (yukon.cccsn.ca).

4.2.2 Snowpack

The accumulation and growth of the snowpack is an important driver of the hydrologic cycle in snow-dominated northern basins. Snowcover melt and associated floods are the most important hydrologic event of the year in many river basins in Yukon. The Yukon Snow Survey and Water Supply Forecast is prepared three times a year during the snowmelt period to make projections of total volume runoff for the summer period and to estimate peak flow for the main river basins.

Yukon's annual snowmelt runoff generally occurs in late May or June. North of the Ogilvie Mountains, peak flows come in spring due to snowmelt and secondary peak flows arrive later due to rainfall. South of the Ogilvie Mountains, streamflows increase rapidly during early summer due to snowmelt at lower elevations and then peak later in the summer due to snow and glacial melt at higher elevations (Watt *et al*., 1989).

Winter and early spring snow depths decreased significantly over much of Canada in the 1946-1995 period, with the greatest decreases in February and March (Brown and Braaten, 1998). Such decreases were noted consistently over winter in northern Yukon, while increases occurred in parts of northern British Columbia. Snowmelt has started earlier in Yukon over recent decades, particularly in mountain streams where the timing of the freshet has advanced (Whitfield and Cannon, 2000, Whitfield, 2001). A similar trend has been documented in Alaska (Hinzman, 2005). Multiple datasets confirm a decrease in snow-cover duration across the Arctic over the period from 1967-2008 (Brown *et al*., 2010), and 2010 set a new record for low spring snow-cover duration (Derksen *et al*., 2010).

Given the strong sensitivity of spring snowmelt timing to spring temperatures, a continued trend of earlier snowmelt and associated earlier peak flows can be expected. An earlier snowmelt season is projected in high-latitude river basins (e.g., Mackenzie, Yukon) by many general circulation models by the end of the century (Nohara *et al*., 2006).

4.2.3 Evaporation and Evapotranspiration

Evaporation and evapotranspiration are an important part of the hydrologic cycle, influencing the availability of water, particularly for uses such as agriculture. Climate change could have a critical impact on evapotranspiration and, therefore, on water availability. Identifying how climate change affects evaporation trends could help to quantify the potential impacts of climate change on evaporation (Burn and Hesch, 2007).

Mean annual evaporation in northern Canada decreases at higher latitudes, from approximately 250 to 400 mm at latitude 60°N to less than 100 mm in parts of the High Arctic (den Hartog and Ferguson, 1978). Moisture loss to the atmosphere also occurs through sublimation, direct transition of moisture from snow and ice into water vapour (Pomeroy *et al*., 1998). Evaporation is greatest during the summer, especially in areas with bogs and shallow lakes. Large deep bodies of water store the summer heat longer, producing significant evaporation during the fall (Oswald and Rouse, 2004). North of the wetland and forested zones, transpiration decreases because the vegetation is less dense vegetation and more of it is mosses and lichens. However, the relative importance of evapotranspiration in the water balance tends to be higher farther north because precipitation is lower (Lemmen *et al*., 2008).

A number of authorities predict that climate change will lead to an intensified hydrologic cycle. One possible result is an increase in the evaporation rate, leading to greater dryness in some areas. However, trends in evaporation have been analyzed for many regions, with differing conclusions, and the mechanisms causing the trends are not clearly understood. Increasing temperatures are not the only meteorological factors that can result in an increase or a decrease in evaporation. Other possible factors include increased cloudiness or even a discrepancy between the instrumentation measuring evaporation and actual evaporation under some conditions (Burn and Hesch, 2007).

Accurate projections of the impacts of climate change on evaporation are particularly important in arid regions like Yukon. Average annual precipitation in the territory ranges from about 200 mm west of Whitehorse to more than 400 mm in Watson Lake. The southwest Yukon, where most agricultural production occurs, lies within the rain shadow of the St. Elias and Coastal mountains. Southwest Yukon is subject to droughts between April and July, which poses a serious problem for crop germination (Agriculture Branch, 2008). Increased evaporation leading to greater aridity would make the problem worse.

On the Canadian Prairies, analysis of monthly and warm-season evaporation trends over periods of 30, 40, and 50 years revealed a significant number of decreasing trends in June, July, October and warm-season evaporation. Trends for August and September were more variable over different time periods. In general, the more northern regions experienced increasing evaporation trends, while more southern regions saw decreasing trends (Burn and Hesch, 2007).

An analysis of world evaporation trends using climate inputs from 19 different general circulation model simulations, based on an emission scenario of rapid economic growth and increased globalization, generally found that increasing temperature results in increasing potential evaporation because the water-holding capacity of the air increases. Figure 11 illustrates future changes in the annual mean evaporation relative to the present. Not only does evaporation increase in high latitudes, but the amount of increased evaporation in latitudes from 45° to 65°N is larger than the increase in runoff (Nohara *et al*., 2006).

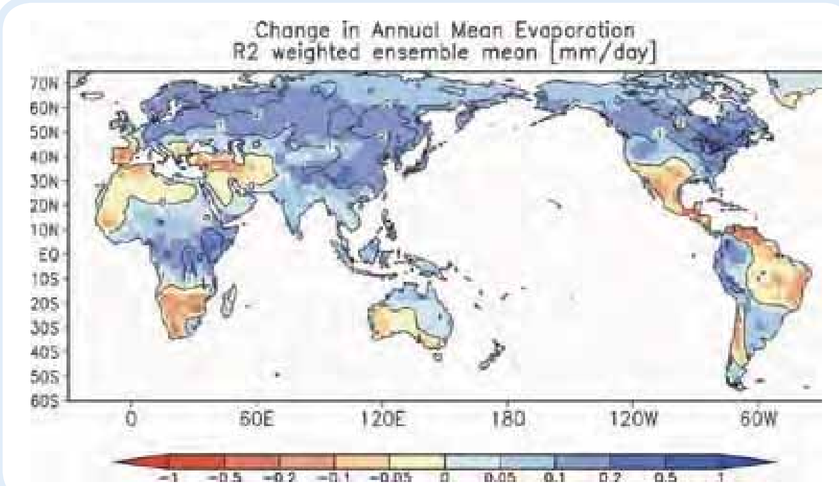


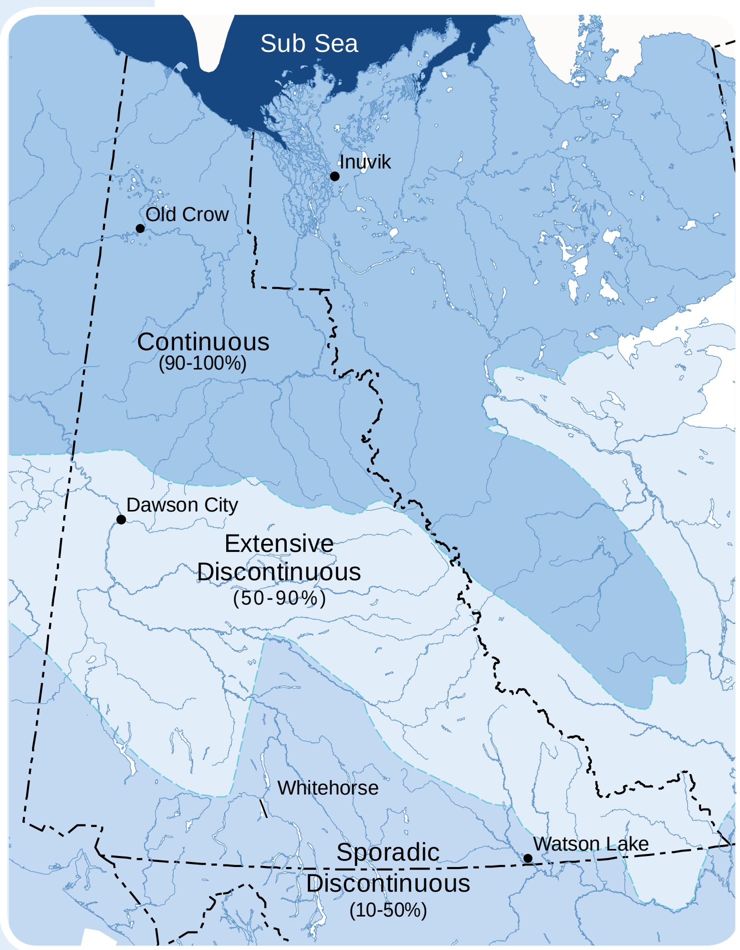
Figure 11 Change in the annual mean evaporation (mm/day) (Nohara, et al., 2006).

The colour shading shows the change in evaporation for the future against the present. The contour shows the normalized evaporation change. (Nohara *et al*., 2006)

4.2.4 Permafrost

In northern regions, the primary control over hydrologic response is permafrost distribution, permafrost thickness, and the thickness of the active layer (Hinzman *et al*. 2005). For example, thick underlying permafrost and a thin active layer produce short pathways to the stream channel, with little or no interaction with subsurface processes. Ice-rich permafrost restricts rain or snowmelt infiltration to subsurface zones, resulting in surface storage in the form of ponds or wetlands. A thicker active layer enhances infiltration and associated groundwater recharge, which results in greater groundwater contributions to streamflow. Yukon hydrologic response follows this principle and is closely tied to the underlying permafrost (Janowicz, 2008).

Figure 12 Yukon permafrost zones



Three permafrost zones exist in Yukon, distinguished by the relative amount of underlying permafrost (Figure 12). Continuous permafrost areas have greater than 90% coverage, discontinuous areas have between 50–90% coverage, and sporadic areas have 10–50% coverage (Brown *et al*. 1997). According to a 1995 assessment, continuous permafrost underlies 30% of the territory, the discontinuous zone accounts for 45%, and 25% of Yukon falls in the sporadic permafrost zone (Janowicz, 2008).

Climate change appears to be causing a change in the permafrost distribution of northern regions, including Yukon. Increasing air temperatures are leading to permafrost warming and associated thawing, which results in a thicker active layer (Janowicz, 2008). During the International Polar Year, a snapshot of the thermal state of permafrost in northern North America was developed using ground temperature data from 350 boreholes. New monitoring sites in the mountains of southern and central Yukon suggest that permafrost may be limited in extent, particularly at higher altitudes. In concert with regional air temperatures, permafrost has generally been warming, as indicated by measurements from the western Arctic since the 1970s (Smith *et al*., 2010).

Permafrost degradation is expected to be greatest within the discontinuous and sporadic zones where the permafrost is warmer and more susceptible to thawing (Hinzman *et al*. 2005). In Alaska, thawing permafrost in the discontinuous zone has led to the development of extensive areas of thermokarst terrain (Romanovsky and Osterkamp 1999). Such land-cover change induced by permafrost thaw brings considerable uncertainty regarding the future availability of freshwater resources. For example, permafrost often controls water storage and drainage processes by limiting the water infiltration to the active layer. Permafrost also severely restricts hydrological interaction between water above and below the permafrost layer. Thawing and subsidence of permafrost-based land formations can change drainage patterns, leading to substantial changes in the local hydrologic cycle (Quinton *et al*., 2010).

In Yukon, an assessment of streamflow response to determine trends in permafrost regions as a result of temperature change found that annual maximum flows generally decreased within the continuous permafrost zone. Annual minimum flows showed strong positive trends in all three permafrost zones, with the greatest positive trends in the continuous permafrost zone (Janowicz, 2008). The explanation could be that increased air temperatures are resulting in permafrost degradation, leading to greater interaction between surface and groundwater systems. The interaction would permit increased infiltration rates and greater groundwater contributions to base flow, which would impact both maximum and minimum flows (Janowicz, 2008). Walvoord and Striegl (2007), in fact, report an upward trend in groundwater contribution to total streamflow in the Yukon River Basin and attribute it to permafrost thawing associated with the overall warming trend.

4.2.5 Glaciers

In Yukon, the southwest Coast and Saint Elias mountain regions are dominated by a glacial hydrological response (Janowicz, 2004). Combined with the Mackenzie Mountains, 10,000 km^2 of Yukon is covered in 1396 glaciers (Barrand and Sharp, 2010). Glaciers in northern British Columbia, such as the Llewellyn Glacier, are also important to Yukon's hydrologic regime as they represent the headwaters of the Yukon River Basin. In fact, the hydrology of much of the southwestern Yukon is tied to glaciers.

Glaciers influence both streamflow and water quality. The most important hydrological feature of glacierized basins is substantial fluctuation in yearly, seasonal, and daily river discharge. Climatic conditions determine the total annual runoff from perennial snow and ice within the basin, as well as their net storage capacity. Therefore, streamflow variations from year to year reflect fluctuations in glacier mass balance (Kaser, 2001). The seasonal discharge pattern, with summer peak flows, results from the storage of precipitation as snow and ice over the winter and its later release as summer melt (Röthlisberger and Lang, 1987). Runoff streams can also exhibit repeated cyclic fluctuations at the daily scale during the ablation season, in response to glacier surface energy balance and drainage system processes (Milner *et al*., 2009).

Glaciers can maintain streamflow during the summer, at a time when the flow rates of rivers in non-glacierized basins drop to their lowest levels (Hannah *et al*., 2005b). Hot, dry conditions, which cause low flows in unglacierized catchments, lead to high rates of glacier melt that can increase streamflow, especially during late summer and early autumn (Meier, 1969). In western North America, glacial influences are clearest and most consistent in August, after most non-glacier snow has melted and before the onset of autumn cooling and the precipitation of autumn and winter (Moore *et al*., 2009).

Changes to glaciers due to general climate change could have a profound influence on the hydrology of Yukon's glacier-dominated basins. During the 50 years between the International Geophysical Year and the third International Polar Year, the total ice area in Yukon shrank from 11,622 km^2 in 1958–60 to 9,081 km^2 in 2006–08, a loss of 2,541 ± 189 km^2. This represents a 22% loss of glacier area over the course of 50 years (Barrand and Sharp, 2010). Schiefer *et al*. (2007) calculated glacier volume changes in British Columbia between the mid-1980s and 2000 and found that thinning rates are highest in the North and South Coast and St. Elias mountains, where glacier areas are the most substantial (Moore *et al*., 2009).

Precisely what this change in glaciers means for Yukon's freshwater resources remains unclear. As glaciers recede, streamflow will decrease (Barnett *et al*., 2005), but this may not occur immediately or consistently. At first, meltwater generation might increase due to increased energy inputs, earlier disappearance of reflective snow cover, and exposure of darker, lower-albedo ice. This initial flow increase will be followed by reduced runoff in the long term as the amount of ice diminishes (Milner *et al*., 2009). Fleming and Clarke (2003) found that warming in southwest Yukon and northwest British Columbia in the years preceding 2003 was associated with decreased annual flow for unglacierized catchments, but increased river flow in glacierized catchments (Moore *et al*., 2009).

If the shrinkage of glacial ice continues to the point where some basins lose their glaciers altogether, the result is likely to be a dramatic shift in streamflow patterns. A comparative analysis of glacierized and ice-free basins in the Nepalese Himalayas (Hannah *et al*., 2005a,b) showed that ice-free basins have reduced flow magnitude and shorter recession into the low flow season, compared to glacierized basins. Variability from year to year is higher, due to the absence of the buffering effects of frozen water stores. The researchers suggest that the switch from glacierized to ice-free would result in a basin more strongly influenced by variations in precipitation and less by rising air temperature (Braun *et al*., 2000).

Glacial melt can also lead to short-term, but more catastrophic effects. Unstable glacial lakes could be formed by ice dams. Ice dam failures yield glacial outburst floods. Such floods can occur frequently in some catchments and, indeed, occur annually at some sites in northwest British Columbia, southwest Yukon, and southeast Alaska (Moore *et al*., 2009).

4.2.6 River Ice

River ice is important to both socio-economic and environmental aspects of life in cold regions. In remote, sparsely populated areas, frozen rivers are frequently used for transportation purposes, both for the construction of ice bridges and as transportation networks. In northern North America, river ice frequently serves as a platform for fishing and trapping purposes. Freeze-up and break-up processes often produce ice jams that can result in flooding, with social and economic consequences related to public safety, damage to property and infrastructure, and disruption of transportation and communication networks and hydroelectric operations. Ice jams and subsequent backwater and surges also affect aquatic ecosystems through impacts on biological and chemical processes (Janowicz, 2010).

River ice plays a dominant role in controlling extreme hydrologic events in cold regions. The river ice break-up period is particularly influential, since it often coincides with the arrival of the spring freshet (Prowse *et al*., 2006). Backwater produced by broken and jammed ice can augment water levels on rivers already receiving large amounts of discharge from snowmelt runoff. In many areas, the resulting highwater consistently surpasses open-water maximums (e.g., de Rham *et al*., 2008) and can result in flooding of riverside communities. The physical action of ice during break-up ice jams can also cause substantial damage.

In Yukon, freeze-up generally progresses from north to south. On a regional scale, stream channel characteristics contribute significantly to freeze-up. Freeze-up observations have been recorded sporadically in Yukon since the 1890s, primarily for river transportation reasons. These records show that freeze-up of the Yukon River at Whitehorse has been delayed by approximately 30 days since 1902 (Janowicz, 2010), although the construction and operation of the Whitehorse Rapids dam and the addition of the fourth turbine have inevitably influenced this date.

Because of Yukon's history of river transportation, there is an excellent record of break-up dates for the Yukon River at Dawson. Over the period of record, 1896-2009, break-up at Dawson has ranged from 28 April to 29 May, with a mean date of 9 May. Jasek (1999) carried out an assessment of the data to 1998 and observed that the break-up date advanced 5 days per century. The last two decades have seen an unprecedented advance of the break-up date (Figure 13). A similar trend is noted for the Porcupine River at Old Crow, although the record there begins in

1961. The break-up date ranges from 2 May to 30 May, with an overall mean of 16 May. The mean break-up date has advanced from 18 May during the first 20 years of record to 14 May in the last 20 years (Janowicz, 2010).

Historically, numerous Yukon communities have experienced ice jam flooding, with the most severe floods at Dawson City on the Yukon River and Old Crow on the Porcupine River. Dawson City suffered six major ice jam floods in the last century, and Old Crow, four. Data from 1896 to 1986 was compiled for Dawson to provide design information for the construction of an engineered dyke after the 1979 flood of record (Klohn Leonoff 1987) and has been maintained since. This record shows a trend of increasing water level during break-up from the early 1970s to the present for Dawson City, possibly reflecting the influence of climate warming. Though there is considerable range and scatter, the trend of increasing elevations is evident at both low and high elevations (Janowicz, 2010).

Most information on the effects of long-term changes in climate on river-ice processes is limited to simple measures, such as the timing and duration of the ice regime. Less is known about more complex variables, such as ice-cover thickness or ice jams (Beltaos and Prowse, 2009). For example, changes in climate can modify both the resisting and driving factors that control the break-up process. In terms of resistance, the important climate-related factors are ice competence (the thickness and flexural strength of the ice cover) and the river stage during the preceding freeze-up. The major factors driving break-up are the size of the accumulated winter snowpack and the intensity of spring snowmelt (Beltaos and Prowse, 2009). Both factors are influenced by freeze-up, winter accumulation, and spring ablation conditions. High freeze-up level, a thick and minimally weakened ice cover, and the rapid melt of a large upstream winter snowpack would likely produce the most extreme break-up events.

Yukon might already be experiencing climate change operating on these more complex processes. A midwinter break-up event and associated ice jam occurred on the Klondike River at Dawson during the winter of 2002–3 resulting in flooding of the community. The mid-winter event was triggered by record high air temperatures and rainfall (Janowicz, 2010). Though the occurrence of such events is becoming more common in temperate regions (Beltaos 2002; Beltaos & Burrell 2003), this is the first recorded mid-winter event in Yukon and may be a direct result of climate warming (Janowicz, 2010). With increasing winter temperatures, mid-winter melt events are likely to become more frequent (Beltaos and Prowse, 2009).

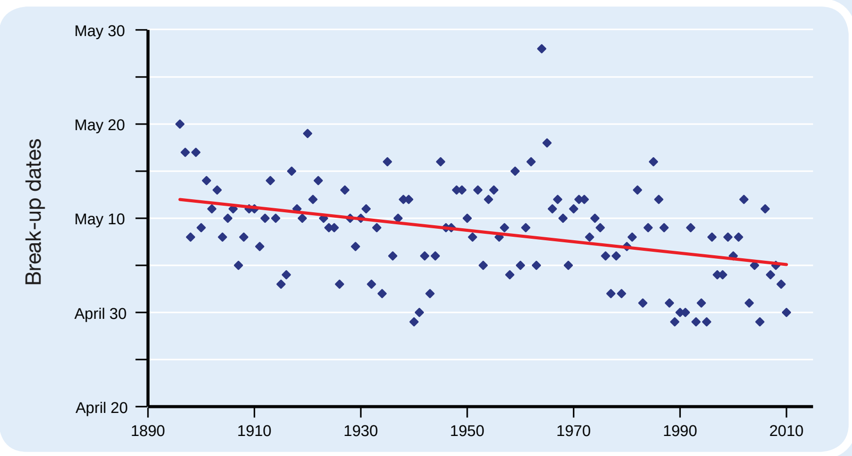


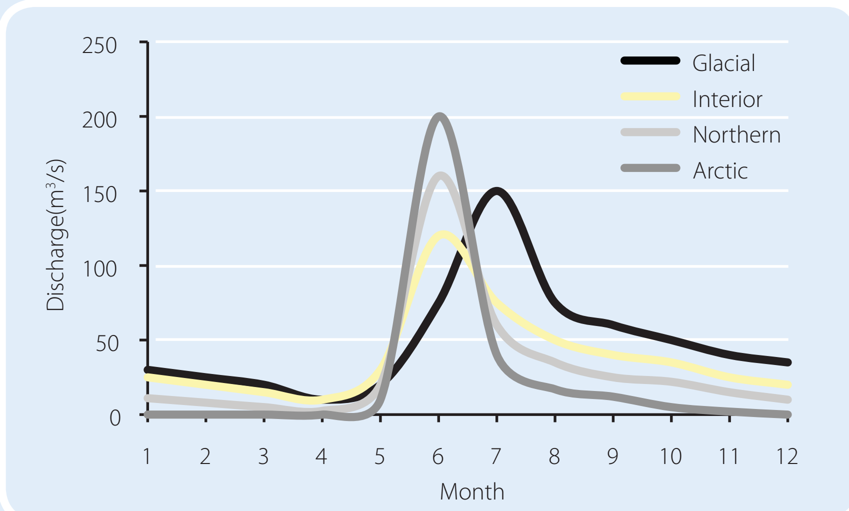
Figure 13 Yukon River at Dawson break-up dates (1896-2009) (Janowicz, 2010)

4.2.7 Streamflow

Yukon streams belong to four distinct hydrologic response types. Situated within the sporadic permafrost zone, the glacial response type has the greatest annual volume of discharge in response to relatively large annual precipitation received by the Coast and Saint Elias mountains (Wahl *et al*. 1987). Hydrologic response in the rest of the territory is closely tied to the three permafrost zones: continuous, discontinuous, and sporadic (Janowicz, 2004). The Interior hydrologic response type is located within the sporadic and southern discontinuous permafrost zones. The Northern hydrologic response type is located within the northern portion of the discontinuous permafrost zone and the southern portion of the continuous permafrost zone. Farther north, the Arctic hydrologic response type is located entirely within the continuous permafrost zone.

Figure 14 provides an illustration of typical runoff hydrographs for the four response types.

Patterns of annual streamflow for the Interior, Northern, and Arctic response types show similar timing, but the magnitude of total, peak, and minimum annual discharge varies. While annual precipitation decreases with latitude, annual discharge increases slightly due to less evapotranspiration. Annual peak flows increase significantly with latitude because the underlying permafrost reduces the pathway to the stream channel. Conversely, annual minimum flows decrease with latitude due to lower groundwater contributions to winter streamflow. In the continuous permafrost zone, many smaller streams are completely dominated by underlying permafrost and have no observed flow later in the winter (Janowicz, 2008). There are indications that streamflow characteristics are currently being affected by climate change in Yukon, although the changes vary by hydrologic regime and season. The degree and direction of future change are under active research.



(a)

(b)

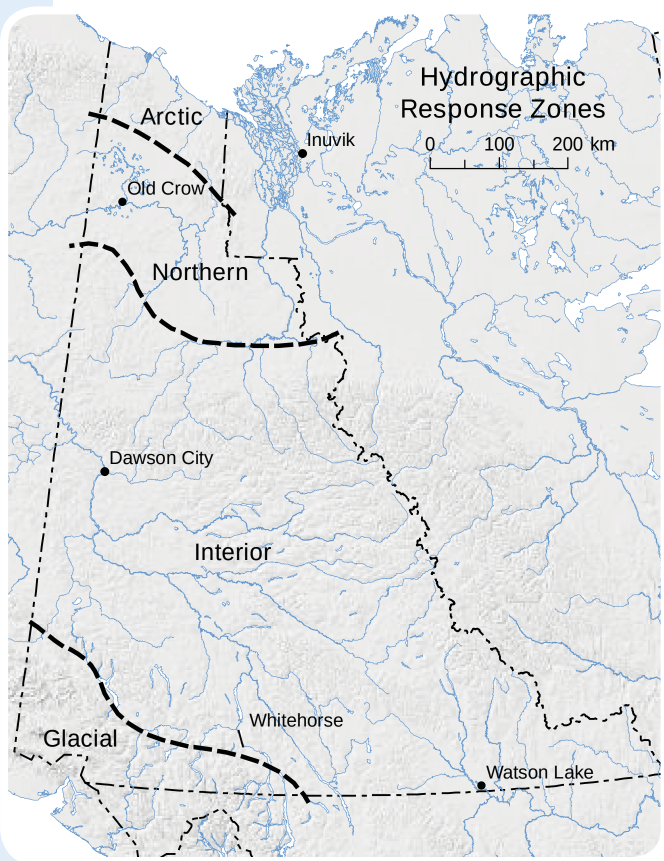


Figure 14
Hydrologic response zones (a) and hydrographs (b) (with permission from Ric Janowicz)

Whitfield & Cannon (2000) & Whitfield (2001) assessed climatic and hydrologic variations between two decades (1976-1985; 1986-1995) for stations in British Columbia and Yukon. Generally, they found that hydrologic response was characterised by higher year-round flows. In mountainous streams, the timing of the freshet had advanced, followed by lower summer and fall discharge (Janowicz, 2008). Zhang *et al*. (2001a) and Yue *et al*. (2003) assessed the streamflow records for 243 Canadian hydrometric stations making up the Reference Hydrometric Basin Network over the period 1967 to 1996. Based on a small number of stations in Yukon or northern British Columbia, they found significant increases in winter low flows in that region. Annual mean and peak flows had increased over the period in glacierized basins of southern Yukon and northern British Columbia (Janowicz, 2008).

Janowicz (2001) carried out an analysis of Yukon streamflow to assess the response of the observed temperature and precipitation changes on peak flows, which normally occur as a result of spring snowmelt. The assessment revealed a dramatic change in mean annual flood in some regions of Yukon over the previous 20 years, with effects strongest in the southern part of the territory. The greatest increases occurred in the sporadic permafrost zone, from predominantly glacierized systems in western Yukon, with smaller increases noted in southeastern Yukon. These increases correspond to the observed increase in both summer temperatures and winter and summer precipitation. Peak flows from central and eastern Yukon, within the discontinuous permafrost zone, exhibited very little change. Within the continuous permafrost zone, peak flows decreased progressively moving northward to the Arctic coast (Janowicz, 2008).

Janowicz's 2008 streamflow assessment used records from 21 hydrometric stations evenly distributed among continuous, discontinuous, and sporadic permafrost zones in Yukon and adjacent areas of northern British Columbia and the western Northwest Territories. Continuous permafrost zones exhibited the greatest positive trend in minimum winter streamflow. Winter streamflow trends within the discontinuous zone were positive but more variable, while trends in the sporadic permafrost zone were not consistent. Strong positive trends in annual minimum flows were obtained for all three permafrost zones, with the largest positive trends in the continuous permafrost zone (Janowicz, 2008). These findings are postulated to result from increased surface-groundwater interaction due to permafrost degradation and increased active layer depth.

Southeast Yukon is drained by rivers feeding into the Mackenzie River basin, primarily the Liard, which—along with other rivers in the mountainous, headwater regions of the Mackenzie basin—has exhibited increases in winter discharge and some increase in snowmelt freshet (Janowicz, 2008). In general, the remainder of the southern half of Yukon is part of the Upper Yukon drainage basin. It includes high mountainous areas and is generally underlain by discontinuous and sporadic permafrost. Streamflow data for the years between 1944 and 2005 indicate that most sites in the Yukon Basin experienced statistically significant increases in winter flow (January 1 to March 31) and average April flow, probably due to increased groundwater discharge to the stream. A declining trend in average flows in June, July, and August, particularly in the Upper Yukon, over the entire period of record is likely a result of earlier spring snowmelt and runoff, which leaves less water to be discharged in summer (Brabets and Walwoord, 2009).

Looking into the future, based on climate inputs from 19 different general circulation model simulations, river flow is projected to increase in high latitudes of North America (Yukon and Mackenzie rivers) to the end of the 21st century (Nohara *et al*., 2006). Janowicz & Ford (1994) used temperature and precipitation projections from the Canadian Climate Centre's General Circulation Model (CCC-GCM) to assess the impacts of climate change on the water supply to the upper Yukon River. Their analyses indicated that annual inflows to the glacierized upper Yukon River would increase by 39%, primarily in the summer months, due to increasing temperature and precipitation (Janowicz, 2008).

4.2.8 Groundwater

Groundwater is water located in the spaces between soil particles and in the fractures of rock formations underground. An aquifer is an underground layer holding water, which can yield a usable quantity of water. The hydrological consequences of climate change on groundwater, such as the effects on groundwater flow rates, pathways, recharge, and discharge to surface water, are not well understood.

During the late winter in Yukon, streamflow consists almost entirely of groundwater (Whitfield *et al*., 1993). Throughout the Yukon River Basin, estimated groundwater contribution to total annual flow can be as high as 50%, largely dependent on geology and permafrost coverage. The Yukon headwaters and the south-central region, characterized by upland glacial meltwater and alpine watersheds, deliver the largest contribution of groundwater, although it is variable. The Porcupine River derives considerably less of its annual flow from groundwater as it drains an extensive low-lying area underlain by continuous permafrost (Walvoord and Stiegl, 2007).

As noted for surface waters, permafrost thawing deepens the active layer and allows for increased infiltration, groundwater-surface water interactions, and ultimately increased groundwater contributions to base flow. Trends in streamflow investigated over 20 to 50 year periods in the Yukon River Basin showed significant increases in estimated groundwater flow and minimal change in annual flow. In Yukon, the largest increases in estimated groundwater inputs were detected in the Yukon River headwaters and in the Porcupine River watershed. The increasing winter flow is postulated to be due mainly to greater groundwater input to streams (Walvoord and Stiegl, 2007).

Groundwater is a vital resource to the majority of Yukon communities; however, the groundwater regimes associated with community water supplies are relatively unstudied. Documentation and assessment of all Yukon community water systems was undertaken in 2001, outlining water system information, including water source, water pumping, storage and treatment facilities, water distribution, operation and maintenance, water licence, and recommendations (Jacobson, 2003). Despite the predominant reliance on groundwater, watershed protection measures and long-term aquifer capacity were only available for some communities. For the City of Whitehorse, which now relies entirely on the Selkirk Aquifer for its drinking water, the Watershed Management Plan identifies areas of recharge and potential risks to the aquifer, as well as water modelling activities that were undertaken to determine the feasibility of complete reliance on groundwater (UMA, 2003). Water well records collected in Wolf Creek and Pineridge subdivisions were used in a groundwater usage study (Gartner Lee, 2001). The study found that groundwater extraction utilized a large portion of the annual infiltration flow available for Wolf Creek base flow. Without long-term water level data, however, it was not possible to determine if consumption rates were causing the reduction in base flows in the creek or the long-term reduction of aquifer storage. The availability of long-term groundwater and surface water monitoring records, drilling and water well records, and usage rates is integral to better understanding of our groundwater supplies.

4.3 Changing Water Quality

The changes in water quantity and water temperature that are expected to result from climate change inevitably lead to changes in water quality. Lower water levels tend to increase concentrations of ions (e.g. dissolved metals) in water; high flow events and flooding increase turbidity and flush contaminants, both natural and anthropogenic, into the water system (Lemmen and Warren, 2004). Higher water temperatures and changes in extreme conditions also have consequences for water quality. Floods and droughts can exacerbate water pollution from sediments, nutrients, dissolved organic carbon, pathogens, pesticides, and salt. Thermal pollution is, itself, a problem, with possible negative effects on ecosystems, human health, and water system reliability and operating costs (Bates *et al*., 2008).

In the North especially, liquid water is not the only component of the hydrologic system. Cryospheric components—snow and ice, in all their forms—dominate northern hydrological processes. With polar regions expected to experience some of the earliest and most profound climate-induced changes to all systems, and the cryosphere particularly vulnerable, northern water resources are at risk (Bates *et al*., 2008). However, the multiple stressors operating on cryspheric elements make it even harder to determine changes for them than for hydrological elements.

Indeed, all water-related impacts of climate change are difficult to predict. Information is inadequate , especially about potential impacts on water quality, aquatic ecosystems, and groundwater, and on the socio-economic dimensions of such impacts (Bates *et al*., 2008).

4.3.1 Water Quality Index

The Canadian Environmental Sustainability Indicators (CESI) initiative provides public information about the status of water quality in Canada, with the goal of protecting aquatic life. CESI information serves as a basis for evaluating Canada's environmental performance and the impacts on the environment of social and economic decisions, such as lifestyle and consumer choices, policies, and commercial and industrial developments. It provides an overall measure of the ability of water bodies to support aquatic life at selected monitoring sites in Canada. The indicator is calculated using the Water Quality Index (WQI) endorsed by the Canadian Council of Ministers of the Environment (CCME) in 2001 (CCME, 2001) and is applied as recommended by the National Round Table on the Environment and the Economy (NRTEE, 2003).

Aquatic life can be influenced by the presence of hundreds of natural and anthropogenic substances in water. The WQI is a useful tool that allows experts concerned with impacts on aquatic life to translate vast amounts of water quality monitoring information into a simple overall rating. In practice, these ratings are based on 4–15 measured substances, usually those of greatest concern for aquatic life (Environment Canada, 2010b).

The WQI measures the frequency and extent to which selected parameters exceed water quality guidelines at individual monitoring sites. When the guidelines are exceeded, it is an indication of possible adverse effects on aquatic life. The WQI water quality guidelines, derived for the protection of aquatic life, include:

- national guidelines developed by the CCME;
- provincial and site-specific guidelines developed by federal, provincial, and territorial partners; and,
- international guidelines developed by the United States Environmental Protection Agency.

The WQI yields a number between 0 and 100, indicating overall water quality for a particular use. The scores are categorized into five groups according to the rating system in Table 5 (Environment Canada, 2010b).

Samples collected from CESI stations in Yukon operated by Environment Canada and Environment Yukon are used to create the WQI. In addition, Yukon uses the WQI as the indicator for water quality in Yukon State of Environment reports. These reports provide early warning of potential problems in the environment, allow the public and government agencies to monitor progress on the objectives of the Environment Act and provide baseline information (Environment Yukon, 2010a).

Rating	Interpretation
Excellent (95.0 to 100.0)	Water quality measurements never or very rarely exceed water quality guidelines.
Good (80.0 to 94.9)	Water quality measurements rarely exceed water quality guidelines and, usually, by a narrow margin.
Fair (65.0 to 79.9)	Water quality measurements sometimes exceed water quality guidelines and, possibly, by a wide margin.
Marginal (45.0 to 64.9)	Water quality measurements often exceed water quality guidelines and/or exceed the guidelines by a considerable margin.
Poor (0 to 44.9)	Water quality measurements usually exceed water quality guidelines and/or exceed the guidelines by a considerable margin.

Table 5 The rating system for the Freshwater Quality Indicator (Environment Canada, 2010b)

In the 2007 Interim State of Environment Report, the Liard and Dezadeash rivers were rated Excellent/Good and Good respectively, with stable index scores since 2001 (Environment Yukon, 2010). Newly included in the 2007 report were:

- The Yukon River at Marsh Lake and above the Takhini River, rated Excellent, with water quality guidelines never or very rarely exceeded.
- The Klondike River above Bonanza Creek, with a stable Fair rating, influenced by historic gold mining, rural development, agriculture, placer mining, and recreation.
- The South McQuesten River, a snowmelt-fed system located downstream of abandoned tailings piles from the Keno Hill silver-lead-zinc mine, given a Marginal rating.

Continued monitoring of these sites over time can provide an indication of how water quality changes in response to the drivers of changing management and use, and the impact of climate change.

The WQI has also been used to assess trends in water quality in the Mackenzie River Basin Board's State of the Aquatic Ecosystem Report, although stations considered for the Liard and Peel basins are outside Yukon (downstream in British Columbia and Northwest Territories, respectively).

4.3.2 Erosion and Sediment Transport

Suspended sediments—fine solids swept up and carried along by flowing water—can result from natural processes such as glacial scouring, riverbank erosion, flood-plain resuspension, and fires, as well as from human disturbances such as mining, logging, dams, agricultural runoff, and urbanization (Meade *et al*., 1990). In the Yukon River Basin, most suspended sediments are created by natural processes (Dornblaser and Striegl, 2009).

Suspended sediments link the terrestrial and aquatic environments, as conveyors of organic carbon, nutrients, metals and contaminants, and carbonates from one location and ecosystem to another. They can affect aquatic life in rivers and coastal estuaries by clogging fish gills, burying spawning sites, or altering benthic habitats (U.S. Environmental Protection Agency, 1977). Suspended sediment discharge is sensitive to climate change, particularly as increased erosion and sediment transport can result from changing hydrological conditions, including permafrost degradation through increased peak flows or permafrost-induced landslides, glacial retreat, and changing snowmelt and spring break-up conditions.

The Yukon River Basin varies greatly in topography, climate, geology, permafrost, land cover, and water quality (Brabets *et al*., 2000), all of which affect the nature and scale of its sediment load. Mountainous, glaciated terrain occupies small but important areas of suspended sediment generation in the river's headwaters in British Columbia and Yukon, the St. Elias Range in the White River Basin, and the Wrangell and Alaska ranges in the Tanana River Basin. The Yukon River normally flows clear until it reaches the White River. There, it receives large amounts of sediment and carbonate. Downstream from the White River, the sediment-laden Yukon River has a secchi depth of about 2 cm (Dornblaser and Striegl, 2009).

As with most arctic and subarctic rivers, the Yukon River's sediment concentrations and loads are strongly seasonal and highly variable (Holmes *et al*., 2002). In spring, which includes break-up and peak discharge, the main sources of sediment are bank erosion and resuspension of previously deposited sediments. In summer and fall, as peak discharges recede, glacial melt becomes the dominant source of suspended sediment (Dornblaser and Striegl, 2009).

Generally, the more glacier cover in mountain watersheds, the greater the suspended sediment yield (Hallet *et al*., 1996). Therefore, conditions that cause glaciers to shrink and retreat, such as climate change, can produce elevated suspended sediment concentrations in glacial streams. The mechanisms involved include sediment delivery via debris flows and other processes associated with glacier retreat and, during years of strongly negative mass balance when high volumes of meltwater reach the glacier bed, the flushing of subglacial sediments (Jansson *et al*., 2005). Rapid glacier retreat can also release sediments stored in ice near the glacier's terminus, near its bed, and from recently deglaciated moraines and forefields (Moore, 2009).

Forecasting the impact of glacier retreat on suspended sediment is not straightforward. Suspended sediment concentration in rivers could, in some circumstances, drop. As glaciers become smaller, for example, the area of the glacier in contact with its bed will decline, resulting in less basal erosion (Hallet *et al*., 1996). Furthermore, terminal retreat often results in formation of proglacial lakes, which can trap andstore sediment discharged by a glacier, at least until the lakes fill (Moore *et al*., 2009).

Both increasing and decreasing sedimentation trends will likely occur, in succession, in many basins. Glacier recession is expected to increase concentrations of suspended sediments in many rivers at time scales of years to decades. Then, suspended sediments from glacial sources are expected to decline as the area of glacier cover decreases and land uncovered by retreating ice stabilizes. In some catchments, the decline could be erratic, marked by occasional inputs of substantial amounts of both fine and coarse sediment to downstream channels (Moore *et al*., 2009).

The impact of glacial retreat on suspended sediments depends not just on climate warming but also on the elevation of the glacier. A rapidly retreating glacier at high altitude produces a pro-glacial area dominated by sediment and a growing length of active channel braiding and instability. At low altitude, sediment and runoff from a rapidly retreating ice mass are affected by riparian vegetation. Vegetated islands stabilize the recently glaciated land relatively quickly, although a high sediment load ensures the persistence of some braiding between islands. Bed-load and suspended sediment transport will potentially decrease in the long term as glacial erosion decreases and runoff diminishes (Fleming and Clarke, 2005).

Glaciers are not the only source of sediment in Yukon waters. Several studies have documented permafrost-related landslides in south and central Yukon and northern British Columbia. These studies highlight the fact that such failures are common in discontinuous permafrost regions. Findings from the studies show that permafrost-related landslides commonly occur in or near valley bottoms, suggesting that they are a source of significant sediment in watercourses (Lipovsky and Huscroft, 2007).

Permafrost-related landslides happen when disturbance causes the active layer to become saturated or ground ice to thaw. Rapid thawing can happen when ice is exposed directly to the atmosphere or water. Changes in runoff and groundwater flow can also cause thermal erosion or the build-up of high pore pressure (Lipovsky and Huscroft, 2007).

The potential effects of temperature and precipitation increases on slope stability in southern Yukon over the next 50 years were discussed by Huscroft *et al*. (2004). Climate is linked to many factors that influence the frequency of landslides. They include forest-fire frequency and severity, riverflow levels, bank-erosion rates, and extreme synoptic events such as intense rainfall and snowmelt events. Climate is also strongly linked to factors that control the distribution of permafrost, including the duration and depth of seasonal snow cover, summer and winter air temperatures, soil moisture, vegetation, and microclimate effects. The warming expected in Yukon over the next several decades is therefore likely to have a stronger effect on the frequency and/or magnitude of landslide-triggering events than on the regional distribution and degradation of permafrost (Lewkowicz and Harris, 2005).

The most common disturbances to permafrost and active-layer hydrology in the area studied by Lipovsky and Huscroft (2007) seem to be forest fires and river erosion, combined with the related influences of local synoptic weather conditions and long-term climate trends. Forest fires dramatically alter surface thermal and hydrological conditions, both during and immediately after the fire, leading to rapid increases in active-layer depth and changes in soil moisture regimes (Burn, 1998; Yoshikawa *et al*., 2002; Lipovsky *et al*., 2006). At least 16 of the failures identified in the study area were likely triggered or re-activated by fires that occurred in 2004. McCoy and Burn (2005) estimated that the maximum annual burned area in central Yukon could increase by more than 300% by 2069. It is reasonable to expect that the frequency of failures triggered by forest fires in the region will also increase over this period (Lipovsky and Huscroft, 2007).

4.3.3 Metals and Contaminants

Concern around the introduction and transport of metals and contaminants in Yukon waters, and the resulting effect on aquatic organisms has generally been focused on anthropogenic activities such as mining or municipal wastewater. However, permafrost thaw will likely lead to changes in the groundwater flows (Walvoord and Striegl, 2007) and the quantity and quality of organic carbon in rivers, streams, and lakes

(Striegl and others, 2005; 2007). The associated possible changes in metal and contaminant levels in the aquatic ecosystem resulting from permafrost melt are an emerging area of investigation.

Several baseline studies have been conducted over the past 40 years to characterize surface water in Yukon. Some of these have considered metal and contaminant concentrations and loads. Aquatic life objectives for copper and lead were exceeded more than 20% of the time at some stations in the Yukon River Basin baseline water quality assessment, conducted over 13 months in 1982/83 on the Yukon River mainstem and headwaters and on its major tributaries. The authors of the assessment suggest that the presence of these metals and the softness of the waters in the Yukon River Basin means that additional loads of these metals from man-made sources could increase the risk of sublethal stress to aquatic life (Jack *et al*., 1983).

A water contaminants evaluation conducted in 1998 on the Yukon River found dissolved solids and phosphorus levels to be significantly different between Nares Lake in the south and Thirty Mile Creek in the north (Roach, 1998). A preliminary study of possible changes in water quality of the Klondike River between 1982 and 2009 suggests increased winter concentrations of sulphate, selenium, and arsenic, while sodium, chloride, calcium, potassium, and phosphorus decreased. The winter loading trends for chloride, potassium, and phosphorus are downward, while those for selenium, arsenic, and sulphate are upward (Whitley, 2010, unpublished report). The Peel River Water and Suspended Sediment Sampling Program between 2002 and 2007 found that most metals sampled (including aluminum, arsenic, cadmium, chromium, copper, iron, lead, mercury, nickel, selenium, uranium, and zinc) were within the historical range of water quality at Peel River above Fort McPherson (1969-2000). Some metals did not meet the *Guidelines for the Protection of Fresh Water Aquatic Life*, yet it was found unlikely that the levels of metals in the Peel River represent a hazard to aquatic life. Most metals are attached to suspended sediment, which makes their availability for uptake by fish and other aquatic life very low (INAC, 2008).

A warming climate is postulated to affect the fluvial transport and possibly increase the export of organic carbon-bound mercury (Hg) from permafrost-dominated northern region river basins. Continuous and discontinuous permafrost cover more than three quarters of the land surface in the Yukon River Basin and represent a potential terrestrial landscape source of Hg to fluvial systems. Recent investigations measuring total Hg in permafrost cores indicate a large Hg reservoir, likely associated with the permafrost carbon pool. Studies focused on Hg in the Yukon River Basin have shown that total organic carbon yields account for 87-92% of the variance of total Hg yields, thus suggesting that organic carbon yields can be used as a reliable predictor of Hg yields (Shuester *et al*., 2010). A better understanding of Hg-organic carbon interactions in large-scale northern ecosystems is important, given the vast reservoirs of organic carbon that exist in arctic regions, recent widespread evidence of permafrost melting, and the serious potential threat Hg methylation poses to human health and aquatic biota.

4.3.4 Solute and Nutrient Concentrations

High-latitude northern rivers exhibit a highly seasonal discharge, with elevated dissolved organic carbon (DOC) concentrations during the spring freshet. Dissolved organic matter fluxes, both within and issuing from the Yukon River Basin, are controlled primarily by the type of source waters and the time of year. Organic-rich blackwater rivers contain more dissolved organic carbon, coloured dissolved organic matter, and carbon derived from vascular plants than tributaries fed predominantly by glacial meltwaters and groundwater. This trend is consistent year-round and results from landscape features such as extensive wetlands, which yield higher dissolved organic carbon and vascular-plant-derived carbon, or areas dominated by bare rock and ice and snowfields, which yield lower amounts of these types of carbon (Striegl *et al*., 2007).

Warming air temperatures that lead to permafrost thaw and degradation can have significant impacts on hydrology, ecosystems, and biogeochemical cycling. It is crucial to note that the impacts of warming and permafrost degradation on river biogeochemistry depend not only on watershed environmental characteristics (e.g., land cover, soil type, and topography), but also on current permafrost conditions, sensitivity to thawing, and mode of permafrost degradation (wholesale permafrost thaw, active layer deepening, and/or thermokarst processes) (Frey and McClelland, 2009). Differences in flow paths influence water biogeochemistry through water–soil exchange reactions, as well as through microbial processes that vary with soil depth and water residence time. Changing permafrost characteristics (e.g., active layer depth, the presence or absence of permafrost) strongly influence the depth of water flow through soils during the summer. During the spring freshet, meltwater is restricted to shallow flow paths over both permafrost and seasonally frozen ground. A shallow active layer keeps water flow relatively near the soil surface, increasing interaction with organic-rich soils, whereas a deeper active layer, or complete lack of permafrost, allows greater water flow through underlying mineral soils (Frey and McClelland, 2009).

As the depth, temperature, and seasonal duration of the active layer increase with climate warming, thawed permafrost and/or vegetation changes may contribute new inputs of dissolved organic carbon (Sturm *et al*., 2005). The newly mobilized DOC will either contribute higher exports of carbon to the ocean or linger in upland areas, eventually entering the atmosphere through respiration (Carey, 2003). To some degree, what happens depends on temperature, since DOC respiration is partly stimulated by increased temperature (Meentemeyer, 1978). More importantly, however, permafrost melting will greatly influence transport of DOC to the riverine environment.

A greater volume of subsurface drainage resulting from increased active layer depths could result in soil-water DOC remaining underground longer and in the rerouting of DOC into shallow groundwater. The result would be increased microbial mineralization and decreased riverine export of the terrestrially derived DOC (Stiegl *et al*., 2005). In the Yukon River system, decreased DOC export relative to total summer-through-autumn water discharge was observed over a 25-year time period (Striegl *et al*., 2005). This change was hypothesized to result from increased flow path, residence time, and microbial mineralization of DOC in the soil active layer and groundwater, due to climatic warming and changes in permafrost condition (Spencer *et al*., 2008). In some cases, long-term decreases are projected to occur only after an initial period of higher dissolved organic matter concentrations that result from permafrost meltwater (e.g., Striegl *et al*., 2007). Degradation of permafrost and increases in active layer depths may, in fact, result in a larger proportion of older organic carbon being released to rivers. This possibility suggests a new, large source pool of potentially reactive soil organic matter, should permafrost thaw in arctic and subarctic regions (Frey and McClelland, 2009).

Changes to dissolved nitrogen export are another potential and not well understood problem. Where the export of dissolved organic carbon to rivers could either increase or decrease as permafrost degrades across the Arctic, dissolved organic nitrogen (DON) exports are expected to show consistent increases (Frey and McClelland, 2009). However, there is considerable uncertainty about how changes in permafrost might affect inorganic nitrogen in arctic rivers (Frey and McClelland, 2009).

The expected impacts of degrading permafrost on dissolved silicate and phosphate in arctic rivers are more predictable than for carbon and nitrogen. Mineral weathering is the primary source of both dissolved silicate and phosphate in soil waters. Deeper flow paths through previously frozen mineral soils, resulting from permafrost thaw, would lead to an increase in the concentrations of these inorganic nutrients (Frey and McClelland, 2009).

Permafrost degradation is also expected to have significant impacts on major ions in rivers, with these changes projected to be relatively consistent across the pan-arctic region. However, the mode of permafrost degradation (i.e., wholesale permafrost thaw, active-layer deepening, and/or thermokarst processes) may determine how and where new flow paths are formed. This, in turn, will affect the concentrations and types of major ions delivered to streams and rivers. In general, concentrations of major ions (e.g., Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}) are predicted to increase markedly because of less interaction with organic shallow soils as the active layer grows and enhanced interaction with deep mineral horizons. In some cases, permafrost thaw and water table lowering may cause oxidation of the soil itself, leading to release of major and trace elements accumulated during soil and peatland development (Frey and McClelland, 2009).

Although impacts of permafrost degradation on major ions in streams and rivers are relatively simple, concentrations and fluxes of these major ions might be affected by changes in river discharge. Studies show a positive relationship between dissolved organic concentrations and discharge due to the flushing of carbon and organic matter when moist conditions return to previously aerated soils (Evans *et al*., 2002). However, the opposite is the case for major ions, where discharge is negatively correlated with concentrations of major ions because of dilution effects (Frey and McClelland, 2009).

One of the most profound potential changes accompanying future arctic warming could be the shift of the Arctic System from surface-water dominated to groundwater dominated, with cascading impacts on hydrology, ecosystems, and biogeochemical cycling. Groundwater currently comprises almost one fourth of Yukon River water discharged to the Bering Sea and contributes 5–10% of the dissolved organic carbon (DOC) and nitrogen (DON) and 35–45% of the dissolved inorganic carbon (DIC) and nitrogen (DIN) loads. Long-term streamflow records of the Yukon River Basin indicate a general upward trend in groundwater contribution to streamflow and no pervasive change in annual flow, suggesting a tendency toward greater groundwater input to streams (Walvoord and Stiegl, 2007). Assuming that winter flow chemistry represents the chemistry of groundwater, projections can be made as to how changes in the ratio of groundwater contribution to annual flow might affect carbon and nitrogen exports from the system. Based on 2001-2005 carbon and nitrogen data from the Yukon River, dissolved organic carbon and dissolved organic nitrogen exports will decrease by 9-11% and 8-9%, respectively, from 1960 to 2050. Conversely, dissolved inorganic carbon and dissolved inorganic nitrogen exports will increase by 16-19% and 17-21%. Assuming the same conditions, the combined DOC and DIN export is projected to increase by an estimated 10–12% from 1960 to 2050. Indeed, it could be more, since groundwater flow during the warmer months might produce even larger increases than cold-weather flow (Walvoord and Stiegl, 2007).

Changes in the timing and magnitude of glacial melt will also lead to changes in solute and nutrient concentrations (Moore *et al*., 2009). Glacier meltwaters tend, at first, to be relatively dilute, leading to dilute stream water downstream, at least during the melt season (Moore *et al*., 2009). Most solutes exported from glaciers are acquired by water flowing beneath the glaciers (Richards *et al*., 1996). As glaciers retreat, however, several processes may influence the chemistry of their meltwater. Areas exposed by deglaciation are subjected to fundamentally different weathering processes than those in the subglacial environment. The result is a shift in chemical species and concentrations in water draining from these areas (Anderson *et al*., 1997). Following deglaciation, weathering rates and processes in glacier forefields continue to evolve, especially as plants become established and soil development progresses (Anderson *et al*., 2000). At any point along a stream, water chemistry depends not only on the chemical characteristics of the water sources, but also on the rates of contribution from each source and the effects of in-stream processing. Given this complexity (Anderson, 2007), it is difficult to predict how streamwater chemistry will respond to glacier retreat (Moore *et al*., 2009).

4.3.5 Temperature

A modest change in water temperature can have profound effects on aquatic ecosystems and freshwater quality (e.g. warmer water cannot carry as much dissolved oxygen as cooler water). Lakes and rivers across the northern hemisphere are already exhibiting higher temperatures in response to warmer conditions, with surface water temperatures up as much as 2°C in North America, Europe, and Asia since the 1960s. The consequences of higher temperatures and a longer ice-free season include changes to the internal structure of lakes. For example, in warmer years, when surface water temperatures are higher, evaporative water loss increases, summer stratification occurs earlier in the season, and thermoclines become shallower (Bates, 2008). Such changes affect habitat within the lake, water balance, water volume, and water chemistry, among other things.

Old Crow Flats, the internationally recognized expanse of shallow lakes and wetlands in northern Yukon, is particularly sensitive to climate change. Turner *et al*. (2010) have divided the shallow lakes of the Flats into five water-balance categories: snowmelt-dominated, rainfall-dominated, groundwater-influenced, evaporation-dominated, and drained lake types. These types are strongly associated with landscape characteristics and susceptible in different ways to changing climate. Snowmelt-dominated lakes are located where more dense vegetation cover entraps drifting snow. Rainfall-dominated lakes occupy areas of sparse tundra vegetation cover where less snow accumulates. Groundwater-influenced oxbow lakes, along the floodplains of river and creek channels, are fed from snowmelt-recharged channel fens and sub-surface flow. Some lakes can shift to evaporation-dominated status from season to season, depending on climatic conditions. During the 2007 open-water season, only one basin became evaporation-dominated. Turner *et al*. (2010) speculated that the reason was extremely high precipitation during the preceding late summer, late winter, and early spring, which offset vapour loss. Rainfall-dominated lakes appear more likely than snowmelt-dominated and groundwater-influenced lakes to evolve into evaporation-dominated lakes during drier summers (Turner *et al*., 2010).

A significant proportion of Yukon's freshwater supply comes from glacier-dominated systems, which respond differently to air temperature changes than do the shallow lakes of Old Crow Flats. The degree to which glaciers affect downstream water temperatures is influenced by glacier area, distance downstream, climate and flow conditions, and the flux of non-glacial water to the streams (Brown *et al*., 2006). Water temperature is positively related to air temperature and negatively associated with river flow/thermal capacity (Brown and Hannah, 2008). Climate warming and glacier recession is expected to lead to a long-term decrease in streamflow. The consequence could be an increase in the water temperature in glacier-fed systems due to higher air temperatures, lower contribution of cold meltwater relative to warmer groundwater, and the reduced thermal capacity of rivers with lower flow (Milner, 2009).

4.4 Extreme Events

Precipitation is influenced by climatic oscillations, particularly decadal variations, so identifying trends in extreme precipitation events related to global climate change is challenging. No change is apparent in the frequency or intensity of extreme precipitation for Canada as a whole during the 20th century, apart from the decadal variation (Zhang *et al*., 2001b). There was an increasing trend in precipitation over that period (Zhang *et al*. 2000), but mainly due to increases in the number of non-heavy events. There appears to be an upward trend in the number of heavy snowfall events for autumn and winter over northern Canada with strong decadal variability (Zhang *et al*., 2001b). For the 1950-1995 period, heavy events became more frequent in winter and spring in northwestern Canada, along with intermediate events in winter, while lighter events decreased (Stone *et al*., 2000). Given a continuation of this trend, greater heavy snowfall events could be experienced in Yukon, with a possible increase in smaller precipitation events.

Thermokarst lakes are susceptible to drainage into rivers as lakes expand in response to continued permafrost degradation. Mackay (1992) concluded that thermokarst lakes along Canada's western Arctic coast have drained at a rate of one to two lakes per year over the past few millennia (Turner *et al*., 2010). On Old Crow Flats, researchers observed two lake drainage events in June 2007 (Turner *et al*., 2010). Zelma Lake was one of the largest (~12 km^2) lakes in the Old Crow Flats. Aerial photographs taken in July and water depth measurements indicated that the drainage caused an approximate 43% reduction in lake area, and over 80% reduction in lake volume (Wolfe and Turner, 2008). OCF56 is an oxbow lake located within a few metres of the Old Crow River. The water level of OCF56 was at full capacity in early June 2007 and was slowly draining into the Old Crow River via a small surface outlet. By late July, OCF56 had been reduced to a small pond, the majority of which was occupied by thick emergent vegetation (Turner *et al*., 2010).

Significant flooding in the Southern Lakes Region in the summer of 2007, with levels surpassing the 2004 high and the 1981 record, highlighted the effect that increased glacial melt (from the hot summer) and summer precipitation can have on lake levels.

5 Water Quantity and Quality Monitoring

Yukon's water monitoring networks—the stations, sites, and surveys that are used to measure parameters such as precipitation, snowpack, streamflow, water quality, and ground and water temperature—represent a key tool to improving our ability to adapt to climate change impacts on water resources. Each network was established and has evolved over time to meet economic, environmental, regional, or regulatory needs. Very few were designed primarily to monitor the impacts of climate change or to help us in adapting to those impacts.

This section provides an inventory of monitoring networks that collect water quantity and quality parameters that could be used for climate change adaptation planning, as well as better informing water management decisions. Many of these networks are well-known and readily available and actively used; others are relatively unknown. The identification of these networks for use in climate change adaptation activities is a first step toward improved access to accurate, sufficient, and relevant data on hydrological conditions and water quality for climate change assessments and adaptation planning.

5.1 Data Collection Agencies

A wide range of governments, departments, and organizations—governmental and non-governmental—are engaged in water monitoring and data collection in Yukon. Due to the cross-boundary nature of the territory's watersheds, the groups include both Canadian and American government agencies, as well as First Nation organizations and universities from both countries. Several departments of the Government of Yukon are involved in monitoring as part of their mandates.

Following are the principal governments and agencies monitoring Yukon water resources:

Government of Yukon Departments

- Yukon Community Services: responsibilities related to drinking water, wildfire management and fire danger ratings
- Yukon Energy, Mines and Resources: responsibilities related to abandoned mines, placer mining, and permafrost status.
- Environment Yukon: primary responsibility for water quality and quantity, including monitoring activities of water licence auditing, snowpack monitoring, flood forecasting, small streams and groundwater.
- Yukon Highways and Public Works: responsibilities related to drinking water.
- Yukon Health and Social Services: regulatory responsibilities related to drinking water quality and sewage disposal.

Government of Canada Departments

- Environment Canada
- Natural Resources Canada
- Fisheries and Oceans Canada
- Government of the United States of America
- United States Geological Survey

Yukon First Nation Governments

Yukon First Nations with self-government agreements have responsibilities related to freshwater resources within their Traditional Territories. As the self-government agreements are implemented, more First Nations are likely to become actively involved in monitoring and research related to freshwater resources. First Nations currently engaged in aspects of water monitoring include:

- Vuntut Gwitchin First Nation
- Ta'an Kwäch'än Council
- Kwanlin Dün First Nation
- Tr'ondëk Hwëch'in
- Cross-border Organizations
- Yukon River Inter-Tribal Watershed Council

A number of other organizations conduct research and monitoring related to freshwater resources in Yukon, in addition to governments and related agencies. Several universities, both Canadian and international, have engaged in water-related research in the territory, often in conjunction with one or more of the agencies listed above. Co-management bodies, established under various land claim agreements, are also participants or instigators in water-related research and monitoring. In addition, private companies collect data required to satisfy the requirements of water licensing or environmental assessment processes. Since the data collected by these various organizations and agencies are not always publicly available, most have not been included in the following list of monitoring networks.

5.2 Monitoring Networks

At least three dozen monitoring networks and data collection programs are accumulating information about the Yukon's water resources. The networks and programs fall into three broad categories:

- Hydrometeorologic networks, which deal with monitoring of environmental parameters related to water quantity. This group includes networks monitoring meteorological factors and groundwater.
- Water quality networks, which deal with monitoring of environmental parameters related to water quality. This classification of networks includes water quality monitoring networks associated with drinking water and with tracking changes in long-term surface and groundwater chemistry.
- Aquatic health networks, which deal with environmental parameters related to contaminants and the impact of water quality on aquatic health.

5.2.1 Hydrology Networks

Name: Canada-Yukon Hydrometric Monitoring Network

Agency: Water Survey of Canada, Environment Canada

Other agencies involved: Water Resources Branch, Environment Yukon

Program objectives and description: To provide Yukon hydrometric information as part of a national framework for hydrometric monitoring. Originally established in the 1940s to provide hydrometric information related to river transportation, and expanded several times to allow for hydroelectric and mining development. Currently, there are 48 active stations in Yukon.

Parameters measured & reported: Water level and/or streamflow discharge recorded at all stations. Sediment (sediment concentration and loading) recorded at 12 stations (1968-1992). Other parameters such as river width, depth, velocity, water temperature, ice thickness, river conditions, and pictures are collected during site visits and are available by request.

Period of record: 1940s to present.

Data availability: Real-time and archived data are available online.

Name: Yukon Hydrometric Network

Agency: Water Resources Branch, Environment Yukon

Program objectives and description: To collect long-term hydrometric data on small drainage basins (<500 km^2) and provide baseline information for future developments (e.g., culverts, fisheries concerns, gas pipelines, hydroelectric, and quartz and placer mining developments). The network incorporates key stations representing the streamflow characteristics of different hydrologic regions. In the late 1970s and early 1980s, 40 manual crest gauge stations were discontinued when the network was converted to continuous monitoring. Currently, there are 14 active stations on small streams in Yukon, as well as 83 historical stations.

Parameters measured & reported: Water level, streamflow discharge.

Period of record: 1974 to present.

Data availability: Historical data from 1975 to 2004 are available online. Data since 2004 are maintained internally by the Water Resources Branch.

Name: Canadian Meteorological Network

Agency: Meteorological Service of Canada, Environment Canada

Program objectives and description: To collect meteorological information. The network provides accurate meteorological data from key stations to both government agencies and the public. Raw data and specialized analytical products (e.g., climate normals and rainfall intensity-duration curves) are made available electronically for a variety of purposes, such as weather forecasts, planning and design for development projects, climate change research, and travel. There are 53 active and 79 historical stations in Yukon. Many stations are located at airports and townsites. Most active stations have automated monitoring equipment, with some of the data available in real time.

Parameters measured: Wind speed and direction, temperature, barometric pressure, precipitation amount and type, and humidity. Some stations monitor lightning strikes, cloud type and height, and pressure aloft.

Period of record: 1920s to present.

Data availability: Climate data and climate normals are available online.

Name: Community Services Weather Network

Agency: Wildland Fire Management Program, Yukon Community Services

Program objectives and description: To monitor and predict the daily fire danger rating for Yukon during the forest fire season. The network consists of meteorological stations throughout Yukon. Precipitation values are not valid from fall freeze-up to spring snowmelt as the rain gauges are not designed to operate in the cold.

Parameters measured: Relative humidity, wind speed and direction, temperature, precipitation monitored continuously. Precipitation is not measured at Mt. Sima station.

Period of record: 1993 to present.

Data availability: Hourly station data are transmitted to Yukon iScada network. Year-to date and daily data files are also available online.

Name: Yukon Meteorological Network

Agency: Water Resources Branch, Environment Yukon

Program objectives and description: To collect meteorological data in support of the Yukon Streamflow Forecasting Program. The current meteorological network includes seven stations, of which four have real-time snow pillow data. The three remaining meteorological stations were established in 1993 at different elevations within the Wolf Creek Research Basin to provide baseline data for the Wolf Creek Research Basin project.

Parameters measured: Air temperature, precipitation, relative humidity, wind speed and direction, solar radiation, and barometric pressure. Additionally, soil heat flux, air-snow interface temperature, infrared canopy temperature, soil temperature, snow depth, and soil moisture, incoming and outgoing short wave radiation and net radiation and blowing snow rate are measured at the Wolf Creek meteorological stations.

Period of record: 1993 to present.

Data availability: Data maintained internally by Water Resources Branch.

Name: Yukon Snow Survey Network

Agency: Water Resources Branch, Environment Yukon

Other agencies involved: Field collection assistance from Client Service and Inspections Branch, Yukon Energy Mines and Resources; British Columbia Ministry of Environment, Water Stewardship Division; USDA Natural Resources Conservation Service; Yukon Highways and Public Works; Parks Canada; Yukon Energy Corporation; and private contractors.

Program objectives and description: To collect snow water equivalent data for runoff forecasting, as well as to assist in planning and design of development projects, wildlife studies, avalanche forecasting, highway maintenance, forest fire indexing, and building design. The current network consists of 62 active snow courses in Yukon's six major basins, including several stations in British Columbia and Alaska. Measurements are taken three times a year: March 1, April 1, and May 1.

Parameters measured: Snow depth, snow water equivalent, density. The number reported is an average of 10 samples.

Period of record: 1975 to present.

Data availability: Snow survey data are maintained internally in an Access database, and reported after each sampling event in the Yukon Snow Survey Bulletins and Water Supply Forecasts, prepared and issued by Environment Yukon's Water Resources Branch.

Name: Yukon River Ice Break-up at Dawson City Monitoring

Agency: Water Resources Branch, Environment Yukon

Other agencies involved: The Imperial Order of the Daughters of the Empire (I.O.D.E.)

Program objectives and description: To track the date of ice break-up on the Yukon River at Dawson. The Water Resources Branch has assembled a continuous record of break-up timing for the site since 1896, through assembling local records, infilling missing years, and continued monitoring.

Parameters measured: Date of ice break-up.

Period of record: 1896 to present.

Data availability: Data are maintained internally by the Water Resources Branch.

Name: Yukon-wide Long-term Groundwater Monitoring Program

Agency: Water Resources Branch, Environment Yukon

Program objectives and description: To collect information on long-term trends in groundwater in areas where there is infrastructure (e.g., country residential sub-divisions). This long-term groundwater monitoring program was initiated in 2001 as part of a multi-disciplinary research program in the Wolf Creek drainage and later expanded to other locations. There are currently five continuous monitoring stations in the network, of which four (Faro, Dawson City, Selkirk, and Whitehorse Copper) were added in 2008.

Parameters measured: Depth to groundwater.

Period of record: 2001 to present for Wolf Creek well; 2008 to present for others.

Data availability: Data are maintained internally by the Water Resources Branch.

Name: Yukon Water Well Registry

Agency: Water Resources Branch, Environment Yukon

Other agencies involved: Natural Resources Canada

Program objectives and description: To improve knowledge of the characteristics of groundwater aquifers in Yukon through information from the development of groundwater wells. The registry was established in 2005 as a publically accessible groundwater database containing construction details and groundwater level information from water wells around Yukon. Some information is provided voluntarily, and some comes through the Rural Domestic Well Water Program, which requires reporting about well drilling through a Water Well Drillers Form.

Parameters measured: One-time record of well construction details; nature of overburden and bedrock; groundwater levels and characterization.

Period of record: Earliest record is 1963.

Data availability: Data available through the Groundwater Information Network.

5.2.2 Water Quality Networks

Name: Pacific Yukon Water Quality Monitoring Program

Agency: Environment Canada – Pacific & Yukon Region

Other agencies involved: Water Resources Branch, Environment Yukon; Parks Canada; Vuntut Gwitchin First Nation

Program objectives and description: To provide information to assess long-term trends in water quality. Information from this network is also used for a variety of other purposes: e.g., development of water quality guidelines, environmental assessments, reporting on environmental health, and the assessment of water quality compliance with existing guidelines and objectives. There are 10 active and 47 discontinued stations in Yukon, with most stations located on drainages of interest to both federal and territorial governments.

Parameters measured: Acid/base chemistry, carbon, carbon-nitrogen compounds, major ions, metals, dissolved non-metals, nutrients, organic contaminants, oxygen, pathogens, and in-situ benthic invetebrates. Most stations are sampled every month. One continuous automated sensor is deployed on the Klondike River during the ice-free period.

Period of record: 1983 to present, for active stations.

Data availability: Available on Environment Canada's website.

Name: Yukon River Water Quality Monitoring Project

Agency: Yukon River Inter-Tribal Watershed Council

Other agencies involved: United States Geological Survey; Environment Yukon; Environment Canada

Program objectives and description: The program is intended to provide a better understanding of variations in water quality as the Yukon River flows from the Canadian headwaters to the Bering Sea. Monitoring is conducted at 12 stations in Yukon and includes sampling of major tributary systems of the Yukon River.

Parameters measured: pH, temperature, conductivity, dissolved oxygen recorded in field. Dissolved gas, major ions, nutrients, oxygen 18 and dissolved organic carbon content analyses conducted in laboratory.

Period of record: 2004 to present.

Data availability: Data are available from the YRITWC's Yukon River Hydrological Information System website.

Name: Water Licence Water Quality Reporting and Audits

Agency: Water Resources Branch, Environment Yukon

Program objectives and description: To monitor and audit licensee compliance with the conditions of water licences issued by the Yukon Water Board under the *Waters Act*, where licence activities pose a potential threat to water resources. Site visits and audits are prioritized based on the risk potential and activity level of the project and typically include the collection of water quality samples, in situ water chemistry and flow measurements. Approximately 700 sites are identified in a water quality database, for licences that have identified water quality standards and sampling sites; these are mostly industrial, quartz mining, and municipal licences.

Parameters measured: Licence-dependent, but typically water chemistry (total or dissolved metals).

Period of record: 1970s to present.

Data availability: Data are stored in a database maintained by Water Resources.

Name: Environment Canada Water Quality Baseline and Audit Repository

Agency: Environmental Protection Operations Directorate, Environment Canada

Program objectives and description: To collect and manage water quality data for the purpose of analysis and standardized information archival. Data is gathered from various branches of Environment Canada, Yukon Environment Water Resources water licence audits, and industry handling water quality data (ex: mining and exploration).

Parameters measured: Extensive (varies by site).

Period of record: 1990s to present.

Data availability: Internal Government of Canada database.

Name: Placer Water Quality Objectives Monitoring

Agency: Client Services and Inspections Branch, Yukon Energy, Mines and Resources

Program objectives and description: To monitor water quality under the *Fish Habitat Management System for Yukon Placer Mining*. Water quality and quantity data are collected from 13 of the 18 Yukon watersheds that are subject to historic or ongoing placer mining activity. As many as 28 automated sampling stations are deployed seasonally (mid-May through September), with an additional 260 sites monitored on a sporadic basis. The network also includes a meteorological monitoring component to assist in the interpretation of the collected water quality data, with 16 portable weather stations deployed annually over the sampling period in the major watersheds.

Parameters measured: Total suspended solids, settleable solids, turbidity, and conductivity, pH; air and water temperature at all stations. Stream flow and routine water chemistry including metals and nutrients are collected at some stations depending on physical and environmental conditions. Continuous air, ground and water temperature, along with precipitation is collected at sites equipped with portable weather stations.

Period of record: 1992 to present.

Data availability: 1992 to 2007: water quality only, available in hard copy format. 2008 to present: data from stations stored on Yukon Placer Secretariat website.

Name: Water Quality Monitoring at Type II Abandoned Mines

Agency: Assessment and Abandoned Mines Branch, Yukon Energy, Mines and Resources

Other agencies involved: Private contractors

Program objectives and description: To monitor water quantity and quality at Type II Abandoned Mines (Faro, Mount Nansen, and Clinton Creek). At Clinton Creek, monitoring is conducted once per year. At Mount Nansen, 15 sites are sampled every two weeks. At the Faro Anvil Mine, sampling includes all requirements in the previous water licences for the site, with daily to quarterly sampling frequencies for various parameters. Sampling at all sites is typically conducted by contractors, and the results are submitted to the AAMB as part of monthly and annual reporting.

Parameters measured: Flows, contaminants (heavy metals, arsenic, cyanide, suspended solids). Each site also has a weather station.

Period of record: Varies by site, approximately 10 years.

Data availability: Inquire at Assessment and Abandoned Mines Branch.

Name: Metal Mining Effluent Regulations Reporting Requirements

Agency: Environment Canada

Program objectives and description: To monitor effluent discharges from mines under the federal *Metal Mining Effluent Regulations* (MMER). The MMER establish monitoring and reporting requirements with respect to prescribed effluent limits for deleterious substances and require Environmental Effects Monitoring (EEM) in order to detect and quantify changes in aquatic ecosystems affected by mine effluent discharges. Mine operators subject to the MMER are required to collect weekly and quarterly samples at identified final discharge points at each site. Environment Canada inspectors also conduct periodic inspections of these mines and collect additional samples for quality control purposes.

Parameters measured: Deleterious substances (arsenic, copper, cyanide, lead, nickel, zinc, total suspended solids, and radium 226) and pH; acute lethality tests and Daphnia magna tests; EEM data (effluent characterization, water quality monitoring, and sublethal toxicity testing). Additional biological monitoring data collected for EEM are submitted to the National Environmental Effects Monitoring

Office (NEEMO) of Environment Canada.

Period of record: 2006 to present for Yukon sites.

Data availability: Access restricted to mine operators and Environment Canada.

Name: Drinking Water Bacteriological Testing

Agency: Environmental Health Services, Yukon Health and Social Services

Program objectives and description: To provide an accredited water quality laboratory for testing total coliforms and E. coli at no cost for analysis to drinking water operators and private owners. Sampling requirements for large public drinking water systems (15 or more service connections) and for bulk water delivery are outlined in Part 1 and 2 of the Yukon *Drinking Water Regulation*. Sampling results for private systems or private wells are reported to owners. Physical and chemical testing is undertaken by public drinking water system operators and private well owners at accredited labs outside of Yukon. Environmental Health Services must be notified immediately by operators of any result that exceeds the acceptable concentration for health related contaminants set out in the *Guidelines for Canadian Drinking Water Quality*.

Parameters measured: Total coliforms and E. coli.

Period of record: 1997 to present.

Data availability: Internal Government of Yukon database.

Name: Property Management Drinking Water Database

Agency: Property Management Division, Yukon Highways and Public Works

Program objectives and description: To maintain bacteriological water quality information for all Yukon government-owned buildings not serviced by a public drinking water system. The monitoring program and database track the results of sampling and analysis that will soon be required under Part 3 of the Yukon *Drinking Water Regulation*. Information comes from highways work camps, grader stations, schools, and community centres.

Parameters measured: Bacteriological, physical and chemical water quality.

Period of record: 2004 to present.

Data availability: Results are stored in a database containing system infrastructure and treatment information as well as well logs, where available.

Name: Community Services Drinking Water Database

Agency: Community Development Division, Yukon Community Services

Program objectives and description: To provide safe drinking water for Community Services operated public drinking water systems in unincorporated communities. The monitoring program track the results of sampling and analysis required under the Yukon *Drinking Water Regulation* following *Canadian Drinking Water Guidelines*. Bacteriological water quality information is stored in a database, while physical and chemical results are filed separately.

Parameters measured: Bacteriological, physical and chemical water quality parameters.

Period of record: 1990s to present.

Data availability: Internal Government of Yukon database.

Name: Groundwater and Surface Water Monitoring at Yukon Contaminated Sites

Agency: Environmental Programs Branch, Environment Yukon

Program objectives and description: To monitor groundwater and surface water at contaminated sites in Yukon, as part of the mandate of Environment Yukon's Environmental Programs Branch (EPB) under the *Environment Act*'s *Contaminated Sites Regulation* (CSR). The CSR establishes cleanup standards, processes for identifying and investigating contaminated sites, and permits for managing contaminated material. The EPB maintains the Public Registry of Contaminated Sites (PRCS), which summarizes past site investigations, site assessments, test results, Certificates of Compliance that may have been issued, and various other relevant information about the contaminated sites. EPB also maintains a database for sites where hydrocarbon spills, leaking tanks, or other potential sources of contamination have been reported.

Parameters measured: Wide variety of information about contaminated sites.

Period of record: N/A

Data availability: Information contained in the Public Registry of Contaminated Sites can be accessed by contacting the EPB at envprot@gov.yk.ca.

Name: Solid Waste Disposal Facilities Permitee Monitoring for Leachate Impacts

Agency: Environmental Programs Branch, Environment Yukon

Program objectives and description: To monitor permit requirements for dumps and landfills in Yukon, as required by Environment Yukon's Environmental Programs Branch (EPB) under the *Environment Act*'s *Solid Waste Regulations*. Solid waste permits issued for facilities set out specific surface and groundwater monitoring requirements on a site-specific basis. There are currently 7 sites with active monitoring programs out of a total of 31 solid waste disposal facilities. The number of sites with active monitoring programs will increase as each municipal solid waste facility and all landfills under the Departments of Community Services and Highways and Public Works undergo hydrogeological assessments and installation of groundwater monitoring wells. Sites that currently have groundwater analytical results are Dawson, Carmacks, Carcross, Marsh Lake, Teslin, Whitehorse, and Upper Liard.

Parameters measured: Water chemistry; varies by site.

Period of record: 2001 to present for Whitehorse; sampling more recently introduced at other sites.

Data availability: Data are maintained internally by the Monitoring and Inspections and Standards and Approvals sections of the EPB.

5.2.3 Aquatic Health Networks

Name: Biomonitoring Information System of the Yukon

Agency: Environment Canada

Program objectives and description: To collect aquatic biological data and gather historical data and information from both published and unpublished sources. BISY currently holds data records from more than 400 drainages in Yukon and portions of Northern British Columbia, representing more than 2700 unique site visits.

Parameters measured: Freshwater benthic invertebrates (regardless of methodology), stream sediment chemistry, in situ stream measurements, geo-reference information, habitat, specimen photographs, site photographs, short video clips, and water chemistry (extensive parameters; varies by site).

Period of record: 1973 to present; water chemistry 2002 to present.

Data availability: Available upon request.

Name: Canadian Aquatic Biomonitoring Network (CABIN)

Agency: Environment Canada

Program objectives and description: To provide a series of standardized protocols to collect, measure, and report on benthic invertebrates, and physical and chemical habitat parameters. CABIN supports a network of networks to establish a shared online database where information on the biological health of freshwater systems in Canada can be stored and analyzed by all CABIN users. Through a website, users can enter, share, and access comparable data in a standardized way. CABIN also provides a suite of analytical tools for users to make meaning of the data they enter. Of particular note is the ability to use predictive models based on reference data collected by users to ascertain whether human activities are having an impact on the aquatic environment. Data from more than 350 Yukon sites have been collated to create a Yukon River Basin Model used by researchers and by government agencies as part of Aquatic

Health Monitoring under the Fish Habitat Management System for Yukon Placer Mining.

Parameters measured: Benthic invertebrate communities, physical and chemical habitat parameters.

Period of record: Early 2000s to present.

Data availability: Online database.

Name: Yukon Government Fisheries Database

Agency: Fish and Wildlife Branch, Environment Yukon

Program objectives and description: To document and track fisheries-related data collected by Environment Yukon. The database contains biological data on fish and some physical and chemical data for select lakes and streams in Yukon. Source material is departmental or scientific reports and documentation for all freshwater aquatic systems containing fish species.

Parameters measured: Fish presence, fish species, biological characteristics of fish, reports, physical and chemical data, where available.

Period of record: 1990s to present.

Data availability: Internal Yukon Government databases.

Name: Ecological Monitoring of Freshwater Thermal Regimes

Agency: Ta'an Kwäch'än Council

Program objectives and description: To develop series data on water temperature in the Yukon River and its tributaries within TKC Traditional Territory in order to monitor impacts of climate change, with specific focus on chinook salmon migration and spawning. In 2010, data loggers were installed in a number of locations on the river itself, on tributaries, and in groundwater seepage areas. The data loggers measure temperature within 0.2°C, every hour.

Parameters measured: Water temperature.

Period of record: 2010 to present

Data availability: Will be available on TKC website.

Name: Monitoring of Freshwater Thermal, Chemical & Biological Regimes of Salmon Migration Habitat

Agency: Tr'ondëk Hwëch'in

Program objectives and description: To collect baseline data on climate-related variables linked to traditional food security. The program has two elements: monitoring the thermal regime of primary chinook and chum salmon migration habitat, and characterizing the thermal and chemical regimes and associated biological communities of groundwater discharges utilized by chinook salmon for rearing and overwintering habitat. In 2010, data loggers were installed on the Yukon River near the Klondike River and on two creeks downstream of Dawson. The thermal data loggers measure temperature within 0.2°C, every hour. As well, 10 sites were established near the Klondike River to analyse groundwater characteristics to serve as a basis for trend analyses of changing water quality related to permafrost melt.

Parameters measured: Water temperature, pH, turbidity, conductivity, dissolved oxygen, total dissolved solids, nutrients and metals.

Period of record: 2010 to present

Data availability: Internal TH database at present. Broader availability pending.

Name: Michie Creek Monitoring Project

Agency: Kwanlin Dün First Nation, Yukon River Panel

Program objectives and description: To develop series data on chinook salmon response to annual fluctuations in water temperature and flow at the Michie Creek chinook spawning site. The project focuses each year on maintaining access of adult chinook salmon to critical spawning habitat in the drainage. Adult salmon and associated redds are enumerated at the Michie Creek spawning site and the relative abundance of wild and hatchery-origin juveniles is determined through minnow trapping. Freshwater benthic invertebrates are sampled each year to determine diversity and relative abundance at the Michie Creek spawning site.

Parameters measured: Adult chinook

salmon and redd enumeration, juvenile salmon abundance, freshwater benthic invertebrates , water temperature and flow.

Period of record: 2003 to present

Data availability: Internal database. Available on request from KDFN.

5.3 Regional Coverage

An assessment of regional coverage of monitoring stations was beyond the scope of this study. However, for networks with available sampling site locational information, maps were prepared to show Yukon-wide coverage for common network types. These include Yukon Hydrometric Networks, the Yukon Snow Survey Network, Yukon Meteorological Networks, and Yukon Water Quality Monitoring (Appendix B).

A high-level investigation of spatial coverage indicates that hydrometric, meteorological, and snow networks provide good regional coverage in the territory, although a large gap is apparent in the coverage of water quality in northern Yukon, with no active stations in the Peel Watershed.

6 Vulnerabilities & Further Considerations

This report attempts to summarize the vulnerability of Yukon water resources to climate change by documenting existing and forecasted uses of water and practices throughout Yukon, current knowledge and modelling related to climate change impacts on Yukon's water quantity and quality regimes, and existing water quantity and quality data collection programs. It ultimately provides a snapshot of current and forecasted water resource issues in Yukon related to climate change.

This section highlights the key water use vulnerabilities identified, presents general trends and projections available for Yukon water resources, and highlights the importance of our water monitoring networks as water resources continue to be affected by climate change. A discussion of water use in Yukon's changing river basins completes the assessment of vulnerabilities. Further considerations are outlined through a list of potential areas for action.

6.1 Key Water Use Vulnerabilities

Yukoners have many water needs. Our natural resource sectors draw, divert, and alter water from major rivers, small creeks, and groundwater sources. Some industries, such as agriculture and placer mining, depend entirely on the availability of water for successful operation. Hydro power plants also depend on reliable river flows, as well as water storage, in order to meet energy demands, while quartz mining operations often have an abundance of water and attempt to minimize impacts on surrounding water quality through on-site water management. In communities, groundwater is usually the main source of drinking water. In addition, water bodies and waterways are used for travel, firefighting, recreation, and harvesting, and have cultural significance for Yukon residents.

The variability of accurate, reliable data on water use by various resource sectors has been identified as a concern nationally by the National Round Table on the Environment and the Economy. In Yukon, annual water use data required under water licences has not been collated for undertakings or assessed on a watershed basis, due in part to relatively low pressures in most large watersheds.

6.1.1 Ecosystem Services

Freshwater systems play a vital role in providing ecosystem services, such as basic provision of food, controls on flooding, and recreational opportunities. Effective water management requires an understanding how much water is available and how much is required to maintain healthy and sustainable ecosystems, as well as the consideration of these factors in decision-making processes. Environmental assessment and water licensing processes promote the responsible use of water and require monitoring and reporting, which helps regulators to track water use and the health of the aquatic ecosystem. With added stresses on watersheds from increased development pressures and climate change, the consideration of environmental flows to ensure the health and productivity of aquatic ecosystems could become increasingly important, particularly for water uses on smaller streams.

6.1.2 Hydro Power

Hydro power is the main form of electricity production in Yukon. As demand grows, secure access to water for existing and new hydroelectric power generation facilities will be critical. The effect of extremes on hydro systems is also of concern.

6.1.3 Oil and Gas

Very little development of oil and gas resources has occurred in Yukon to date, with only two producing wells in southeastern Yukon. Growth of the sector in remote parts of the territory, such as Eagle Plains, could be constrained by the availability of water required for the construction of ice roads.

6.1.4 Agriculture

Less than 2% of Yukon lands are suitable for agricultural development, and, with droughts a common reality in agriculture-rich southwest Yukon, irrigation is an essential element influencing agricultural yield. Greater future demand for local vegetables and locally grown foods could increase water demand. While the scale of farming in the territory is not likely to significantly impact or be threatened by water availability, the potential for stresses on smaller creeks will require consideration in environmental assessment and licensing processes.

6.1.5 Fisheries and Aquaculture

The health of fish and fish stocks is inextricably linked to a healthy aquatic ecosystem. While growth is not expected in this sector, many stressors are present, including the spread of invasive species and the degradation of fish habitat.

6.1.6 Mining

Mining is a significant industry in Yukon. For hard rock mining, the management of on-site water to ensure water quality is the most important management consideration. Accordingly, water use and protection are important issues to be considered during the assessment and throughout the life of a mine. This will become increasingly important with the considerable growth projected in the hard rock mining sector.

The availability of water is critical to placer mining. While increased frontier exploration may be encouraged by a sustained high in gold prices, accessibility and meeting sediment discharge standards will continue to challenge the industry.

6.1.7 Forestry

Sustainable forest management has a critical influence on the hydrology and water quality of watersheds. Given the small scale of the Yukon forestry industry and its required forest management planning, the impact on water resources is likely limited.

6.1.8 Municipal

Water use in Yukon communities is the highest in Canada on a per-capita basis, and Yukoners generally take water for granted, perceiving the territory to have an abundance of this resource. In reality, supply is primarily extracted from groundwater sources, about which little is known. There is also significant concern about protecting groundwater from contamination. Upgrades to water systems in the coming years due to aging infrastructure will be costly and will challenge planners, who can no longer rely on historical data to predict the future.

6.2 General Trends and Projections for Yukon Water Resources

Climate change is intrinsically linked with hydrological changes, but determining climate change effects on water resources at the Yukon scale remains challenging. Trends analyses are sensitive to the time scales considered and to natural variability on interannual to decadal time scales, while uncertainty in projections can originate from the chosen emission scenarios, global climate models, downscaling techniques, model runs, and hydrologic parameterizations. While some studies have examined climate change impacts on water resources in Yukon, many gaps remain.

6.2.1 Temperature

In Yukon over the last several decades, winter and summer temperatures have increased in all regions, and the forecast is for continued warming over the coming decades.

6.2.2 Precipitation

Increased precipitation has been observed in the territory for some regions over the last half century. Increased winter precipitation in northern regions of the territory is consistent across several assessments, while the greatest summer precipitation increases have been observed in southeast and central Yukon. Most projections for precipitation suggest continued increases, particularly in winter.

6.2.3 Snowpack

Winter and early spring snow depths decreased significantly over much of Canada in the last half of the 20th century. Northern Yukon experienced similar decreases, while parts of northern British Columbia saw increases. Snowmelt has started earlier in Yukon over recent decades, particularly in mountain streams, and multiple analyses confirm that the period of snow cover is decreasing across the Arctic. Given the strong sensitivity of spring snowmelt timing to spring temperatures, a continued trend of earlier snowmelt and associated earlier peak flows can be expected.

6.2.4 Evaporation and Evapotranspiration

Climate change could have a critical impact on evapotranspiration and, therefore, on water availability. However, the mechanisms governing evaporation are not clearly understood, and trends analyzed for different regions have resulted in differing conclusions. No regional analyses have been conducted in Yukon or northwestern North America, but an analysis of global evaporation trends using several global climate models found that increasing temperature could result in increasing potential evaporation, particularly in high latitudes.

6.2.5 Permafrost

Increasing air temperatures are leading to permafrost warming and degradation, ultimately changing the permafrost distribution of northern regions, including Yukon. Permafrost degradation is expected to be greatest within the discontinuous and sporadic zones, where the permafrost is warmer and more susceptible to thawing.

6.2.6 Glaciers

A 22% reduction in glacial cover was calculated over the last 50 years in Yukon's St. Elias and Mackenzie mountain ranges. Continued glacial decline could have a profound influence on the hydrology of Yukon's glacier-dominated basins, particularly if the shrinkage continues to the point where some basins lose their glaciers altogether.

6.2.7 River Ice

An advance of five days per century was calculated for break-up timing on the Yukon River at Dawson between 1896 and 1998. In the last two decades, the advance has been even more dramatic. A similar trend is noted for the Porcupine River at Old Crow. A trend of increasing water level during break-up from the early 1970s to the present for Dawson has also been observed. Projections about the severity of ice jamming are not readily made, given the complexity of processes influencing the occurrence and evolution of ice jams. However, the occurrence of a midwinter break-up event and associated ice jam on the Klondike River in 2002–3 indicates a possible shift in Yukon's river ice regime.

6.2.8 Streamflow

There are indications that Yukon streamflow characteristics are currently being affected by climate change, although the changes vary by hydrologic regime and season. These include increased winter low flows and an advanced spring freshet in mountainous streams, increased annual mean and peak flows in glacierized basins in southwestern Yukon, decreased peak flows and increased minimum winter streamflow within the continuous permafrost zone, and increased winter flow and a declining trend in average flows in summer in the Yukon River Basin. Increased river flow is generally projected for high-latitude rivers to the end of the 21st century.

6.2.9 Groundwater

How climate change will affect groundwater is not well understood. Trends in streamflow investigated over periods of 20 to 50 years in the Yukon River Basin showed significant increases in estimated groundwater flow. In Yukon, the largest increases in estimated groundwater inputs were detected in the Yukon headwaters and in the Porcupine River watershed. Trends or projections of groundwater availability or recharge for community water supplies have not yet been well documented.

6.2.10 Erosion and Sediment Transport

Suspended sediment discharge is sensitive to climate change, particularly as changing hydrological conditions could cause increased erosion and sediment transport. These conditions include permafrost degradation (both through increased peak flows and permafrost-related landslides), glacial retreat, and changing snowmelt and spring break-up conditions.

6.2.11 Metals and Contaminants

Concern around the introduction and transport of metals and contaminants in Yukon waters, and the resulting effect on aquatic organisms, has generally been focused on anthropogenic activities such as mining or municipal wastewater. However, permafrost thaw will likely lead to changes in groundwater flows and the quantity and quality of organic carbon in rivers, streams, and lakes, with associated possible changes in metal and contaminant levels.

6.2.12 Solute and Nutrient Concentrations

Warming air temperatures that lead to permafrost thaw and degradation can have significant impacts on hydrology, ecosystems, and biogeochemical cycling. Changes in the timing and magnitude of glacial melt will also lead to changes in solute and nutrient concentrations. Changing nutrient concentrations in riverine systems will vary depending on the parameter and a multitude of factors, including watershed environmental characteristics, the influencing process (i.e., increased active layer depth), length of flow pathway, and changes in river discharge.

6.2.13 Temperature

Lakes and rivers across the northern hemisphere are already exhibiting higher temperatures in response to warmer conditions, with surface water temperatures up as much as 2°C since the 1960s.

6.2.14 Extreme Events

There appears to be an upward trend in the number of heavy snowfall events for autumn and winter over northern Canada, with no change in intense precipitation events. The Klondike River mid-winter break-up event, rapid lake drainage from thermokarst development in the Old Crow Flats, and Southern Lakes flooding are other extreme events of note in the last decade.

6.3 Water Monitoring for Climate Change

Many governments, departments, and organizations are engaged in water monitoring and data collection in Yukon. Data from most of these water monitoring networks or programs are publicly available, but only a small portion are accessible online. Many—even longer-term networks—are largely unknown outside their discipline or sector. While the majority of these programs are not collecting data for the purpose of climate change detection and adaptation monitoring, their spatial, temporal, and parameter coverage are invaluable to climate change planning.

Monitoring data and information collected by universities, community organizations, and the private sector are not included in the inventory, given their often limited public availability. Nevertheless, they represent another valuable subset of data that could benefit climate change adaptation planning.

Increased dissemination of water monitoring data and information is particularly important in Yukon, given the general sparsity of data collection networks in northern Canada. Climate-change-related data collection programs have been initiated in recent years in response to adaptation concerns. While these are incredibly valuable, the continuation of long-term data collection networks is paramount to trend analysis and modelling.

A high-level investigation of spatial coverage indicates that hydrometric, meteorological, and snow networks provide good regional coverage in the territory , although a large gap is apparent in the coverage of water quality in northern Yukon, with no active stations in the Peel Watershed.

An analysis of adequate parameter coverage for climate change adaptation planning was not part of this assessment, but would be a valuable exercise to undertake in order to maximize the benefit of water data collection programs.

6.4 Water Use in Changing River Basins

A regional analysis of future water use needs compared with projected climate change impacts on water resources is not currently possible, due to limitations in economic and scientific projections. However, several high-level links can be drawn between municipal and industry water use needs and changing hydrological and water quality regimes:

Changing streamflow timing, particularly the advance of the spring freshet and long-term decreases in flow in glacierized basins, could impose new constraints on water availability in certain watersheds and in certain seasons, for which better water-use monitoring and management would be required. Further study could help determine the time scale for these constraints.

Increased near-term peak flows in glacier-dominated basins followed by potential long-term decreases, increased magnitude of low flows from permafrost warming, earlier snowmelt, and potentially increased precipitation and evaporation, all represent hydrologic changes that require consideration in near- and long-term planning for hydro power production.

Access to water, particularly from small creeks, by the oil and gas sector for the construction of ice roads in the Eagle Plains area could be impacted by changing flow regimes in the continuous permafrost zone.

Changing temperature, precipitation, and evaporation conditions will affect agriculture most strongly through the amount of irrigation water required to produce a crop. Increased water demand arising from a progression toward higher-value crops and changing streamflow regimes resulting from changing permafrost and snowmelt conditions could, together, become an issue for smaller creeks.

Changing hydrological or water quality conditions caused by climate change could facilitate the spread of fish diseases and invasive species and exacerbate existing stresses on fish habitat from such pressures as residential development, forestry, hydro projects, roads, and mining.

Increased low flows and earlier spring snowmelt could benefit the placer mining industry, but shorter ice-road seasons would limit access to mining and exploration sites for placer mining. For hard rock mining, management of on-site water could become more challenging, given greater precipitation inputs, and require more frequent adjustments of site water balances, changes to water management plans and potentially, increased treatment. Hydrologic changes could also challenge efforts to divert clean water. Changing background water quality conditions as a result of climate impacts and the incorporation of climate change into closure planning are additional concerns.

Increased prevalence of forest fires, insect disturbances, and changes to forest species could have dramatic effects on forests and water resources in forested watersheds.

Increased groundwater-surface water interactions as a result of melting permafrost, and increased groundwater contribution to streamflow could alter and possibly threaten the quality and quantity of our municipal groundwater sources.

6.5 Possible Areas for Further Consideration

Much work remains in order to address the vulnerabilities identified for Yukon water use and inform both users and decision makers about how to adapt their actions in response to the impact of climate change on Yukon's water resources. From this first step, several areas for further consideration present themselves, including:

- Progression of water management decisions and activities toward the consideration of water use activities and changes on a watershed basis. Combining this consideration with a review of water monitoring programs from a watershed perspective would be productive.
- Incorporation of water valuation principles and a more formalized approach to environmental flow assessments into water management.
- Confirmation that projected hydrologic changes are appropriately considered in near- and long-term planning for hydro power production.
- Assessment of future high-potential agriculture growth areas, with respect to water supply options and implications resulting from future changes to water flow and quality.
- Regular review and revision of minesite water balance and water management plans that better reflect understanding of localized climate and hydrologic regimes and that respond to climate changes.
- A review and, if necessary, greater consideration of climate change implications for closure planning, including how changes are considered in the design of infrastructure and the appropriateness confirmed through on-going monitoring.
- Development of community risk evaluations and adaptive management plans in Yukon communities to ensure a secure long-term water supply.
- Better understanding of groundwater resources, perhaps on a regional basis and prioritized by activity, and effective communication of the information from researchers and monitoring agencies to decision makers.
- Review and adjustment of water monitoring networks using a methodological approach that takes into consideration future needs, climate change, and adaptation measures.
- Continued and possibly enhanced support of watershed modelling research that could improve regional analyses, which can then be used by decision makers to ensure projects affecting water are sustainable in the near and long term.
- Increased dissemination of water monitoring data and information.
- Recurring review of the different facets of water management to ensure that decision making pertaining to water use activities, as well as the monitoring and modelling that support these decisions, are informed by and responsive to changing climatic conditions.

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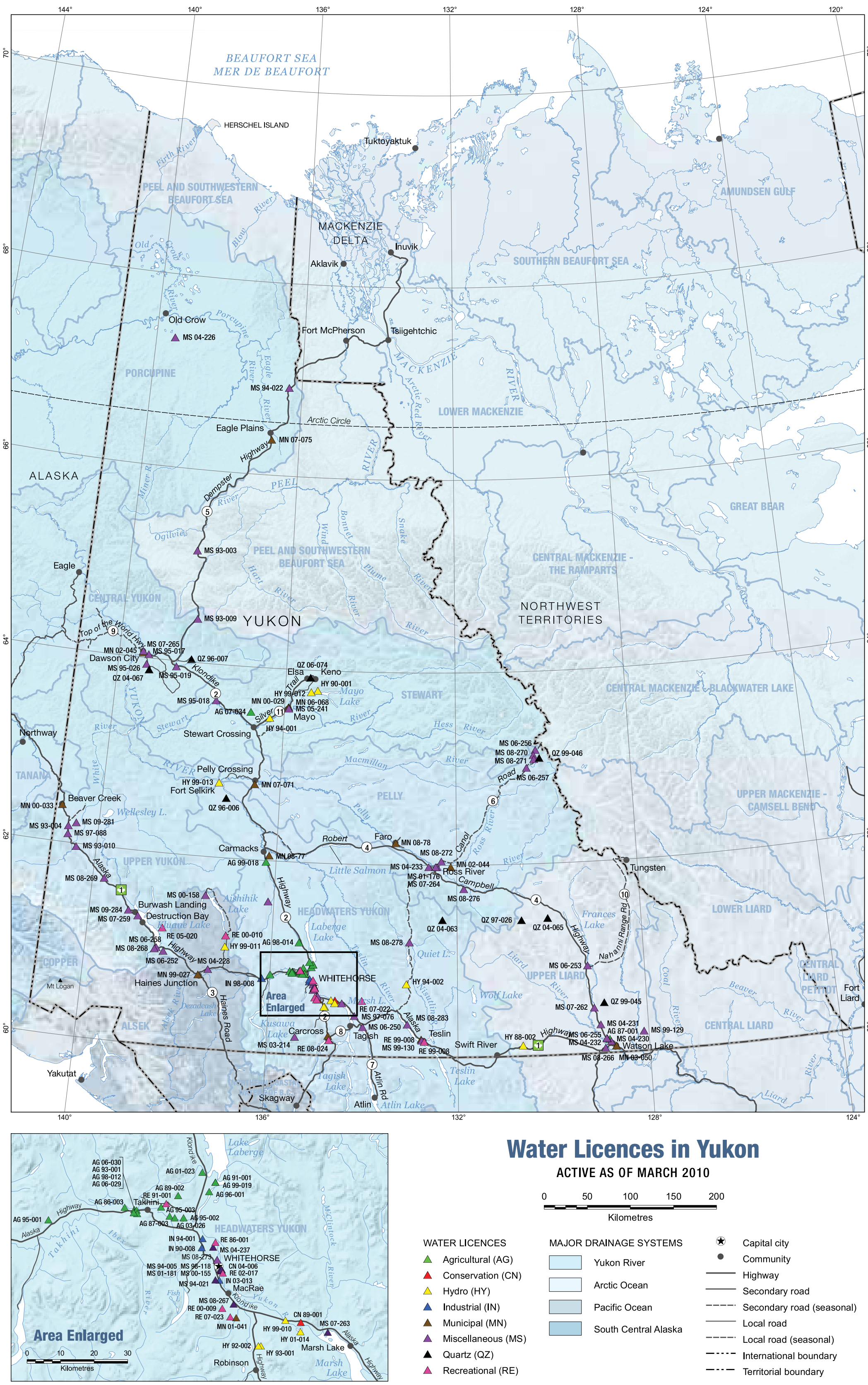
Appendix A

Appendix A

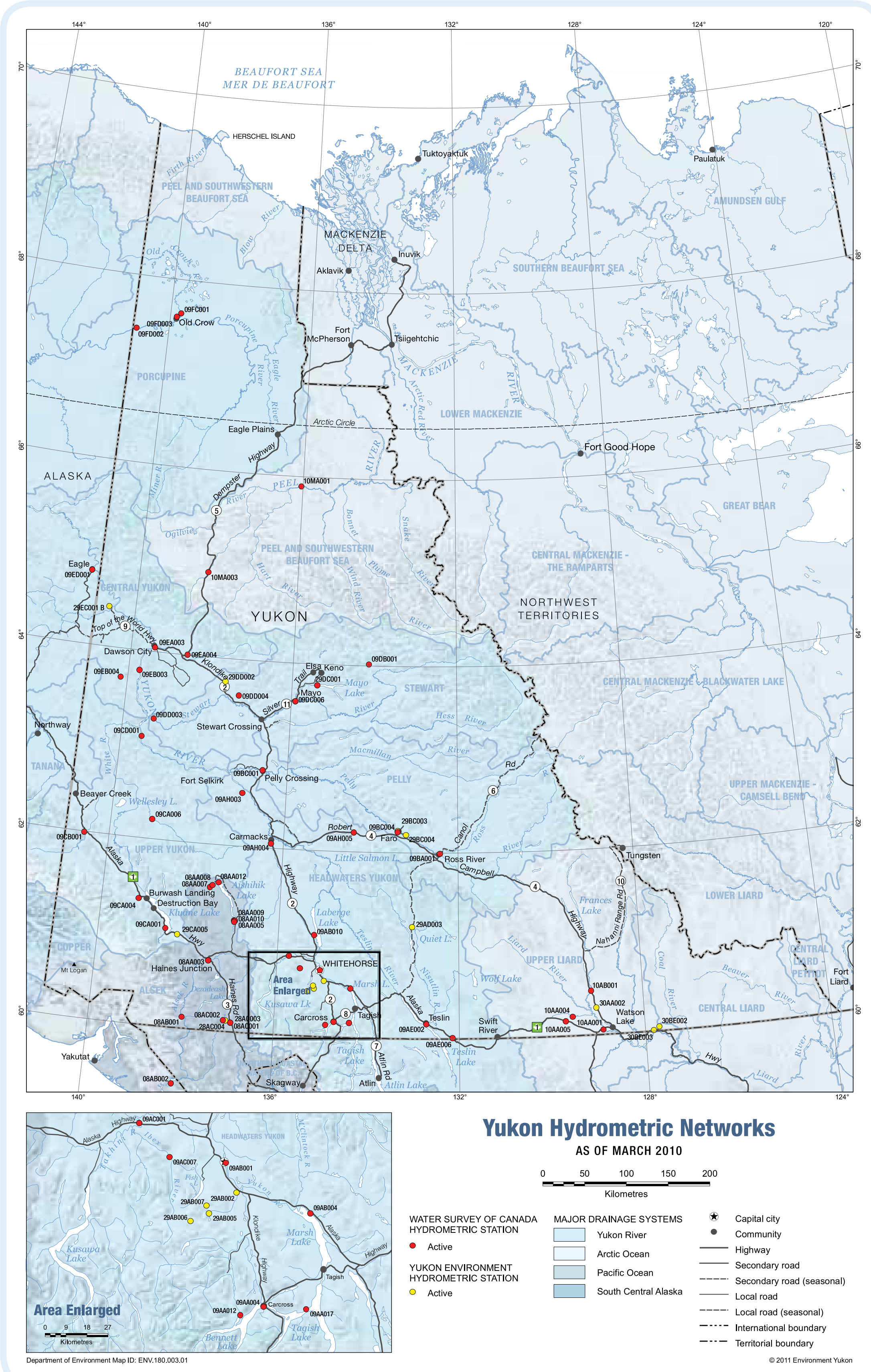
Water licences in Yukon



Appendix B

Appendix B

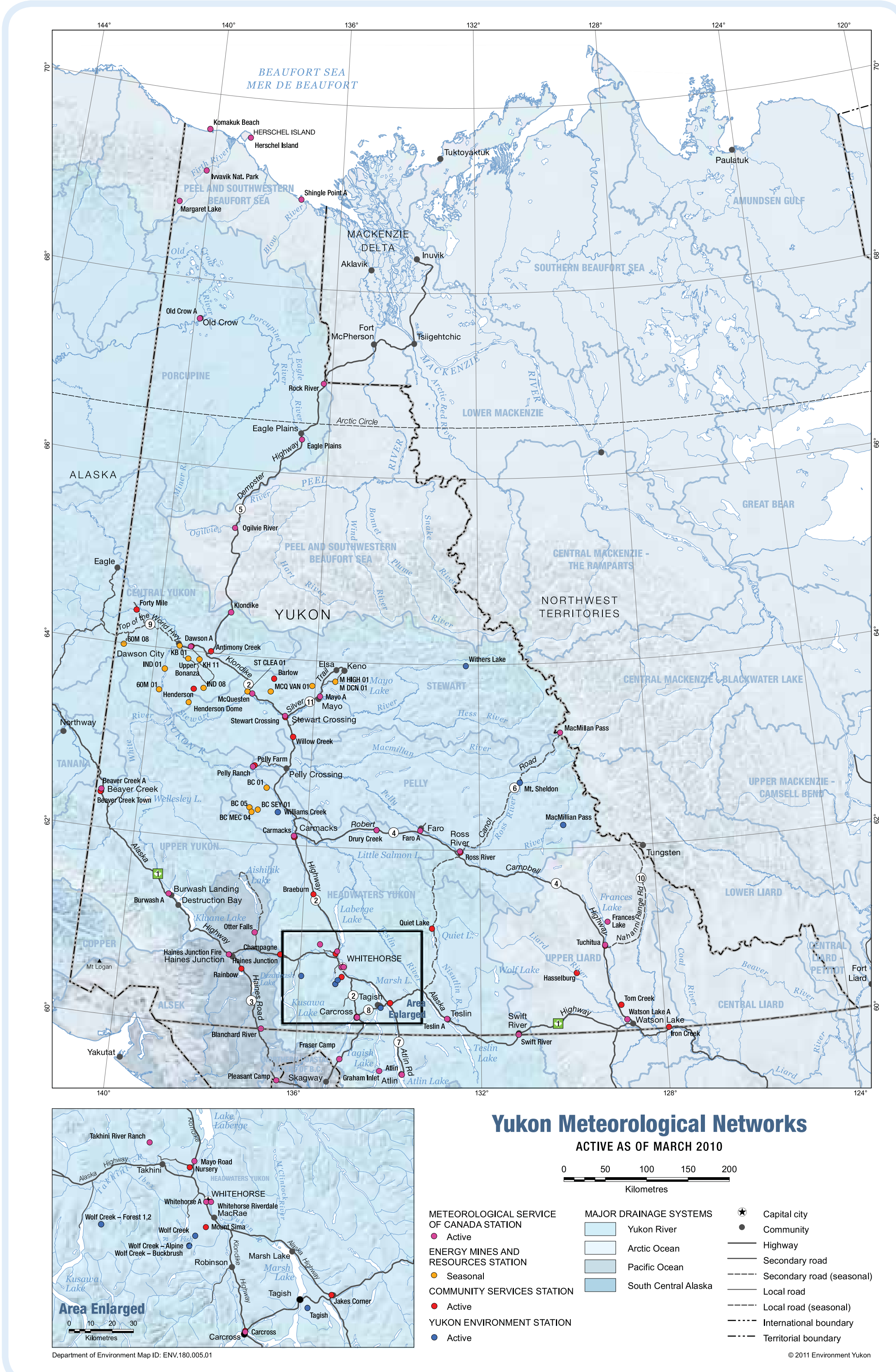
Yukon Hydrometric Networks

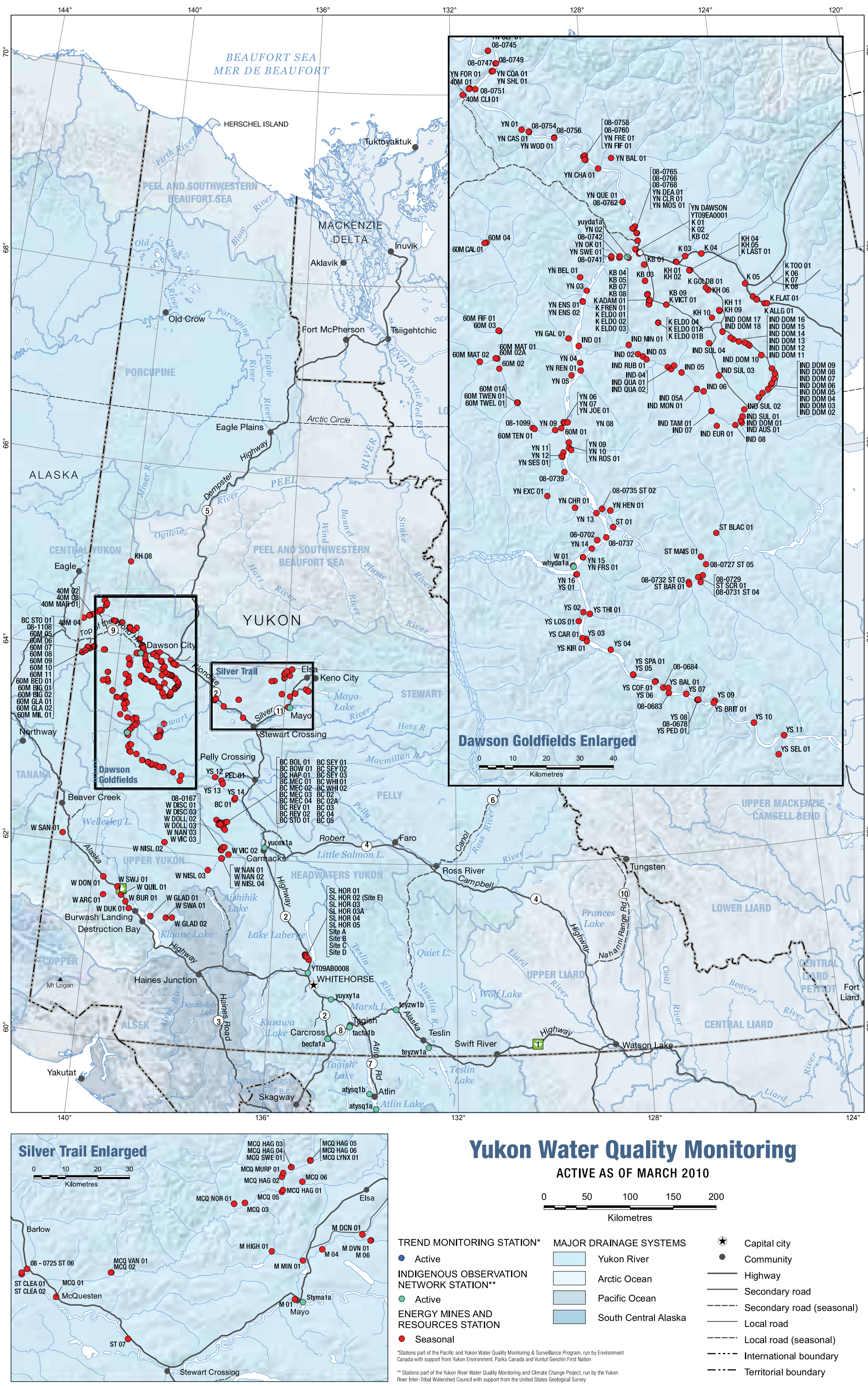


Appendix B

Yukon Snow Survey Network

Yukon Meteorological Networks





Yukon Water Quality Monitoring
ACTIVE AS OF MARCH 2010
0 50 100 150 200
Kilometres
TREND MONITORING STATION*
Active
INDIGENOUS OBSERVATION NETWORK STATION**
Active
ENERGY MINES AND RESOURCES STATION
Seasonal
MAJOR DRAINAGE SYSTEMS
Yukon River
Arctic Ocean
Pacific Ocean
South Central Alaska
Capital city
Community
Highway
Secondary road
Secondary road (seasonal)
Local road
Local road (seasonal)
International boundary
Territorial boundary
*Stations part of the Pacific and Yukon Water Quality Monitoring & Surveillance Program, run by Environment Canada with support from Yukon Environment, Parks Canada and Vuntut Gwitchin First Nation
** Stations part of the Yukon River Water Quality Monitoring and Climate Change Project, run by the Yukon River Inter-Tribal Watershed Council with support from the United States Geological Survey
Department of Environment Map ID: ENV.180.006.01
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Dawson Goldfields Enlarged
Silver Trail Enlarged
BEAUFORT SEA
MER DE BEAUFORT
HERSCHEL ISLAND
Tuktoyaktuk
MACKENZIE DELTA
Inuvik
Aklavik
Old Crow
Fort McPherson
Tsiigehtchic
PEEL AND SOUTHWESTERN BEAUFORT SEA
PORCUPINE
Eagle Plains
Arctic Circle
ALASKA
YUKON
CENTRAL YUKON
Eagle
Dawson City
Silver Trail
Elsa
Keno City
Mayo
Stewart Crossing
STEWART
Pelly Crossing
PELLY
Beaver Creek
Carmacks
UPPER YUKON
HEADWATERS YUKON
Faro
Ross River
Tungsten
Burwash Landing
Destruction Bay
Haines Junction
WHITEHORSE
Carcross
Tagish
Teslin
Swift River
Watson Lake
Atlin
Skagway
Yakutat
Mt Logan
UPPER LIARD
LOWER LIARD
CENTRAL LIARD
UPPER MACKENZIE - CAMSELL BEND
Fort Liard
Northway
Barlow
McQuesten

TAKING ACTION ON CLIMATE CHANGE

Yukon
Environment