Changing Landscapes, Changing Lives:

Exploring climate change impacts in the Nechako Watershed, and implications to natural resource development

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Executive Summary

The Nechako River is an important waterway in North-central British Columbia (BC). The river forms the second largest tributary of the Fraser River and provides valuable habitat for salmon, white sturgeon and trout fish species. It is also central to the lives of several First Nations and non-First Nations communities in the region. People who live in the Nechako River Basin (NRB) enjoy easy access to the outdoors and a diverse range of recreational activities including hunting, fishing, boating and snowshoeing. The primary economic drivers in the region are related to natural resource extraction.

The NRB has undergone many changes over the last 100 years. An abundance of hydro-electric, agricultural, forestry and mining activities have, and continue to, change the landscape. Most notably the Kenney Dam - constructed by Alcan in the 1950s to power an aluminum smelter in Kitimat – has permanently changed the hydrological and ecological nature of the basin. The current outbreak of the mountain pine beetle has also had significant impacts in northern BC, and is ultimately expected to kill up to three quarters of the mature pine trees in parts of the watershed. These changes have altered the NRB and the way that people live and work within it.

A variety of future changes have the potential to further transform and impact the river basin over the next 50 years and beyond. One major source of future uncertainty relates to climate change, as northern areas of BC are warming at nearly double the global average rate. A number of research studies have been conducted that focused on climate change in the NRB. These studies show that air temperatures have increased by approximately 1.6°C over the last century, and that there has been increasing rainfall and decreasing snowfall over this period. Future temperature projections, created by analyzing the outputs of Global Climate Models (GCMs), indicate that the NRB is expected to become approximately 2°C warmer in the 2050s than baseline average conditions (1961-1990). An increase in total precipitation is projected (although there will be a decrease in snow) as well as an increase in total annual river discharge. These and other changes have the potential to significantly affect the flow and flooding regimes of the Nechako River. A detailed review of nine research studies focused on the in the Nechako region reveal four main categories of climate change impacts that are highly significant in the watershed:

1. **Ecosystems:** Climate change is changing the way that ecosystems function in many ways. Two ecosystems types of particular concern are:
   - I. *Forests:* Climate change is having a large impact on how forests grow, what types of trees grow in forests and how (and how often) forests are disturbed.
   - II. *Aquatic ecosystems:* First Nations and non-First Nations people depend on the rivers. Impacts related to salmon and white sturgeon populations are extremely important.

2. **Water supply:** Climate change is leading to impacts on the amount and the quality of water available. Water supply in the NRB is being affected by a number of factors including decreased snowfall, increased winter rain, decreased soil moisture, more forest pests and warming temperatures. These factors may drive more extremes such as floods.
3. **Agriculture and food security:** A warming climate can increase growing seasons in more northerly latitudes; however, an increase in extreme weather events (that can spoil or damage crops and farm infrastructure) may offset these positive changes. Implications related to losses of traditional foods are important and must be considered.
4. **Community well-being:** Climate change and related changes to social-ecological systems can affect the health, well-being and resilience of communities within watersheds in many interrelated ways. Climate change has had a direct effect on many sectors of the economy, and all impacts ultimately affect human and community wellness.

The impacts associated with climate change cannot be considered independently of the developments and changes that have already occurred in the NRB, or the developments and changes that may occur in the future. As noted, many human activities (such as agriculture, hydro-electric development, mining and forestry) have already changed the nature of the region, and continue to alter the natural and human systems within it. The following table (Table i) provides a preliminary assessment of the degree of interaction regarding climate impacts and resource development. Many other activities are also occurring on the landscape such as fishing, hunting and trapping (commercially and recreationally), non-consumptive recreation and tourism activities, and renewable energy development projects.

Table i: Interactions between climate impacts and types of resource development in the Nechako River Basin.

	A: Ecosystems	B: Water Supply	C: Agriculture and Food Security	D: Community Well-being
Hydro-electric power	Very High*	Very High*	Medium*	Very High
Forestry	Very High	High*	Medium	Very High
Agriculture	Medium	High *	Very High	High
Mining	Medium	Medium*	Low*	High*
Oil and gas	Low*	Low*	Low*	Medium*

**These values are projected to increase in the future.*

To effectively manage the NRB we must consider the cumulative impacts of all activities and changes, and if the natural and human systems in the region can adapt to them. Communities can apply the existing knowledge regarding climate change in the NRB to help proactively plan for the future and responsibly manage development activities so that they do not cause irreversible or unacceptable impacts. The information in this report can help in the establishment of limits and acceptable thresholds and change for the watershed, and lead to progress toward the integrated management of land and water resources in a way that promotes economic, social and environmental benefits for all people within the Nechako watershed.

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Forward to report

The purpose of this guide is to help us to increase our awareness about the changes that have occurred, are occurring and are expected to occur in the Nechako River Basin (NRB) (also commonly referred to as the Nechako Watershed). Although it is written primarily by researchers, we have attempted to create a report that is accessible and engaging to a wide audience. We have included a Glossary section at the end of the report that defines some of the terms that are used in this document. Words that are included in the glossary are **bolded and highlighted in purple** when they are first used. Please consult the footnotes and the references for more information regarding the scientific or technical information contained within the report, or contact the authors. An academic review article is being drafted on this same topic that will contain more technical and background information, and should be available shortly.

We have made every effort to summarise information in a neutral and unbiased manner. Toward this goal we invited feedback and review on the guide from a wide variety of parties, including local governments, First Nations, local and regional organizations, and topical experts. This feedback has shaped the final document in a large way. Everyone has biases - ourselves included - and the final draft has been influenced by the groups and individuals that provided feedback, and also those that did not.

Thank you very much,

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Figure 1 Man watching the construction of the Kenney dam at the grand canyon of the Nechako. (Courtesy of the Kitimat museum archives)

"When we try to pick out anything by itself, we find it hitched to everything else in the universe."
John Muir

[1] NWA alliance members who were present at the March 2014 workshop were: Lara Becket (Fraser Fort George Regional District), Barry Booth (UNBC), Christina Ciesielski (Carrier Sekani Tribal Council), Stephen Déry (UNBC), Theresa Fresco (FBC), Chelton Van Geloven (BC Ministry of Forests, Lands and Natural Resources [FLNRO]), Melanie Karjala (Resources North Association[RNA]), Steve Korpi (FBC Watersheds and Water Resources Committee), Steve Litke (FBC), Carling Matthews (UNBC), Phil Owens (UNBC), Ellen Petticrew (UNBC), Margot Parkes (UNBC), Ian Picketts (UNBC), Terry Roberts (FBC & First Nations Fisheries Council), Mike Robertson (Cheslatta First Nation), Wayne Salewski (Nechako Environment and Water Stewardship Society), Gerry Thiessen (District of Vanderhoof), and Jun Yin– (FLNRO). NWA members who were not able to attend but contributed to the report include: Dan Adamson (City of Prince George), Lucy Beck (Northern Health), Norm Billodeau (FLNRO), Tom Greenway (Bulkley-Nechako Regional District), John Rex (FLNRO) Guy Scarf (Department of Fisheries and Oceans), and Kathi Zimmerman (RNA).

1 The Nechako River and Nechako Watershed:

The Nechako[2] River begins in the Coast Mountains of western British Columbia (BC) and flows eastward through the **Interior Plateau Region** until it ends at the Fraser River near the geographical centre of the Province, at what is now the City of Prince George (Hartman, 1996). Before the River was dammed (see Section 5.1), the Nechako River was 440 km long. The Nechako River Basin (NRB) spans an area of 52,000 km^2 (Benke and Cushing, 2005), which is approximately the same size as the Country of Switzerland. The Stuart River, which flows southeast from the Coast Mountains, is the biggest tributary (by flow volume) of the Nechako River. The Nechako is in turn the second biggest tributary of the Fraser River (after the Thompson River). The Fraser River originates in the northern Rocky Mountains near Mount Robson (west of Jasper, Alberta), flows westward until it is joined by the Nechako River, and flows south and then west into the Pacific Ocean at Vancouver. The Fraser drains a quarter of BC, is home to over two thirds of the Province's residents, and is the third largest River in Canada (by mean flow) (FBC, 2009). It is the longest intact (i.e., undammed) river in North America (Benke and Cushing, 2005). The Fraser River Basin (FRB) covers 220,000 km^2, which is an area nearly as large as the United Kingdom. Figure 2 provides an overview map of the NRB.

Most of the land within the Nechako basin, like much of central and northern BC, is dominated by coniferous forests. The forested and gently rolling terrain in and around the Nechako area is known as the sub-boreal spruce bio-geoclimatic zone, and its large tracks of mature coniferous forests have made it well-suited for logging (see Section 5.2) (BC MoF, 1998). The remainder of the NRB consists of surface water (including Fraser Lake and Francois Lake), agricultural lands, wetlands and alpine regions. The watershed's climate is continental in nature and has cold wet winters and warm dry summers. The conditions are moderated by the presence of the Pacific Ocean to the west (BC MoF, 1998). Because of the long wet winters, the Nechako River naturally has high flows in spring and early summer, when the snow melts (i.e., during the freshet period) (Moore, 1991; Benke and Cushing, 2005).

The Nechako River is biologically significant. The river is home to many fish species including rainbow trout, a large chinook salmon run, and a genetically unique population of white sturgeon. There are also two major sockeye salmon run in the Stuart river system (BC MoE, 2001; Benke and Cushing, 2005). The white sturgeon is the largest freshwater fish in Canada, and adults may grow to over 6 metres in length and live for over 100 years. The sturgeon subspecies that lives within the Nechako River (and the Stuart) usually grow to about 3 metres in length (Figure 3). This is due to shorter winters and different food sources (Fisheries and Oceans Canada, ND). The Nechako sturgeon population is classified as 'critically imperilled' (Benke and Cushing, 2005), which means that the species is facing a very high risk of extinction. Although the Nechako sturgeon are found throughout the watershed, only one spawning area

[2] Nechako means 'big river' in the Carrier language.

for the Nechako Sturgeon (near Vanderhoof) has been located to date (Wood, 2013). They are listed under the Species At Risk Act (SARA), which means that it is illegal to kill, possess, harm or damage these animals. Because the Nechako sturgeon is in a critical state of decline, there are many efforts underway to try to protect the remaining individuals and promote a population resurgence. For example a sturgeon hatchery and conservation centre was approved in 2013, and should be operational in the spring of 2014 (NWSRI, 2014). Many birds and mammals also live in the NRB including the highest concentrations of moose in BC, and also bears, wolves, great horned owls and many other species (BC MoF, 1998).

Figure 2 Overview map of the Nechako River Basin and its major tributaries. The red dots depict where there are active hydrometric gauges.

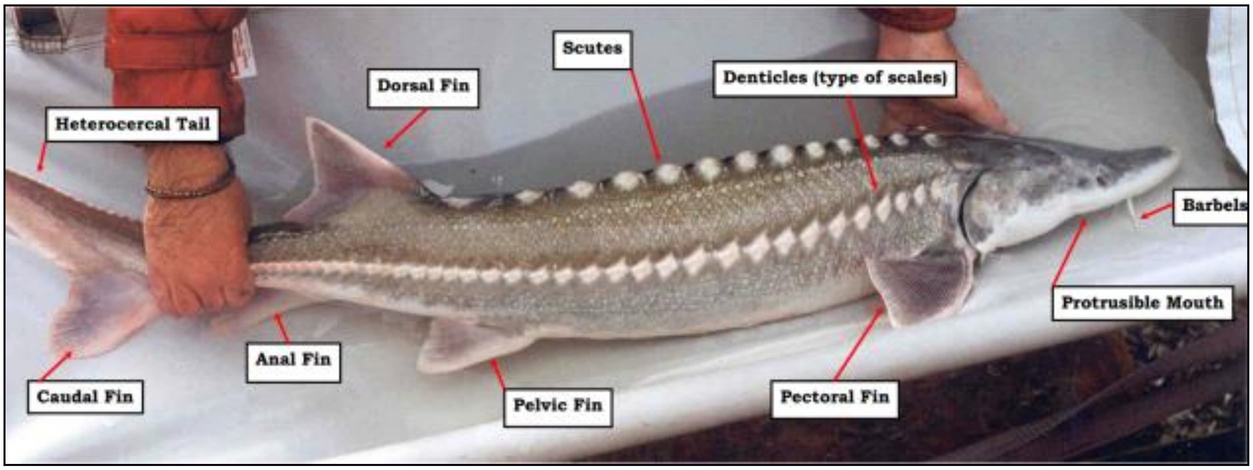

Figure 3 Labelled photo of the Nechako white sturgeon. (Fisheries and Oceans Canada, ND)

1.1 The Peoples of the Nechako

1.1.1 Traditional Peoples

Since long before European settlers lay eyes on what is now known as British Columbia (BC) and travelled its great Rivers, people have been living and flourishing here. BC has been home to a large and diverse population of aboriginal people, who spread across the entire province, for millennia. It is thought that, before contact was established with Europeans, approximately 40% of Canada's Aboriginal people lived in BC (BC MoFML, 2010). There are many different groups of First Nations people in British Columbia, and they each have traditional territories where they historically - and continue to - live, travel and hunt[3]. The indigenous group that has lived throughout the entire Nechako Watershed for thousands of years is known as the Carrier (Or Dakelh) people (Attili and Sandercock, 2010; CSTC, 2011; Hudson, 2013).

The Carrier people were generally semi-nomadic, and governed themselves based on the clan system. Like many First Nations peoples in Canada, they passed down knowledge and tradition through oral story telling methods (CSTC, 2011). They relied principally on animals such as, trout, salmon, moose and deer for food. The rivers in the region (including the Nechako and its tributaries including the Stuart, Stellako, Nautley and Tachie) were important for transportation and for food (Wood, 2013). There are many Carrier bands in the Nechako watershed including the Cheslatta, Sai'kuz (or Stoney Creek), Stellat'en, Lheidli T'enneh, Nadleh Whut'en, Wet'suwet'en, Tlazten, Tsil Kazkoh (BLB) and Takla lake First Nation.

[3] The relationships between territories is complex and many boundaries of traditional territories blend into each other and/or overlap (BC MoE http://www.bced.gov.bc.ca/abed/map.htm)

1.1.2 First Nations communities within the Nechako watershed:

There are a large number of First Nations communities within the Nechako Watershed. An overview of some of the communities (organized by estimated size) is as follows[4]:

Tl'azt'en First Nation is made up of approximately 2000 members, and has its main office on Stuart Lake. It is a member of the Carrier Sekani Tribal Council.

The **Nak'azdli First Nation** is a member of the Carrier Sekani Tribal Council that has approximately 1800 members. Their main office is located near Fort St. James.

The **Saik'uz First Nation** (also called Stoney Creek) is a member of the Carrier Sekani Tribal Council. It has approximately 1000 members, and its main office is situated south-east of Vanderhoof.

The **Takla Lake First Nation** is a member of the Carrier Sekani Tribal Council. This First Nation has approximately 750 members, and has its main office near Takla Landing (150 km northeast of Fort St. James).

The **Stellat'en First Nation** is a member of the Carrier Sekani Tribal Council that has approximately 500 members, and has its main office near Fraser Lake.

The **Lheidli T'enneh First Nation** is estimated at 380 members, with a main office in Shelley (near Prince George) and strong links with the confluence of the Fraser and the Nechako Rivers. The word Lheidli means "where the two rivers flow together" and T'enneh means "the People".

The **Cheslatta First Nation** has just over 300 members, and has its main office on Cheslatta Lake.

The **Nadleh Whut'en First Nation** is a member of the Carrier Sekani Tribal Council. It is made up of approximately 170 members, and has its main office in Fraser Lake.

The **Ts'il Kaz Koh First Nation** (also known as the Burns Lake Band) is a member of the Carrier Sekani Tribal Council. It has approximately 150 members, and has its main office in Burns Lake.

The **Wet'suwet'en** First Nation is made up of approximately 150 members, and most member live just west of Burns Lake. It is a member of the Carrier Sekani Tribal Council.

The **Nee Tahi Buhn** (Yekooche) band has approximiately 130 members, and has its main office in Burns Lake.

[4] Information about the Carrier Sekani First Nations groups, and maps of their traditional territories, can be found at: http://www.carriersekani.ca/

1.2 European settlement and modern populations

The first Europeans to venture into the Nechako Watershed arrived in the late 1700s looking for fur-trading opportunities (CSTC, 2011). In the early 1800s, Simon Fraser established a trading post on Stuart Lake, and Fort St. James grew into a major trading and government centre. Fort St. James is strategically located on Stuart Lake, and is a natural trading hub as it is connected to a large number of major lakes and rivers in the region. It is thought to be the oldest European settlement on the BC mainland.

Throughout the 1800s there were many changes in northwestern BC. Missionaries arrived and settled throughout the region. BC became a British colony and then BC joined the Canadian federation in 1871. Throughout this time there were many terrible colonial disease outbreaks that traditional people were subjected to. First Nations people had not been exposed to (and developed immunities to) diseases such as influenza, measles and small pox. As an unfortunate result First Nations populations were decimated (CSTC, 2011; Hudson, 2013; Wood, 2013).

In the early 1900s farmers began to settle in the Vanderhoof area, Prince George was growing as a railroad town, and residential schools began operating in the region. After World War II logging in northern BC increased dramatically as cities around the world were being rebuilt. At this time Prince George grew into a major forestry centre. In the early 1950s the Kemano Construction Project development occurred (see *Resource Development in the Nechako Basin* Section), and as a result the Kenney Dam and town of Kitimat were constructed. (The town of Kitimat is not located within the Nechako Watershed.) Since the 1950s the population of the NRB has increased steadily, although growth rates have been slow compared to other areas in BC such as the Okanagan and the Lower Mainland area (BC MoFML, 2010).

There have been tremendous changes in BC in a relatively short period of time. Between 1867 and 2008, BC's population went from 33,000 to 4,400,000: more than a 100 fold increase (BC MoFML, 2010). Although there are many cities, towns, villages and reserves within the Nechako Watershed (see Figure 4), this vast area is still quite sparsely populated. The population of the Nechako watershed is estimated at approximately 105,000, if the entire population of greater Prince George (~83,000) is included. Therefore less than 22,000 people live within the watershed outside of Prince George. Currently the Nechako River is used extensively for agricultural purposes, drinking water and recreation (BC MoE, 2001).

First Nations communities are included in the previous section. Moving from largest to smallest the major non-First Nations settlements are as follows:

Prince George is a City of 76,000, located at the confluence of the Nechako and Fraser Rivers. It is known as BC's 'northern capital', and is a major centre for forestry operations with 12 sawmills and three pulp mills. The City is also a hub for regional mining operations, government services, education, health care and transportation throughout the Pacific Rim. It is situated on the historical territory of the Lheidli T'enneh First Nation, and was the site of the original Fort George trading post (City of Prince George, 2013a).

Figure 4 Settlements in the Nechako River Basin.

The district municipality of **Vanderhoof** has a population of 4,000. It is surrounded by rural areas and the Saik'uz First Nations reserve is nearby; therefore, the community serves as a supply centre for nearly 10,000 people. Vanderhoof is situated 100 km west of Prince George at the geographical centre of BC. The town is a major agricultural hub, a forestry centre, and also a staging area for mining operations taking place in the Stuart watershed. It is the largest centre located entirely within the Nechako Watershed (Vanderhoof, 2010).

Burns Lake is a village of 2,000 residents, but serves as a supply centre for nearly 8,000 surrounding people. The community is almost evenly split between First Nations and people from European descent, and three First Nations reserves are part of the town: Wets'sewet'en, Lake Babine and Burns Lake. Burns Lake is located 220 km west of Prince George. The main industries in the town are forestry, mining, and tourism. In 2012 the Babine Forest Products mill exploded, and left many concerned about the future of the community. The mill is reportedly being rebuilt, but will be smaller than before (Bulkey-Nechako, 2012).

The district of **Fort St. James** has a population of 4,500 people, including nearby rural areas and First Nations communities. The community is situated on scenic Stuart Lake, 60 km northwest of Vanderhoof. The area is very historically significant, and is home to the Fort St. James National Historic Site. Mining, tourism and agriculture are the main economic drivers in the area (Fort St. James, 2013).

The village of **Fraser Lake** has a population of 1,200 people and is situated 160 km west of Prince George at the east end of the 'Lakes District'. Most residents are employed in the forestry or mining industry, and some also work in tourism and agriculture. The area is known for its fishing and recreation opportunities, and its resident population of trumpeter swans (Fraser Lake, 2013). The Fort Fraser fur-trading post, established in 1806, is located just east of the village.

Generally, the people who live within the Nechako River Basin enjoy settlements that are smaller in size, an affordable cost of living and an abundance of natural areas that are easily accessible. The rivers and large lakes in the region provide a plethora of outdoor recreation activities, as do the forests and the snowy winters. There are many economic opportunities in most of the centres, many of these relate closely to the natural resources sector.

2 Climate Change:

This section covers an introduction to the concept of climate change, looks at changes (both past and projected) in the NRB and then examines the impacts of these changes.

Climate is a term that refers to patterns of weather over long periods of time. When discussing the climate, researchers are usually referring to a period of time of at least 30 years.[5] Therefore, when someone discusses **climate change**, they should be referring to changes in temperature, precipitation and/or the number of events or extremes over multiple decades.

[5] This is different than climate variability, which refers to short term changes over months to years. It is also different than weather, which refers to changes and events that occur over hours to weeks.

Recent climate change is also often referred to as global warming, or anthropogenic global warming.

Since the 1800s scientists have been exploring how certain compounds, known as **greenhouse gases (GHGs)**, warm the atmosphere. Since the 1980s, scientists around the world have overwhelmingly agreed that earth's climate has been changing since about 1850[6], and changing rapidly over the past 50 years. There has been a significant rise in global air temperatures, and also shifts in the global hydrological cycle resulting in more precipitation in some areas of the world and droughts in others. Increasing evidence shows that most of the changes to the climate system that have occurred over the last 50 years (and longer) are due to GHG emissions generated by human activities, and not only to natural **climate variability**. The activities that are primarily responsible for the increased levels of GHGs (Davidson et al. 2003) are:

- fossil fuel production and use, which emits large amounts of GHGs (primarily carbon dioxide) into the atmosphere;
- livestock rearing, which emits GHGs (primarily methane) into the atmosphere; and
- deforestation, which both releases carbon dioxide from the trees and the industrial activities, and removes the trees that play a crucial role in removing (or sequestering) carbon dioxide from the atmosphere through photosynthesis.

These activities are all very relevant to the Nechako region and to Western Canada.

The signs of climate change are all around us, and there is a large number and variety of examples that show that the climate is changing, and that this is affecting more than simply the surface temperature of the earth. Examples of these statistics include:

- Nine of the 10 warmest years on record have been within the last decade (2002-2012). (*The other warmest year was 1998*.)
- There has been a loss of volume, and sometimes complete disappearance, of glaciers around the world over the twentieth century.
- Significant increases in extreme events - such as multi-day heat waves, heavy precipitation events, droughts and tropical cyclones - have been noted.
- Changes in biological activities and cycles have been observed worldwide, such as earlier plant leaf unfolding, bird egg-laying and animal migrations.

The **Intergovernmental Panel on Climate Change (IPCC)** recently released their fifth assessment report from Working Group I, which focuses on the evidence of climate change, and observed and expected changes. This report was written by 259 lead and over 600 contributing authors, and was reviewed by over 50,000 individuals. The authors, working collaboratively and on a volunteer basis, came to a number of significant conclusions regarding climate change. A

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[6] Almost all scientists agree that the global climate was quite stable for thousands of years before 1850. This information has been gathered from sources such as ice core data, tree rings and ancient records.

few of the major conclusions overviewed in the 'summary for policy-makers report' are as follows (IPCC, 2013):

The climate system is undoubtedly warming. Each of the last three decades has been warmer than the last and the changes observed since the 1960s have resulted in conditions that probably have not occurred on earth for thousands of years. Global air temperatures have increased by approximately 0.85°C between 1880-2012[7], and warming trends are evident in almost every region on earth.

Humans are the primary cause of the warming. Global GHG concentrations have increased by 40% since preindustrial times, and are currently higher than they probably have been for at least the last 800,000 years. The evidence for humans' role in climate change is clear, and it is 'extremely likely'[8] that human (or anthropogenic) activities are responsible for the majority of the changes that have occurred.

Warming will continue, even if humans reduce their GHG emissions. There is more than a 50% chance that global air temperatures will rise by over 2°C by 2100. Changes in precipitation are more difficult to predict, but wet areas generally will get wetter and dry areas will get drier. Extreme events are expected to continue to increase, glacier volumes will continue to decrease, and sea levels will likely rise an additional 26 to 55 cm. These and other changes will continue for a long period of time whether or not humans decrease their GHG emissions.

Although some people argue that taking action on climate change and lowering GHG emissions will negatively affect the economy, a large body of evidence shows that the economic impacts of not acting on climate change will be much greater than taking proactive measures (e.g., Stern, 2006). BC is a good example of an economy that has prospered even though there is a provincial carbon tax and many initiatives designed to decrease emissions, and a climate change adaptation strategy and many initiatives designed to help adjust to climate impacts as well.

2.1 Climate change in BC and in the Nechako Watershed

Different continents, countries, ecozones and regions around the world are warming and changing at different rates. Generally the following trends apply:

1. Air temperatures above land areas (i.e., continents) are warming more quickly than over oceans.
2. Inland areas are warming more rapidly than coastal zones.

[7] Before 1880 there was not enough information available to produce reliable global temperature records from.
[8] In the IPCC, extremely likely equates to a greater than 95% chance.

3. High latitude areas are warming more quickly than areas near the equator.

The following paragraphs provide an overview of our understanding of how these overall trends are impacting on the province of BC and, where possible, the NRB. There is a focus on specific research studies focused on or relevant to this region. Details from these studies regarding past climate trends and future climate projections are then extracted for discussion.

The **Pacific Climate Impacts Consortium (PCIC)** performed an analysis of past temperatures and precipitation patterns across BC between 1906 and 2006. Over the past century, mean temperatures in the Province increased by 1.2°C, maximum daily temperatures increased by 0.6°C and minimum daily temperatures increased by 1.7°C. Precipitation changes were also documented throughout the province. These changes were primarily positive (i.e., more precipitation) and with more increases in winter than summer. Precipitation changes were much less consistent than temperature changes across the province (Rodenhuis et al., 2009; Walker and Sydneysmith, 2008).

Although the climate is changing in the Pacific Northwest, there are also natural cycles of **climate variability** that also affect temperatures and precipitation in the region over seasons and years. The **El Niño Southern Oscillation (ENSO)** and the **Pacific Decadal Oscillation (PDO)** are two cycles of climate variability that are linked to temperature changes in the Pacific Ocean that cause cycles of warmer and colder (or wetter and drier) conditions in BC over years to decades. Therefore, because of climate variability, cooler temperatures may happen from time to time in spite of a long term warming trend. Also, warm phases of variability can provide us with clues about what the average climate may look like 10, 20 or 50 years in the future.

Previous research activities in the Nechako region have identified climate change as a key concern and research need in the watershed. A number of studies have focused on communities and areas within the Nechako Watershed, and provide detailed information regarding past climate trends, future climate **projections** and/or climate impacts in the region. This research has begun to examine climate change in and around of the NRB, and what it might mean for natural and human systems. There is a need for more information about climate change, particularly as it relates to water, to inform and guide emerging resource development and watershed governance efforts. Although more research is probably necessary, for now the existing studies can help us to gain an understanding climate change and climate impacts in the Nechako region.

2.2 Primary research studies

In this report we will look at four research studies in detail that are most directly relevant to climate impacts in the NRB. We also briefly examine several additional research studies (section

2.3) that explore more specific topics or a greater area (such as the FRB). An introductory summary of these nine studies follows below:

There are four primary research studies, and five additional research studies that help us to

2.2.1 Research study I: Climate change and forestry in Vanderhoof

Between 2004 and 2008, Natural Resources Canada performed a detailed assessment examining how climate change may affect forests, the forest industry and forest-dependent communities in the north. A key part of the project was the development of a framework for assessing the **vulnerability** of forest-based communities to climate change. Researchers built a framework that outlines 14 detailed steps that forest-dependent communities can follow to:

1. Examine past and future climate change (see tables 1 and 2).
2. Identify and assess ecosystem and community impacts.
3. Plan and implement adaptation strategies.

The Framework was applied to a 200 km x 200 km area centred on Vanderhoof in a detailed study led by Natural Resources Canada. Experts from Vanderhoof and across Canada studied recent and projected future changes in the region, applied the climate information to identify potential impacts on the forest resources and the broader community, and came up with adaptation strategies through the use of scenarios. The scenarios were compiled to outline how the community and the landscape will be impacted climate change impacts. A report of the framework for assessing vulnerability for forest based communities can be found at http://cfs.nrcan.gc.ca/bookstore_pdfs/27507.pdf (Williamson et al., 2007) and results from the Vanderhoof research study are available at: http://publications.gc.ca/collections/collection_2009/nrcan/Fo133-1-415E.pdf (Williamson et al., 2008).

2.2.2 Research Study II: Climate change adaptation in Prince George

Since 2007, the **University of Northern BC (UNBC)** has been working closely with the City of Prince George to understand the changes that have been occurring in and around the City, and to identify strategies to plan for the impacts of climate change. Over the last six years a great deal of research and action has occurred, including:

- A detailed overview of the past climate changes in the region and projections of future changes, completed in partnership with PCIC (see Tables 1 and 2).
- Multiple engagements with City staff, local experts and members of the public to understand what these changes might mean for Prince George, and what the priority impacts are locally.
- The incorporation of climate change adaptation measures into the City's local Official Community Plan and the Integrated Community Sustainability Plan.

- Further research and action on priority impacts in Prince George, including forests, flooding and transportation infrastructure.
- An evaluation of the effectiveness of the adaptation actions, and an outline of which undertakings are likely to continue.

Detailed information about the Prince George project and many reports can be found on the City's website at: http://princegeorge.ca/environment/climatechange/adaptation/pages/default.aspx (City of Prince George, 2013b).

2.2.3 Research Study III: Climate change research with the Stellaquo:

In 2009 the Stellat'en First Nation (near Fraser Lake) created a plan to **mitigate** its GHG emissions. Building on this work, the community partnered with researchers at UNBC to examine the impacts of climate change in the Nechako area with a focus on water. This study was unique in that it was guided by local Elders, and it used information from both western scientific and **Traditional Ecological Knowledge** perspectives to examine changes in the area and identify possible solutions. The work consisted of three major parts:

1. Climate information was gathered from nearby weather and hydrometric stations, and analyzed.
2. Climate information was gathered from local youth and Elders regarding their learned experiences with climate and climate change through interviews, focus groups and a survey of community members.
3. The climate information compiled (in parts 1 and 2) was brought together in two knowledge intersection workshops in 2010. These events included background presentations on water and climate change, and talks related to the 'western' and 'traditional' information compiled. After a group discussion, people formed focus groups and were asked about what climate change means to them, how it has impacted their families and what they can do about it.

When it is finalized, the article will be available online at: http://onlinelibrary.wiley.com/journal/10.1111/(ISSN)1541-0064[9]

Article citation: Sanderson, D., Picketts, I. M., Déry, S. J., Fell, B., Baker, S., Lee-Johnson, E., and Auger, M. (2014). Climate change and water at Stellat'en First Nation, British Columbia, Canada: Insights from western science and traditional knowledge, The Canadian Geographer, accepted pending revisions.

[9] You need a subscription to the journal to access the article for free. You can access the article at a University library.

2.2.4 Research study IV: Omineca region climate overview

PCIC has been involved in a number of studies, reports and projects in BC (including the Prince George adaptation project). Recently PCIC, in partnership with the BC Government, released a series of eight reports outlining changes that have been observed and are expected in different regions of BC. One of the reports focused on the **Omineca region**, which includes most of the Nechako watershed, and parts of the Liard and Peace watersheds as well (figure 5)[10]. PCIC has briefly summarized past climatic changes as well as future projected changes – and they use that information to outline what some of the major impacts may be in the region. The report is available at: http://www.pacificclimate.org/news-and-events/news/2013/regional-climate-summaries (PCIC, 2013).

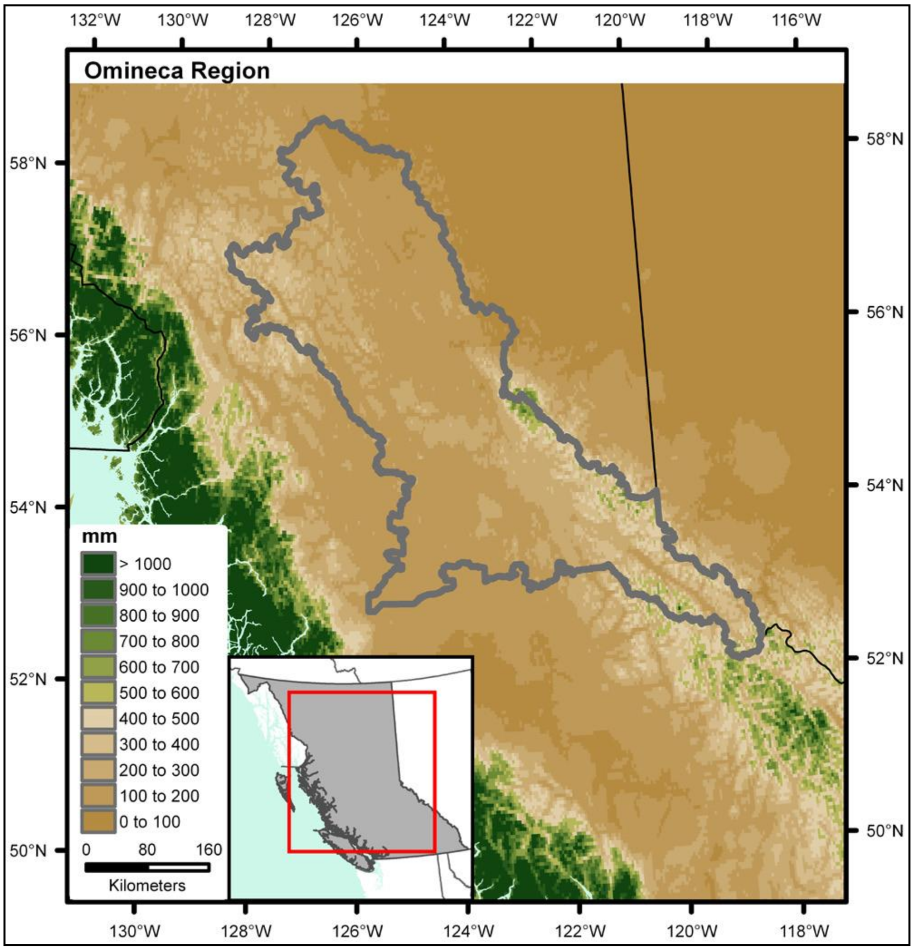

Figure 5 The 'Omineca' Region as defined by PCIC. (PCIC, 2013)

[10] Almost all of the Nechako Watershed is within the 'Omineca' region as defined by PCIC, but a small part of the watershed is located falls within the 'Skeena' region.

2.3 Additional research studies

2.3.1 Research study V: Hydrologic impacts of climate change on the Fraser River Basin

Researchers at PCIC and the University of Victoria performed a modelling study to examine the effects of climate change on hydrology in the FRB. The researchers focused on 11 sub-basins, two of which are located within the Nechako Watershed: one on the Stuart River near Fort St. James and another on the Nechako River at Vanderhoof. They used models to explore current hydrologic patterns and project what hydrologic patterns may look like in the 2050s. Changes in temperature, precipitation, snow storage and annual run-off were calculated, and the implications of these changes on hydrology explored. The complete article is available online at: http://onlinelibrary.wiley.com/doi/10.1002/hyp.9283/abstract[11] (Shrestha et al., 2012).

Article citation: Shrestha, R. R., Schnorbus, M. A., Werner, A. T. and Berland, A. J. (2012) Modelling spatial and temporal variability of hydrologic impacts of climate change in the Fraser River basin, British Columbia, Canada. *Hydrological Processes*, 26: 1840–1860. doi: 10.1002/hyp.9283

2.3.2 Research study VI: snow budget research

Researchers from Canada and the United States collaborated to study the changing contribution of snow to the FRB. This study builds upon a large body of research suggesting that snowfall and snowpacks are decreasing in western north-America. By analyzing past weather data in the basin and applying the outputs of the **Variable Infiltration Capacity (VIC) model**, researchers analyzed many trends that are occurring in the sub-watersheds of the Fraser. The article is available online at: http://journals.ametsoc.org/doi/abs/10.1175/JHM-D-13-0120.1[11] (Kang et al., 2014).

Article citation: Kang, D. H., Shi, X., Gao, H. and Déry, S. J. 2014. On the changing contribution of snow to the hydrology of the Fraser River Basin, Canada, Journal of Hydrometeorology, in press. doi: 10.1175/JHM-D-13-0120.1

2.3.3 Research study VII: flood analysis

It is very difficult to discern what factors or variables lead to river flooding, as rivers are such complex systems and floods are such complex events. This is particularly true in the NRB, as some of the flow is controlled (or regulated) by humans, and some is not regulated (e.g., the Stellako, Nautley and Stuart tributaries). Climate change adds a whole other dimension to this challenge, as the river systems function is changing over time also. To answer some of these difficult questions, researchers studied how and when past flooding events have occurred in the Nechako River Basin. This was done by examining long-term datasets of discharge from the

[11] You need a subscription to the journal to access the article for free. You can access the article at a University library.

river from 1955 to 2008 (since when the Kenney dam was completed) and studying what factors were present during all of the significant flooding events over this time period (Albers et al., in review). The article summarizing this work is currently in review in the Canadian Water Resources Journal.

Article citation: Albers, S. J., Déry, S. J. and Petticrew, E. L. In Review. Flooding in the Nechako River Basin of Canada: A random forest modeling approach to flood analysis in a highly regulated reservoir system, submitted to *Canadian Water Resources Journal*.

2.3.4 Research study VIII: Ecosystem restoration in Vanderhoof

In 2011, the BC Ministry of Forests and Range (MoFR) led a committee of local and regional experts to create an Ecosystem Restoration plan for the Vanderhoof Forest District. The purpose of the plan is to guide the processes of assisting with and facilitating the recovery of vulnerable, degraded, damaged or destroyed ecosystems. Climate change was one of the major considerations outlined in the plan. The full report is available at: http://www.for.gov.bc.ca/dva/Other%20Documents/Vanderhoof%20ER%20Strategic%20Plan.pdf (LMFRS, 2011).

2.3.5 Research Study IX: impacts on salmon migration in the Fraser Basin

A collaboration of researchers from the University of BC, The University of Saskatchewan and UNBC examined monthly streamflow data from 151 gauges along the FRB over a 100 year period from 1911-2010. Inter-annual variability in streamflow (i.e., changes from year to year) has been increasing over time, and can have negative effects on salmon populations. Water temperatures and flow rates play important roles in the success of salmon migration success and the health of offspring. The article is available at: http://www.tandfonline.com/doi/abs/10.1080/02626667.2014.892602#.U3OxevldXms [12] (Padilla et al., in press).

Article citation: Padilla, A., Rasouli, K. and Déry, S.J. (in press) Impacts of variability and trends in runoff and water temperature on salmon migration in the Fraser River Basin, Canada. Hydrological Sciences Journal. Available online (available online). doi: 10.1080/02626667.2014.892602

[12] You need a subscription to the journal to access the article for free. You can access the article at a University or College library.

3 Climate trends and Future Projections

3.1 Past trends in climate

A number of the research studies focused on the Nechako watershed included detailed study of past trends in temperature, precipitation, hydrology and other factors. An overview of the outputs of the cast studies that included trend analysis is included as Table 1. Afterward the outcomes are briefly summarized.

Table 1 Overview of past climate trends in the Nechako Watershed.

Study description	Past trends documented in temperature, precipitation, hydrology, etc.	Human observations of changes
Forestry in Vanderhoof (I) • Past climate trend data were assembled for Vanderhoof from regional weather stations and from climate records. • Local residents were surveyed about changes they have witnessed in their lifetimes	• Several trends were noted in temperature between 1901-2000, including: ○ Average temperatures increased by 1.7°C per century ○ Minimum temperatures increased by 3.0°C per century ○ Maximum temperatures increased minimally. • Winter, spring, summer and fall precipitation all increased until the 1960s, and since then no major changes have been observed.	• 16 of 18 of local respondents surveyed believed the climate has changed '*appreciably*' over the last 35 years. • Common observations by participants include: milder winters; changes in bird species; shorter logging seasons; increased freeze-thaw cycles; more extreme weather events; and a '*blending*' of the four seasons.
Adaptation in Prince George (II) • Researchers examined past climate trends from the Prince George Airport climate station and analyzed trends from 1918-2006, 1931-2006, 1951-2006 and 1971-2006. • Prince George City staff have been noticing and responding to changes in weather for many years	• The effects of climate variability are significant in Prince George. For example, El Niño winters are approximately 1.7°C warmer and 10% drier than average conditions. • Several trends were noted in temperature between 1918-2006, including: ○ Average air temperatures increased by 1.3°C per century. ○ Minimum temperatures increased by 2.2°C per century. ○ Maximum temperatures increased by 0.4°C per century • Since 1971 mean air temperatures increased at a much more rapid rate of 4.6°C per century. • Since 1931 trends have been negative for snowfall and positive for rainfall, suggesting more precipitation is falling as rain. • Since the 1960s streamflows have increased in winter and decreased in summer.	• In 2004 the Transportation Manager examined local weather data that showed clear warming trends, and decreasing precipitation falling as snow. • Local City staff noted many changes in winter conditions, including an increase in winter thaw events and rain-on-snow events.

Table 1 continued.

Study description	Past trends documented in temperature, precipitation, hydrology, etc.	Human observations of changes
Omineca region climate overview (IV) • Historical trends for the region were created by using the CANGRID dataset. This is a gridded dataset that provides historical climate data in Canada, which are based on Station observations. It has a spatial resolution of 50 km and was created by Environment Canada	• Several trends in temperature from 1901-2009 were noted, including: ○ Average annual temperatures increased by 1.9°C per century ○ Average summer temperatures increased by 1.6°C per century ○ Average winter temperatures increased by 2.6°C per century • Several trends in temperature from 1951-2009 were also noted, including: ○ Average annual temperatures increased by 2.5°C per century ○ Average summer temperatures increased by 2.0°C per century ○ Average winter temperatures increased by 4.2°C per century • From 1901 and 2009, precipitation increased by: ○ 40 mm per century in summer ○ 30 mm per century in winter • From 1951 and 2009, precipitation increased by: ○ 30 mm per century in summer ○ -30 mm (decreased) per century in winter	• No other types of observations were noted in this study.
Other: **Snow budget research (VI)** (The other studies did not include detailed past trend analysis.)	• According to the model simulations (which apply observational data), over the period of 1949 to 2006 there was a: ○ 19% decline in the contribution of snow to run-off in the entire FRB. ○ 11% decline in the contribution of snow to run-off in the Stuart River (a tributary of the Nechako). ○ 17% decline in the contribution of snow to run-off in the Nautley River (a tributary of the Nechako).	• No other types of observations were noted in this study.

3.1.1 Summary:

As a northern inland region, temperatures in Northern BC are warming faster than the Provincial average, and much faster than the global average rate (Rodenhuis et al., 2009; Picketts et al., 2012; Williamson et al., 2008). The results from the nine research studies reveal some very clear trends in the NRB. The basin has been warming at a rate of about 1.3°C - 1.9°C per century since the early 1900s, and the rates of warming have been much greater in recent decades. The basin is warming more quickly in the winter than in the summer, and minimum temperatures (or night-time lows) are increasing faster than maximum temperatures (or day-time highs).

Precipitation trends are much less consistent and less clear, which is not surprising as precipitation varies considerably from year to year and from location to location. Precipitation appears to have increased over the last century, but this may due more to cycles of climate variability (that led to drier periods earlier in the century) than climate change. There have not been major consistent trends in total precipitation in the NRB over the last 50 years; however, one clear trend from the nine research studies is that there has been increasing rainfall and decreasing snowfall throughout the watershed. As a result, stream-flow levels appear to be increasing in the winter and decreasing in the summer.

3.2 Future climate projections

A number of the NRB research studies included future **climate projections** as part of their research and analysis. Climate projections are typically generated by analyzing the outputs of **Global Climate Models (GCMs**). Some studies also employ **Regional Climate Models (RCMs)**, which are like GCMs but are 'zoomed in' on a smaller area. RCMs help to show how temperature and precipitation projections may differ across a landscape, and how geographic features (such as mountains or large bodies of water) affect the local climate. Although RCMs can convey important local information, they rely on complex downscaling methods and are generally perceived as far less certain than GCMs.

GHG emissions scenarios, or estimations of future human emissions, are used to feed into climate models. The emissions scenarios affect the level of future warming, particularly over longer time periods (such as the end of 2100).[13] Future projections are usually represented as a change from **baseline conditions.**[14] Often average conditions from 1961-1990 are used as baseline conditions. This time frame (1961-1990) was used to establish baseline conditions for all of the studies overviewed in Table 2.

It is important to note that most of future climate studies produce projections, and sometimes these are used to create more detailed scenarios. Projections are meant to be exactly that, and should not be thought of as definite **predictions** of what will happen. Most studies include a range of projections that are typically the outputs from a number of GCMs that are run using multiple emissions scenarios. Usually it is best to present a range of projections, rather than just the outputs of one GCM simulation or calculating the average (or median) value of all projections. Showing a range helps to communicate that there is a lot of uncertainty when

[13] Different missions scenarios don't have a large effect on the uncertainty (or range) of future projections until after about the 2050s (Rodenhuis et al. 2009).

[14] Usually baseline conditions are the average conditions over 30 years or more because (as previously mentioned) climate varies naturally due to cycles of weather and climate variability.

looking at future climates, and also reminds people of the need to prepare for a number of different possible sets of conditions and impacts.

An overview of the projections from some of the research studies that included future climate projections is included as Table 2 on the following page.

3.2.1 Summary:

Looking into the future, the climate in northern BC is expected to continue to warm at a rate that is higher than the global average (Rodenhuis et al., 2009, Walker and Sydneysmith, 2008). The range of projections exercises – employing many different GCM outputs and emissions scenarios – show some clear consistencies. All modelling exercises project that the NRB is expected to become approximately 2°C warmer than baseline conditions by the 2050s. By the end of the 21st century temperatures may be much warmer, but these projections vary considerably depending on how many GHGs humans emit into the atmosphere in upcoming decades.

Similar to the past trends, precipitation projections are less consistent. A clear trend of increasing precipitation is evident, and less precipitation will likely be falling as snow. Changes in annual discharge (increases) and **snow water equivalent (SWE)** (decreases) mean that there will be major alterations in the flow patterns of the Nechako and its tributaries.

Table 2 Overview of future climate projections in the Nechako Watershed.

Study	Summary of Future projections*
Forestry in Vanderhoof (I) • Future projections were created by analyzing the simulation results of three Global Climate Models (GCMs) and two GHG emissions scenarios.	Based on the range of projections: • Minimum daily temperatures could increase by 1.5 to 6.0°C by the end of the 21st century • Maximum temperatures could increase by 1.0 to 4.0°C conditions by the end of the 21st century • Projected changes in precipitation are much less clear, but rainfall is expected to increase.
Adaptation in Prince George (II) • A series of 140 projections were created using 22 GCMs and three emissions scenarios. The ranges are the 25th to 75th percentile range of this group. • Maps created from the outputs RCM projections were also created to show the spatial variation in future conditions.	Based on the range of projections, for the 2050s: • Prince George is expected to be approximately 2°C warmer (1.6 - 2.5°C). • Precipitation is projected to increase by approximately 7% (3 - 10%). • These changes will result in 'new' conditions, which is to say that the temperatures and precipitation regimes in the 2050s are expected to be outside of the traditional range of variability for the area.
Water in the Stellaquo (III)	N/A – no future projections were analyzed in this project.
Omineca region climate overview (IV) • A group (or ensemble) of 30 projections from different GCMs and emissions scenarios were specially selected and analyzed by PCIC. The ranges shown are the 10th to 90th percentile of changes from this group.	• The Omineca region is projected to be 1.8°C (1.3°C to 2.7°C) warmer in the 2050s. • The Omineca region is projected to be 2.6°C (1.6°C to 4.4°C) warmer in the 2080s. • Annual precipitation is projected to increase by 8% (2-15%), with summer precipitation levels changing minimally and winter precipitation levels increasing by a greater amount. • Snowfall in the winter is projected to increase slightly (2%), but spring snowfall is projected to decrease by 54%.
Other: **Hydrologic impacts on the Fraser (V)** • A hydrologic model was used to simulate baseline conditions and future projections from eight GCMs and three emissions scenarios. Two of the sites analyzed are located within in the NRB. *(The other studies did not include detailed future projection analysis.)*	Based on the range of projections, for the 2050s: • Air temperatures at Fort St. James are expected to be 1.8°C – 2.5°C warmer. • Air temperatures at Vanderhoof are expected to be 1.7°C-2.5°C warmer. • Precipitation at Fort St. James is expected to increase by 9-12%. • Precipitation at Vanderhoof is expected to increase by 5-10. • The Snow Water Equivalent (SWE) at the Stuart River (at Fort St. James) is expected to decrease by 30-41% (on April 1). • The SWE at the Nechako River (at Vanderhoof) is expected to decrease by 21-33% (on April 1). • Stuart River annual discharge is expected to increase 7-15%. • Nechako River annual discharge is expected to increase 4-10%.
**All projected changes are expressed as differences from the 1961-1990 baseline.*	

4 Climate impacts in the Nechako Watershed

Although climate change is a global issue, its impacts are usually observed and experienced at the community and regional level. Many of the changes that the Nechako region has seen (and can expect to experience) are similar to those that other watersheds around the world are undergoing. Changes in air temperature, precipitation, extreme weather events and the flow regime of the Nechako River will impact the natural and human systems within the NRB.

The nine research studies introduced above discuss climate impacts from various perspectives. Some of these studies focus on forests, some on water, some on First Nations communities and some on cities. The wide range of approaches, methods, worldviews and partnerships that contributed to these studies provides us with a rich overview of climate impacts in the NRB from a variety of perspectives. In this section we overview the major impacts outlined in each of the studies, and then we conclude by attempting to compile them into a few major impact categories.

4.1 Primary research studies

4.1.1 Research study I: Climate change and forestry in Vanderhoof

The Vanderhoof study focused primarily on impacts to forests, and how these impacts in turn will affect forestry and the community. The study authors created models to produce detailed simulations of future changes and their associated impacts. Two major potential impacts to forests, and the related modelling outputs, are as follows:

1. **Composition and productivity**: climate change is affecting how plant and animal species interact and compete, and ultimately what species will be in the forest.
    - Based on model outputs, more drought resistant and hardwood tree species are likely. Forest productivity generally increases[15], but will decrease over time if the forest species composition does not shift to adjust to changing conditions.
2. **Disturbance patterns**: climate change is affecting fires, pests and diseases.
    - A separate model was used to examine how forest fire regimes may change in the future, and predicted large increases in areas high fire susceptibility and an almost tripling of areas with extreme fire susceptibility[16].

The study continued with additional modelling that projected the economic impacts of climate change on the larger adjoining Prince George timber Supply Area (which includes the Vanderhoof area): it was not possible to run the model on the smaller Vanderhoof area. Four future scenarios were created based on the different levels of climate change, and whether or not global and local market conditions become more favourable for forestry. The results of this

[15] This modelling exercise does NOT take into account increased disturbances, such as fires or pests.
[16] This model was only run using the worst-case climate change scenario.

exercise ranged from an increase of $100 million in annual household income related to forestry between 2000 and 2055, to a decrease of $50 million over this time period. These changes will have large implications related to the community of Vanderhoof and the broader region in terms of economic prosperity, infrastructure quality and **community well-being.**

4.1.2 Research study II: Climate change adaptation in Prince George

The Prince George study focused primarily on **climate change adaptation**, or adjusting to the impacts of climate change. Local staff, experts and community members worked with researchers to examine the past and future climate change information in the region (Table 1 and Table 2) and identify impact priorities for the City. The 11 top impacts identified are listed in Table 3, along with a short summary of actions that have been undertaken or recommended related to each impact. The numbered list of impacts does *NOT* necessarily represent the priority for action locally. This is because the City has already undertaken a great deal of work to address some impacts (such as forests), and has only begun to explore other impacts (such as slope stability and transportation infrastructure). Also, the `*other impacts*` are not the lowest priority impacts: they are simply the topics that did not fit exactly into the risk analysis exercise used for the study. Therefore these impacts warrant further discussion and research.

Table 3: Prince George adaptation priorities and examples. (Adapted from Picketts et al. 2013)

Level of Priority		Impact	Local adaptation actions that were implemented or suggested
Top Priorities	1	Forests	The City is removing beetle-kill wood within City limits to mitigate fire risk, and is planting different species in parks
	2	Flooding	Climate projections were incorporated into the City`s flood risk assessment for the Nechako and Fraser Rivers
High Priorities	3	Transportation infrastructure	Local experts explored how to design roads that would be more resilient to freeze-thaw events and other changes
	4	Severe weather / emergency response	The City should ensure that vulnerable residents are protected in extreme weather response plans
	5	Water supply	More work is needed to educate residents about indoor and outdoor water conservation
Medium Priorities	6	Slope stability	There are plans to incorporate future climate projections in slope risk assessments
	7	Storm-water	Infrastructure is being designed for larger storm events, and on-site retention capabilities should be explored
	8	Buildings and utilities	A downtown building has been designed so water can enter the lower parking area during floods or high water levels
Other Priorities	9	Health	More work is needed to partner with local organizations to study climate change and health impacts further
	10	Agriculture	More work is needed to partner with local organizations and prepare for changes to agriculture
	11	New residents and businesses	In the long term Prince George may need to prepare for a large influx of people moving from more affected areas

4.1.3 Research study III: Climate change research with the Stellaquo:

As noted above, climate change information for this study was gathered from both Western and Traditional perspectives. Local Elders and community members believe that the underlying causes of climate change relate to modern values relating to money and development, rather than human and environmental health. Resource activities (including mining, fossil fuel development, hydro-electricity and forestry) were also noted as drivers of climate change.

As this study focused more on accessing and combining different sources of knowledge, there was not a great deal of results focused on climate impacts. The traditional knowledge portion of the research overviewed some major impacts, which were organized into categories and identified to be as follows (Sanderson et al. 2014):

- **Land** impacts, such as soil depletion and less wildlife habitat
- **Air** impacts, such as poorer air quality
- **Water** impacts, including less water, less rain, less snow, less fish, and melting ice.
- **Fire** impacts, including more warm weather and extreme events
- **Health** impacts, which relate to less available traditional foods (e.g. salmon and moose) and medicines

This study went further by identifying some community actions that can be taken to make positive headway regarding climate change. Since the study, a community garden and a ride sharing program have been created, and 10 bicycles were purchased by the Stellat'en First Nations and made available for rental.

4.1.4 Research study IV: Omineca region climate overview

PCIC applied its Plan2Adapt tool to outline some impacts that are potentially associated with the projected changes for the Omineca region:

- There will likely be less snowpack in the winter, and this in turn may shorten the winter logging season (which depends on frozen ground).
- The transition toward a rainfall-dominated system will lead to less water availability in summer.
- More extreme precipitation events, warmer summer temperatures and an increase in dry conditions will affect natural systems, forest fires and water supply.
- River flooding frequency and total runoff may increase, which will affect stream bank erosion and infrastructure.
- Warmer temperatures lead to a longer growing season and new crops may become viable in the region. However, stresses on water supply and extreme events will have negative impacts on agriculture as well.

4.2 Additional research studies:

4.2.1 Research study V: Hydrologic impacts of climate change on the Fraser River Basin

There are many impacts associated with the projected changes to the climate and to snow storage overviewed in the study. Warmer temperatures and drier summer conditions lead to an increase in evapo-transpiration and soil moisture changes. Increases in temperature and changes in snow also change how discharge occurs. Peak flow rates are expected to occur approximately two weeks earlier in the spring in the Nechako River and four weeks earlier in the spring in the Stuart River in the 2050s, compared to baseline conditions. Summer flows will be lower, as there is less soil moisture, less snowmelt, less summer precipitation and warmer temperatures. These changes can have important implications for hydro-power generation (particularly water storage), fish health and recreation. The study authors recommend that the information be applied to help to inform local adaptation work throughout the FRB.

4.2.2 Research study VI: snow budget research

The detailed analysis performed shows that the Fraser watershed may change from a snow-dominated system (i.e., most of the drainage into the river is from snow) to a pluvial regime or a rain-dominated system (i.e., most of the drainage into the river is from rain) over the next 50-100 years. Although this will likely not be the case for the Nechako River due to its northern location, the contribution of rainfall to the Nechako is expected to increase significantly and the implications of these changes are substantial. As a snow-dominated system, the peak flows typically occur in late spring and early summer as the snow melts. If snow accumulations continue to decrease, peak flows will occur earlier and there may be lower flows in the late summer. Changes in snow accumulations also alter water chemistry and water quality (Déry et al., 2012). Changes in flows can have major negative effects on migrating salmon (Rand et al. 2006), which are important to the cultural, social, environmental and economic well-being of the entire watershed.

4.2.3 Research study VII: flood analysis

Looking at previous flooding events, spring (or freshet) flooding events were found to be most closely related to high flows in the unregulated Stellako and Nautley Rivers (which are not affected by the Kenney Dam). However, for winter floods water releases from the Nechako reservoir were found to be the most important variable. Winter releases occur because there is a need to keep the reservoir level down and to prevent the need for water releases in the spring that may lead to a larger **freshet** flood.

With climate change, more total winter precipitation (in the form of rain) is expected in the NRB. This could in turn lead to more winter flood events on the Nechako River if more water needs to be released from the Nechako reservoir at this time. Also, lower summer flows will lead to warmer summer water temperatures, which are potentially disastrous for sturgeon and salmon populations.

4.2.4 Research study VIII: Ecosystem restoration in Vanderhoof

Many climate-related impacts were noted to affect ecosystem structure and function in Vanderhoof including:

- increased fires;
- increased pests and disease;
- shifts in vegetation;
- soil moisture deficits; and
- changes in streamflow.

Four vulnerable ecosystems were targeted for further study and eventually restoration. These were selected to be Douglas fir stands, grasslands, wetlands and berry producing shrub ecosystems.

4.2.5 Research study IX: impacts on salmon migration in the Fraser Basin

Streamflow variability was found to be increasing in many of the sub-watersheds of the Fraser River, but less so in the Nechako because it is regulated by the Kenney Dam. There is a greater rate of increase in variability in spring and early summer months than in fall: therefore early salmon migrations (such as the Stuart River) may be particularly affected. Variability is expected to increase in the future as the climate continues to change and will continue to impact salmon populations.

4.3 Summary of climate change impacts in the Nechako Region

Climate change has far reaching implications that are already affecting and will continue to affect humans' economic, social, cultural and environmental well-being. As noted and summarized above, there have been a large number of studies and projects related to climate change that have focused on the Nechako watershed. Many of these studies were aimed at identifying what the impacts of climate change are and will be in the area. In this section we attempt to summarize and discuss the major impacts outlined in the research studies. For simplicity we have grouped the impacts into four broad categories. These categories do not attempt to cover the whole suite of impacts in the region, and focus on impacts that relate closely to the resource development activities that are occurring on the landscape (see next section).

The four categories of climate impacts are:

- Impact category A: forest and aquatic ecosystems:
- Impact category B: water supply
- Impact category C: agriculture and food security
- Impact category D: community well-being (MEA, 2005)

Below we discuss these categories in more detail. We begin with an introduction to each impact on a global scale and then move to the Nechako Watershed scale. It is important to note that these topics are highly interrelated and interdependent. (For example, water supply relates very closely to agriculture, ecosystem health and community well-being.)

4.3.1 Impact category A: forest and aquatic ecosystems:

Climate change is changing the way that ecosystems function, and changing hydrological (water), plant, animal and other patterns and cycles (Smith & Smith, 2009). Various changes to ecosystems have already been noted around the world, including some shifts of plant and animal populations to more northerly or higher latitude environments. A recent article in the journal *Nature* recently predicted that over a million species may go extinct by 2050 because of rising temperatures (Thomas et al., 2004).

Ecosystems in the NRB are undoubtedly changing. The two categories of ecosystems that have been studied at length have been:

III. **Forest ecosystems**: Climate change is having a large impact on how forests grow, what types of trees grow and how (and how often) forests are disturbed. Climate change may lead to more productive (i.e., faster-growing) forests, but trees may be more susceptible to fires and pests such as the mountain pine beetle. In the future many currently existing tree species in the NRB may no longer be ideally suited for the new regional conditions. A reduction in soil moisture is expected to be a potential source of stress on trees. Large efforts will have to be made to assist forests to adjust to changing conditions.

IV. **Aquatic ecosystems**: Climate change has large implication on water resources. Water is central to the cultural health of the NRB. First Nations and non-First Nations people alike depend on rivers, lakes and wetlands for food, recreation and health. Therefore, impacts to aquatic systems are extremely important and must be carefully monitored. The Nechako white sturgeon is already classified as critically imperiled, and there are major concerns about the health of salmon populations. Increases in water temperatures and decreases in summer flow rates have direct and important implications for the health and viability of aquatic ecosystems in the area. Wetlands perform important functions, and must also be carefully managed and monitored.

4.3.2 Impact category B: water supply

Water is necessary for life. Climate change is affecting water in all forms, including the cryosphere (i.e., glaciers, snow and ice), freshwater (both surface and groundwater) and oceans. Across the globe water temperatures are increasing, streamflow and flooding regimes are changing, and the chemical properties of water (such as nutrient levels and acidity) are shifting as well. These changes are leading to impacts on both the amount and the quality of water that is available for natural cycles and for human use (IPCC, 2008).[17] First Nations people are particularly susceptible to impacts associated with water supply due to their unique spiritual and cultural relationship to water, dependence on fish (and other aquatic creatures) for food and the poor state of drinking water on many reserves (Assembly of First Nations, 2008)

Water supply in the NRB is being affected by a large number of factors including decreasing snowfall, increasing total winter precipitation (in the form of rain), decreasing soil moisture, forest pest outbreaks and warming temperatures. These have led to a change in the annual discharge in the basin, with an earlier peak flow and lower flows in late summer. Future projections indicate that precipitation will increase overall, snowfall will continue to decrease, the spring freshet will continue to come earlier and summer flows may decrease. It is uncertain how these changes will affect flooding, but winter flood events may increase. As we will talk about in the following sections, there are many important human demands on water in the NRB. The water is used for power generation, human consumption, agriculture and mining, just to name a few.

4.3.3 Impact category C: agriculture and food security

This category could be integrated into the others, but due to the importance of food security in global and traditional contexts it is considered on its own. A warming climate can increase growing seasons in more northerly latitudes, and decrease capabilities in hot and arid regions.[18] Although some people in colder climates are optimistic about climate change and a longer growing season, it is expected that an increase in extreme weather events (that can spoil or damage crops and farm infrastructure) may offset these positive changes (Walker and Sydneysmith, 2009). Both positive and negative impacts related to climate change have been noted in the NRB. Potential positive implications related to longer growing season are noted for agriculture, and negative implications related to losses of traditional foods are also noted. The changes outlined in the other three categories all interrelate closely with agriculture and food supply.

[17] In category A we focus primarily on water's role in natural aquatic systems. In category B we focus primarily on water quality and quantity for human use.

[18] The impacts of climate change on food security are expected to be highly negative in warmer and poorer places like Africa.

4.3.4 Impact category D: Community well-being

Climate change affects the health and well-being of communities in many interrelated ways. Direct health effects associated with climate change include heat waves (that can cause dehydration or strokes), extreme events (such as floods and forest fire), reduced availability and quality of food and water, and increases in pollution and diseases (Confalonieri et al., 2007; USGCRP, 2009). Climate change also has indirect impacts on well-being related to changes to the economy, the physical (natural and built) environment, social cohesion and long-term impacts on social and ecological determinants of health (MEA, 2005; Parkes et al., 2010).

Based on the research-studies introduced above, well-being impacts identified in the NRB include those related to poor air quality (often related to forest fires), concerns about water quality and quantity, changes to socio-economic factors, and less available traditional foods. Climate change has direct effects on all components of the ecosystem and many sectors of the economy such as agriculture, forestry and tourism. Climate influences on human health, pollution and natural ecosystems also indirectly impact the economy (IMF 2007). The built environment is vulnerable to shifts in climate, and in Prince George many impacts related to transportation, storm-water, building and utilities infrastructure have already been noted. Many of these impacts relate to warming winter temperatures, which lead to more freezing and thawing events in the winter[19] that damage structures. All of these changes (as well as the changes in categories A, B and C) ultimately affect the well-being and social cohesion of communities. People in communities that are healthy, economically viable, well-built, and sustainable tend to be happier and more productive than those that are not (MEA, 2005).

One common theme related to climate change is that, unfortunately, impacts are not often distributed or experienced equally. Poorer people and those more vulnerable to changes in social and ecological systems are more likely to be negatively influenced by climate change, whether through changes affecting land and water resources or other factors influencing well-being (MEA, 2005; Confalonieri et al., 2007). Poorer countries around the world have fewer options available to them to prepare for or respond to climate change impacts. In Canada, First Nations communities are especially at risk, due to the ways climate change adds to existing challenges for community well-being, in terms of service provision, the availability of resources and the close ties to social and environmental factors that influence health (Parkes 2011). For example, climate change affects the ranges and populations of animal and plant species, affecting those First Nations who rely on hunting and gathering as a primary source of food. Rural and resource dependent communities are also particularly susceptible to the impacts of climate change, due to reliance on one or a small number of resource activities (such as forestry or agriculture) for their livelihoods. These communities can be hit hard if there are shifts in natural ecosystems, resource demands or global markets (Davidson et al., 2003).

[19] Previously temperatures were more likely to remain well below 0°C in winter months, and the freeze-thaw cycles would not happen. These cycles are damaging to infrastructure (particularly concrete), as when water freezes and thaws it expands and contracts and breaks down the structures.

5 Resource Development and climate change in the Nechako Watershed

Since the 1800s, Settlers in BC have been engaging in activities that have dramatically changed the landscape of the NRB. Initially, explorers and settlers came to BC in search of furs. In the early 1900s, forestry emerged as the major industry in the region and starting in the 1940s there were major interests in hydro-electric power generation. Currently, there are a number of resource-related activities occurring in the NRB, all of which are drivers of change in the same landscapes that will be influenced by climate change. These include (but are not limited to): hydro-electric power generation; forestry; farming; mining; and oil and gas exploration, production and transmission.

In this section we overview some important forms of resource development with a focus on their interrelationships with climate change. These activities are briefly discussed in turn below (Sections 5.1-5.5), with a focus on the interrelationships with the impacts of the resource activity and the impacts of climate change. Other resource based human activities that have occurred, and continue to occur, in the NRB that are not summarized in detail include fishing, hunting and trapping (largely for the fur trade) and renewable energy development (such as wind and micro-hydro). A simple rating system (Table 4) is used to provide an approximation of the degree of interaction, consequence, overlay or interrelationship between the types of resource development and the major climate impacts (outlined in Section 4.3). Each section has a chart (Tables 5-9) overviewing the ratings,

In the final section of chapter 5 (5.7) there is a series of spider diagrams (Figures 8-12) that visualize these interactions, and also discuss future projected increases in rating.

Table 4 Rating system for estimating the degree of interaction between resource development and climate impacts in the NRB.

Scale	Rating	Description
1	Minimal or not applicable (N/A)	No or minimal interaction and/or consequence
2	Low	Some interaction, low consequence or priority
3	Medium	Clear interaction with some consequence
4	High	Direct interaction with consequence: a priority
5	Very high	Direct interaction: very high consequence and priority
6	Extreme	Top priority for concern and action

It is important to keep in mind that these ratings are preliminary and somewhat subjective. The ratings were proposed by the primary author, updated in conversations with the authors and a small group of experts, and discussed and finalized during a workshop with a group of approximately 20 stakeholders representing the Nechako Watershed Alliance.

5.1 Hydro-electric power.

The hydro-electric development that has occurred in the Nechako has led to profound changes in the region. This development began in the late 1940s when the BC Government issued the Aluminum Company of Canada (Alcan) a conditional water use license giving them the authority to store up to 42 billion cubic metres of water (Hartman, 1996; CBC, 2014). This resulted in the Kemano development project, which began in 1950 and was completed in 1954. It is the largest privately funded construction project ever in Canada (Boudreau, 2005; CBC, 2014). In 2007 Alcan was purchased by the Australian mining giant Rio Tinto. Shortly afterward Alcan was renamed 'Rio Tinto Alcan'.

There are many different components of the Kemano development project (Hartman, 1996; Boudreau, 2005; Wood, 2013) including the following key features:

- Water is stored in the 880 km^2 **Nechako Reservoir.**
- The water is stored by the 97 m high **Kenney Dam**, which is located at the mouth of the Nechako Canyon, and was the highest rock-filled dam in the world at the time of construction.
- In addition to the Kenney Dam there are nine smaller **Saddle Dams** that are necessary to keep the water in the Nechako Reservoir.
- Because of the Kenney Dam, much of the water in the Nechako flows westward to the Pacific Ocean to produce power for the **Alcan Aluminum smelter**.
- All water that is not used for power generation (including excess water, and water released in summer to maintain flow levels and cold water temperatures) is released through the **Skins Lake Spillway**. The water enters the Cheslatta River through the spillway and joins the original path Nechako River approximately eight kilometres downstream from the Kenney Dam.

The changes brought to the Nechako River by the Kemano project have had many significant and long lasting impacts. These include environmental and physical impacts to flow direction, river channel morphology, hydrology and fisheries (Hartman, 1996; Wood, 2013). Those who have reflected on the project have noted obvious oversights and shortcomings, including: no logging of the lands to be flooded; minimal fish and wildlife impacts assessments; no requirements for cool water release at the Kenney Dam; and massive flow increases in the Cheslatta River leading to major siltation and erosion, and changes in sediment fluxes (Hartman, 1996; Wood, 2007; Windsor and McVey, 2005; Déry et al., 2012).

A detailed discussion is beyond the scope of this paper, but the social and cultural impacts of the Kemano project have been significant. Cheslatta Indian Band members were not consulted, given minimal notice to vacate traditional villages and were ultimately relocated to Vanderhoof. Many important cultural sites, such as graveyards, were flooded. This upheaval has led to many long lasting cultural, social and economic problems for the Cheslatta people (Attili and Sandercock, 2010; CBC, 2013; Windsor and McVey, 2005; Wood, 2013).

There was a second stage of development planned for the early 1990s called the Kemano Completion Project (or Kemano II). This project would have doubled power generating capacities, and reduced the average annual flow of the Nechako River to approximately 13% of its original (e.g., pre-dammed) volume (Hartman, 1996). The BC Government cancelled the Kemano Completion Project in 1995. Many people in the region are concerned that Kemano II may still be constructed, and may further alter flow rates in the Nechako.

5.1.1 Climate change and hydro-electric power

The interrelationships and impacts associated with hydro-electric power generation and climate change are obvious. The Kemano project interrelates with all four of the impact categories defined. A brief summary of the key linkages between hydro-electric power and climate impacts is included as Table 5. Water Supply and aquatic ecosystems are a topic of particular note because both climate change and major hydro-electric projects can have the exact same effects for water, including factors related to:

- flow rates and flooding regimes;
- water availability, particularly for other uses such as agriculture; and
- stream temperatures.

Many of these impacts are permanent and cannot be reversed: decision makers can only move forward and manage the present system responsibly. There are also positive aspects associated with hydro-development and climate change. If managed carefully, water storage facilities can be used to mitigate flood risks and help to keep water temperatures low. Hydro-electric power is also a source of employment that can benefit nearby communities. Furthermore, hydro-electricity is regarded as a low-carbon source of power that can help to mitigate the long term impacts of climate change by reducing GHGs. Steps must also be taken to ensure that the hydro projects also account for anticipated impacts related to climate change, such as changes in flow regimes.

Table 5 Interactions between climate impacts and hydro-electric power impacts.

Climate Impact	Relation to Hydro-electric Power*	Discussion
A: Ecosystems	Very High	➢ Hydro developments have changed the natural function of the Nechako. ➢ Hydro developments lead to warmer water temperatures and lower flows, which impact fish populations.
B: Water Supply	Very High	➢ Hydro development has led to a significant reduction in flow in the Nechako River. ➢ Hydro development has permanently altered the flow regime of the Nechako River. ➢ Dam storage capacities may be used for cooling water temperature, increasing flows or mitigating floods.
C: Agriculture and Food Security	Medium	➢ Agriculture and hydro-electric power both place demands on water supply. ➢ Hydro developments impact traditional food sources. ➢ Agricultural lands may be flooded by hydro projects.
D: Community Well-being	Very High	➢ Displacement of the Carrier people from the Kemano project has permanent implications and impacts. ➢ Hydro projects can lead to jobs. ➢ Hydro-electricity is considered a low-carbon form of power.

**Refer to Table 4 for an overview of the rating system.*

5.2 Forestry

Forests and forestry are focal to the history and development of BC, and to the Province's economic, social, cultural and environmental well-being. This is particularly true in central BC, as the forests here are very large, and many of the communities in the region are heavily reliant on the forest industry. As previously discussed, the mountain pine beetle has had a substantial effect on the forests in central BC. By 2007 it was estimated that 13 million hectares of crown land in BC had been affected (BC MoFR, 2007) and that number has since increased. The FRB and the NRB are near the epicentre of the mountain pine beetle epidemic (Schnorbus et al., 2010). A study of the Lakes Timber Supply Area (TSA) (which covers about half of the NRB) estimates that 76% of the mature pine on the land base would be dead by 2021 (BC MoFLNRO, 2012).

In response to the mountain pine beetle, the Annual Allowable Cuts (AACs), or maximum permissible amounts of timber that can be harvested, in many TSAs in central BC were dramatically increased so that the affected timber could be logged before it had been dead for too long and was not usable (BC MoFLNRO, 2012; BC MoF, 2004). Information about harvest volumes is difficult to find, particularly when looking at the watershed scale. Part of the reason that it is so hard to quantify how much logging has occurred in the NRB is that the watershed spans parts of four different Timber Supply Areas (TSAs) (BC Government, 2012). Although it is exceedingly difficult to estimate how much logging activity is taking place on the watershed scale, it is obvious that a great deal of harvesting has taken place over the last 10 years. AACs and harvesting activities have recently decreased, and are expected to decrease dramatically in the near future, as pine beetle affected trees become un-harvestable and logged or disease-affected stands grow back.

An area that has recently been the focus of a great amount of community concern is the Chilako River (also known as the Mud River), which flows east, then north to join the Nechako River approximately 15 km West of Prince George. There has been a great deal of MPB harvesting in the watershed, and harvest levels in the watershed are currently estimated to be at a level of approximately 60% equivalent clearcut area. This has spurred a great deal of concern from stakeholders in the region regarding hydrological processes and hydrological impacts, and a targeted assessment of the watershed is recommended (T. Robert, pers. comm., 2014). Although forestry has had such a major role in central BC's (and the entire Province's) economy, recently the industry has fallen on tougher times (BC MoFML, 2010). Many communities in the Nechako Watershed have been hard hit by the downturn in forestry (United Steelworkers, ND), and these trends are expected to continue as the AACs decrease. In a BC Ministry of Forests, Mines and Lands (2010) study of the vulnerability of regions downturns in the forest sector: almost the entire NRB was classified as 'most vulnerable'. Many believe that other forms of resource development (such as mining and oil and gas) need to be pursued to offset declines in forestry.

5.2.1 Climate change and forestry

There are many clear interrelationships between forests, forestry and climate change. Logging and climate change are both contributing factors to the recent mountain pine beetle outbreak (Kurz et al., 2008; Hartman, 1996). The changes to forests have significant implications on land and aquatic ecosystems and water supply. The loss of forest cover alters snowpacks, soil and water nutrient cycles, contaminants, erosion, peak river flows, flooding regimes and many other processes (Schnorbus et al., 2010; Kurz et al. 2008), not to mention the aesthetic, recreational, spiritual and community values associated with forests (Wood, 2013).

The risk of urban-interface forest fires (i.e., forest fires that spread into communities) is greatly increasing due to warmer, drier temperatures and the mountain pine beetle. This represents a significant safety concern for cities and towns (Picketts et al., 2013). Some programs in the region propose that mountain pine beetle affected lands can be potentially converted into agricultural lands, and that agricultural lands can act as a break to prevent forest fires from encroaching into urban areas (BC MoFR, 2006; OBAC, 2007). In the future, forests may also be more valued for their ecological functions, such as removing (or sequestering) GHGs from the atmosphere, and purifying and storing water (BC MoFML, 2010). A brief overview of key linkages between forestry and climate impacts follows in Table 6.

Table 6 Interactions between climate impacts and forestry impacts

Climate Impact	Relation to forestry*	Discussion
A: Ecosystems	Very high	➢ Changes related to the mountain pine beetle and forest fires are closely linked to climate change and forestry. ➢ Changes are resulting in a reduced proportion of old growth forests in the area. ➢ Changes affect soil moisture, hydrology and water quality – which in turn affects aquatic species
B: Water Supply	High	➢ Logging and the mountain pine beetle epidemic have many implications related to peak flows and flooding. ➢ Forest composition changes impact hydrological cycles by affecting snow and water storage, and water quality.
C: Agriculture and Food Security	Medium	➢ Agriculture may become as a potential way to offset declines in forestry. ➢ Mountain pine beetle affected land can be potentially converted into agricultural land. ➢ Forest health has strong linkages to the availability of traditional foods (such as moose and salmon).
D: Community Well-being	Very High	➢ Forestry is vital to the viability of communities in northwestern BC. ➢ Urban-interface forests fires are a major community risk. ➢ Forests are a crucial carbon sink that sequester GHGs. ➢ Forests are important for community well-being.

**Refer to Table 4 for an overview of the rating system.*

5.3 Agriculture

Agriculturally productive land is very important in BC: only 5% of the total land area of the Province is considered agriculturally viable and BC farmers produce less than half of the amount of food that is consumed here. Nearly two-thirds of BC's agricultural output is generated in southern BC in the lower Fraser Valley (near Vancouver) (FVRD, 2011). Typically, agricultural activity is limited in northern BC because of the cold climate, hilly terrain and poorly draining soils (BC MoF, 1998). Parts of the NRB are unique because the Nechako River has helped to create fertile lands that are suitable for agriculture. The main agricultural activities in the Nechako Region are forage for beef, ranching and dairy herds. The Vanderhoof District also has a significant amount of cereal crop and alfalfa production (Grow BC, ND).

The land area around Vanderhoof (which is referred to sometimes as the Nechako Valley or the Nechako Agricultural Valley) is known for areas of land that are especially agriculturally productive. Vanderhoof was initially settled as an agricultural community, and agriculture remains a vital part of the economy in the district and surrounding areas. There has been a large expansion in the amount of agricultural lands within and around Vanderhoof over the last 20 years (LMFRS, 2011). The main barrier to agricultural production in the region is cited to be profitability. This is related to high transportation costs to markets, limited local markets for fruits and vegetables and long winter feeding periods for livestock. Part of these costs may be offset by the abundance of affordable land (Grow BC, ND). Local residents in Vanderhoof have noted that agriculture has recently seen a significant increase in profitability (W. Salewski, pers. comm., 2014).

There are many initiatives underway to support and strengthen agriculture in north-central BC. Beyond the market (2014) is an example of an initiative that helps farmers in the Nechako Watershed and across northern BC by supporting new farmers, growing markets and encouraging local food networks.

5.3.1 Climate change and agriculture

Climate change and agriculture have very complex interrelationships. Not only are the significant linkages between climate impacts, adaptation and agriculture, but there are major links between GHGs, mitigation and agriculture as well. Agriculture is a major source of GHG emissions: however, sustainable practices[20] and buying food locally can significantly reduce the number of GHGs and ecosystem impacts associated with what we eat.[21]

There is a common conception that, in northern areas, climate change may result in longer growing seasons and that a greater diversity of crops can be farmed in the north. However, scientists caution that other climate-related impacts (such as more extreme events, such as droughts and periods of heavy precipitation) may offset these benefits (Walker and Syndeysmith, 2008). Both the production of food locally and the procurement of traditional foods have very important spiritual and community implications. In the future, if the impacts of climate change are not properly considered internationally, having a sustainable source of food could be crucial to the continued prosperity of the NRB. A brief overview of key linkages between agriculture and climate impacts follows in Table 7.

[20] Such as organic farming.
[21] Hunting, gathering or catching food from the natural surrounding environment is an extremely sustainable way to procure food.

Table 7 Interactions between climate impacts and agricultural impacts

Climate Impact	Relation to agriculture*	Discussion
A: Ecosystems	Medium	➢ An increase in agriculture could mean more natural areas converted into farmland and/or more waste that can affect natural ecosystems.
B: Water Supply	High	➢ Agriculture can require large amounts of water. ➢ Agricultural outputs (or wastes) can affect water quality.
C: Agriculture and Food Security	Very high	➢ Warmer temperatures lead to longer growing seasons ➢ Droughts, extreme events and unpredictable weather negatively affect agriculture and traditional sources of food.
D: Community Well-being	High	➢ Agriculture is an important source of jobs and helps support many communities in northwestern BC. ➢ Agriculture may become a potential way to offset declines in forestry.

**Refer to Table 4 for an overview of the rating system.*

5.4 Mining

Although mining has not recently been a major economic driver in BC, it is a form of resource extraction that has a rich history in the Province. Just as forestry (and possibly agriculture) seems to be on the decline in BC, mining is rapidly ramping up. According to Northern Development Initiatives (2014), BC currently has Canada's largest mining sector, and it is expanding rapidly. Many people expect that mining will replace forestry in the future as the economic driver of northern BC.

The area in and surrounding the NRB is rich in mineral deposits. Central BC is home to unique geological conditions that have led to high concentrations of molybdenum, gold, silver and/or copper in many locations (Nelson and Bellefontaine, 1996). There are several mines and mining projects located within and near to the Nechako watershed. There has also been a lot of exploration in the region. Major projects in or near the NRB are as follows:

- The **Endako mine**, located west of Fraser lake, is the biggest mining operation in the NRB. It is an open pit molybdenum mine that has been operational since 1965. In 2012 a mill expansion project was completed that replaced the original mill and upgraded the processing capacity (Thompson Creek, 2014).
- The **Huckleberry mine**, located southwest of Houston just north of the Nechako Reservoir, is an open pit copper mine. The mine became operational in 1997. Recently an expansion was approved that will extend the life of the mine to 2021 (Imperial Metals, 2014). There have been conflicts with the Wet'suwe'ten First Nations related to the mine expansion.
- The **Chu Molybdenum Project** is a proposed open pit molybdenum mine 85 km south-southwest of Vanderhoof. If the mine goes forward it will become an open pit mine and

processing area, and will be operational for an estimated 20 years (TTM Resources, 2014).

- *The **Blackwater Gold Project** is near to the NRB, but drains into the Blackwater River (and then the Fraser). It is s a proposed open pit gold and silver mine 110 km southwest of Vanderhoof. If the mine goes forward it would become an open pit gold and silver mine with an estimated 17 year operational life.*

5.4.1 Climate change and mining

There are some interrelationships between the impacts of mining and the impacts of climate change. Mining impacts are very specific to the type of mining, the mine location and how the mine operation is managed and monitored. The impacts of mining can be very serious; however, many of the most serious and ecosystem-scale effects can be largely mitigated by appropriate measures and actions. Therefore mining can have devastating impacts on regional ecosystems, or only have significant impacts near the mining and processing areas.

Regardless of how well a mine is run, an open pit mining operation leads to large changes on the mine site's landscape. Mining areas can potentially affect traditional food sources and agricultural lands by removing habitat (or farmlands), causing noise and disturbances and/or through contamination. As only a small fraction of the material removed is the desired mineral(s), there are large volumes of waste generated. Mine wastes can be acutely toxic to aquatic life at high concentrations (CCMOE, 1999) and lead to surface and groundwater contamination. As mining is a heavily mechanized and labour intensive operation, there are also associated air quality concerns and significant GHG emissions. A brief overview of key linkages between mining and climate impacts follows in Table 8.

Table 8 Interactions between climate impacts and mining impacts

Climate Impact	Relation to mining*	Discussion
A: Ecosystems	Medium	➢ Mining operations can damage and contaminate aquatic and terrestrial ecosystems.
B: Water Supply	Medium	➢ Mining can require large amounts of water. ➢ Mining effluents or wastes can affect water quality.
C: Agriculture and Food Security	Low	➢ Mining and agriculture cannot typically coexist on the same lands (or often adjacent lands). ➢ Mining operations can impact traditional food sources.
D: Community Well-being	High	➢ Mining can be an important source of community employment, revenue and economic diversification. ➢ Depending on the locations, communities may be influenced by presence/absence of work camps.

**Refer to Table 4 for an overview of the rating system.*

5.5 Oil and gas

People began looking for oil and gas deposits in the Nechako watershed in the 1930s, but there has been limited detailed exploration. Recently the Nechako Basin[22] has been highlighted as a region with substantial oil and gas resources[23] (Ferri, 2004). Some of the limiting factors that make oil and gas production difficult in the NRB include the fact that little detailed information is available as only 12 exploration wells have been drilled in the area, the remote and inaccessible locations and that there is very little infrastructure (such as pipelines) available to get the resource to market (Whiticar, 2012). There are also many other basins in BC that have large reserves that are not being developed. Only the Peace region is currently seeing any commercial extraction of oil and gas in BC (Whiticar, 2012).

Another oil and gas-related activity proposed on the landscape is the Enbridge Northern Gateway project. The proposed project would result in two pipelines (one shipping oil westward and one shipping condensate eastward) that would run 1200 km from Bruderheim, Alberta to Kitimat, BC. The purpose of the project is to connect heavy oil mined from Alberta's oil sands to Asian markets. If it is constructed the pipeline would travel directly through the Nechako Watershed (Figures 6 and 7). The Enbridge project has been the subject of heated debate in BC, Canada and internationally. Many First Nations in the NRB have declared opposition to the pipeline and there have been opposition movements in Prince George, Burns Lake and Fort St. James. Major concerns related to the pipeline in the NRB include threats to water quality, aquatic species health (particularly salmon), increased GHG emissions (particularly associated with increased oil sands development) and a lack of proper First Nations consultation and engagement. Some northerners are excited about the project in the hopes that it will 'open up' north-central BC to more oil and gas development.

Figure 6 Map of the proposed Enbridge Northern Gateway pipeline route through Alberta and BC. (Northern Gateway, 2014)

[22] For geologic purposes the Nechako Basin is defined as an area with similar volcanic rocks overlying older sedimentary rock layers. It covers most of the NRB and extends further south.

[23] It is important to note that a resource is different than reserves, as a reserve is the amount of a resource that can be legally and economically extracted and a resource is the total estimated amount. There currently is insufficient information to know what the oil and gas reserves are in the Nechako Basin

Figure 7 Map of the proposed Enbridge Northern Gateway pipeline through the NRB region. (adapted from: Swift et al., 2011)

5.5.1 Climate change and oil and gas

There are many relationships between climate change and oil and gas exploration, exploitation and transportation. Most notably is the fact that the burning of fossil fuels is the main driver (or cause) of climate change (IPCC, 2013). Therefore one could argue that all of the impacts of climate change interrelate at least somewhat with fossil fuels. As there is currently no oil or gas exploitation occurring in the NRB, only a brief overview of these interrelationships presently is provided. That being said, the potential for significant activities and development means that the cumulative impacts of climate change and oil and gas may become a concern in the future. A brief overview of key linkages between oil and gas and climate impacts follows in Table 9.

Table 9 Interactions between climate impacts and oil and gas impacts

Climate Impact	Relation to oil and gas*	Discussion
A: Ecosystems	Low	➢ Oil and gas operations affect the landscapes that they take place upon, and can contaminate ecosystems. ➢ Oil spills can seriously damage aquatic ecosystems
B: Water Supply	Low	➢ Some oil and gas activities demands large amounts of water. ➢ Some gas exploitation requires 'fracking' to occur, which can impact groundwater. ➢ Oil contamination affects water quality.
C: Agriculture and Food Security	Low	➢ Pipelines, wells and other oil and gas facilities can impact traditional food sources. ➢ Exploration activities can impact ungulates (e.g., moose and caribou) by providing hunting opportunities for predators.
D: Community Well-being	Medium	➢ Oil and gas can be an important source of community employment, revenue, economic diversification and socio-demographic change. ➢ As the main driver of climate change, there are many impacts associated with oil and gas.

**Refer to Table 4 for an overview of the rating system.*

5.6 Other

Many 'other' resource-related activities occur on the landscape such as commercial trapping and hunting, fishing and renewable energy exploration. As none of these activities occur on a major commercial scale at this point in time, they are not overviewed in detail.

Tourism is another activity that occurs on the landscape and relies on the natural environment. Hunting, trapping and fishing (both guided and unguided) are important sources of jobs and economic opportunity. There is also a plethora of non-consumptive activities that can occur on the landscape, including:

- Snowshoeing, snowmobiling, cross country skiing, downhill skiing, dogsledding and skating in the winter; and
- ATVing, mountain biking, hiking, swimming, canoeing, kayaking, motorboating, birdwatching, sailing and camping in the summer.

All of these activities are important for tourism as well as recreation. Recreation is the same as tourism, but it refers to people engaging in activities close to home. Although recreation does not typically produce as much revenue as tourism (as people typically do not require accommodation, guides or rental equipment, or purchase souvenirs), it has important benefits related to health, well-being, community pride and general quality of life. Many people in the NRB *(the authors included!)* have made conscious decisions to live in the NRB specifically because of the myriad of recreation activities available and opportunities to engage with nature.

5.7 Visualizing impacts and looking into the future

Climate change, and climate impacts, is an incredibly complex subject and challenge. Resource development, and development impacts, is an equally complex subject and challenge. Therefore it is exceedingly difficult to look at how these two sets of impacts interact with each other. This report is an exploration into this concept and challenge. The tables in sections 5.1 to 5.6 have provided an assessment of the degrees of interaction. A major outcome of the workshop with the members of the NWA in March 2014 was that the tables we provided do not effectively visualize these interactions, and do not take into account future changes in the potential degree of interaction.

In response to this feedback we attempted to visualize the degree of interaction in many different ways. Ultimately, in our opinion, spider diagrams[24] proved to be the most effective tool. Spider diagrams are like graphs that show the relationships between a concept (a type of resource development in this case) and a number of different categories (climate impacts in this case). The resulting shapes of the diagrams can be easily comparable and may help lead to important insights. Ideally, the diagrams have five or more axes, but in this case they only have four.

The spider diagrams also convey any potential increase in the degree of interaction, as determined by the NWA. (Please note that the degree of interaction for some could decrease, but that this was not discussed in detail and thus has not been graphed.) For the purposes of this exercise the future is loosely defined as the period around 2050, or in approximately 35 years. The area and shape of the spider diagram reflects the relevance of the different impacts to the type of resource development. *Refer to Table 4 for an overview of the rating system.*

[24] Spider diagrams are often called radar charts as well

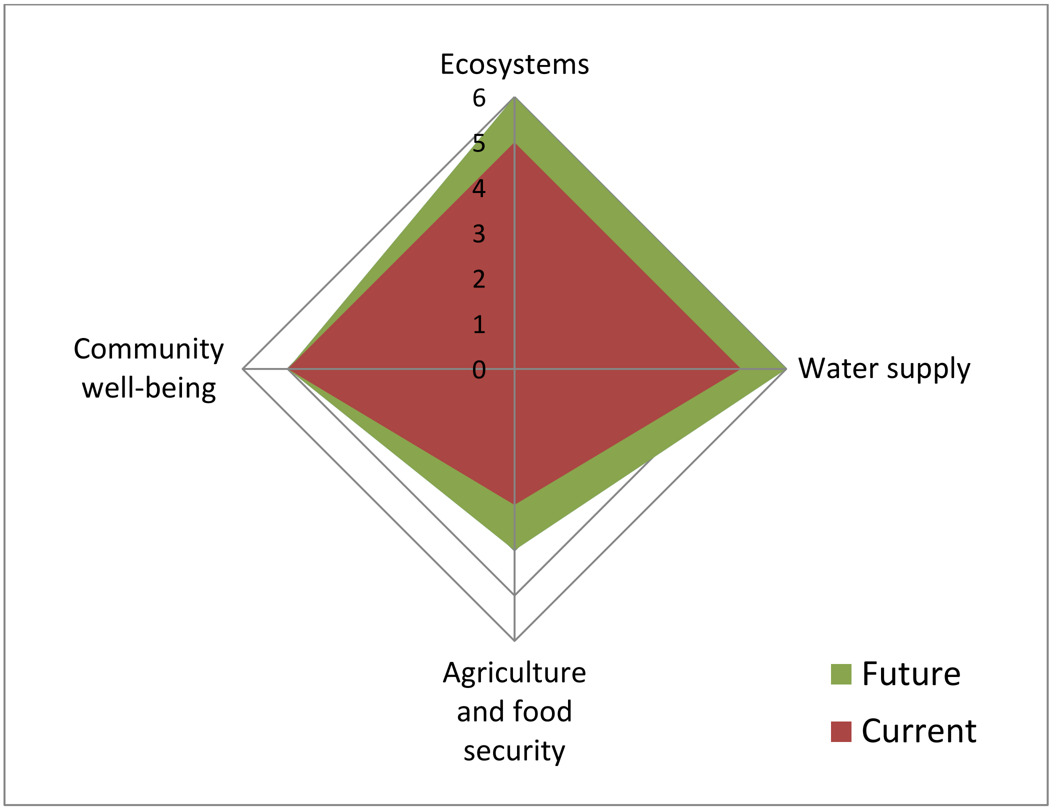

Figure 8 Spider diagram depicting the interaction between hydro-electric development and climate impacts in the NRB. The red area depicts the current interaction and green areas indicate any projected increases.

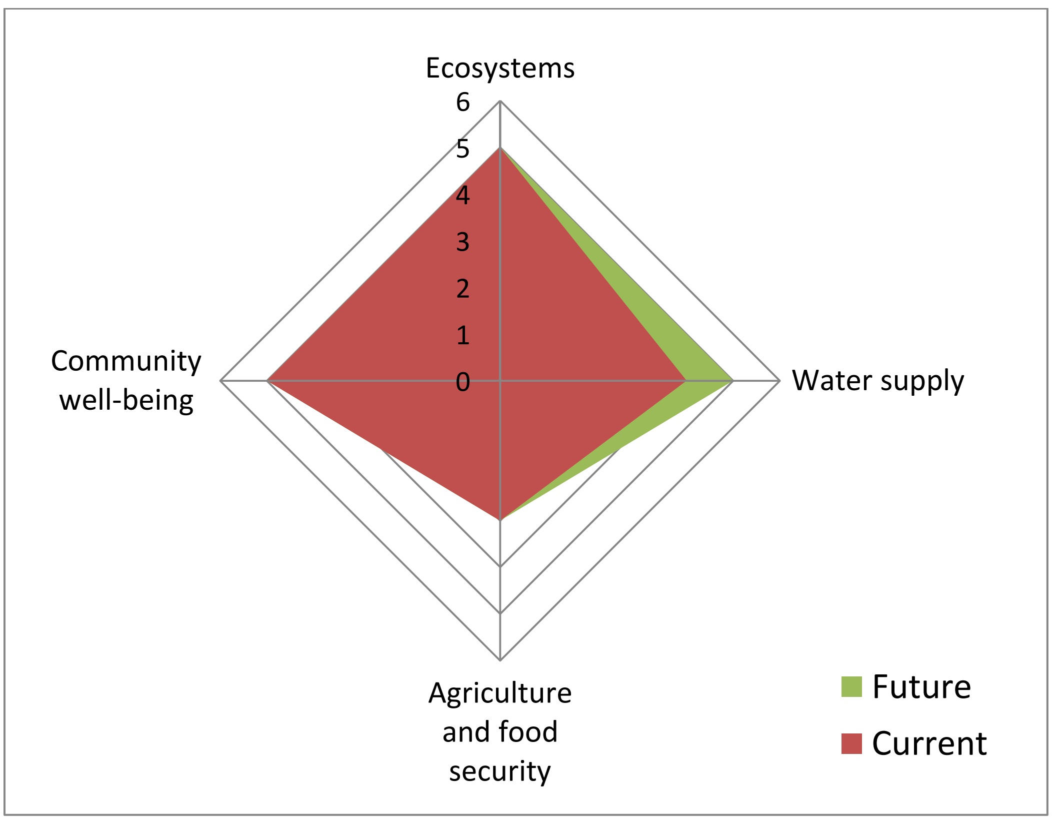

Figure 9 Spider diagram depicting the interaction between forestry and climate impacts in the NRB. The red area depicts the current interaction and green areas indicate any projected increases.

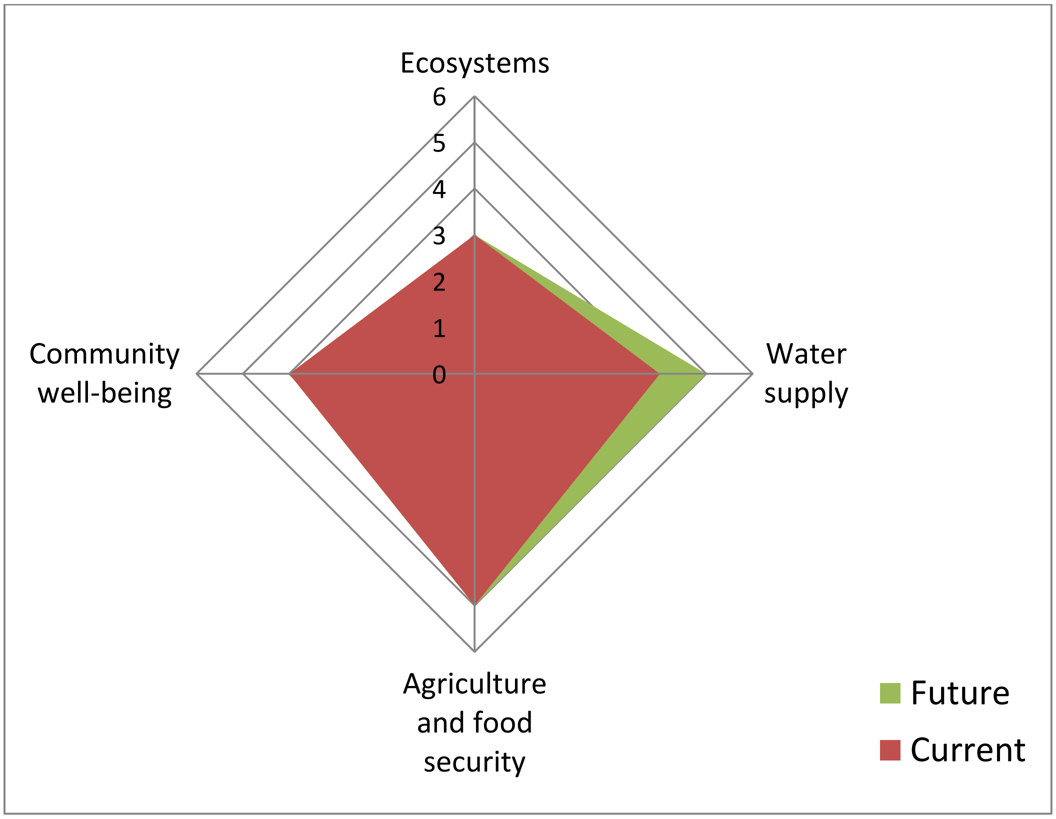

Figure 10 Spider diagram depicting the interaction between agriculture and climate impacts in the NRB. The red area depicts the current interaction and green areas indicate any projected increases.

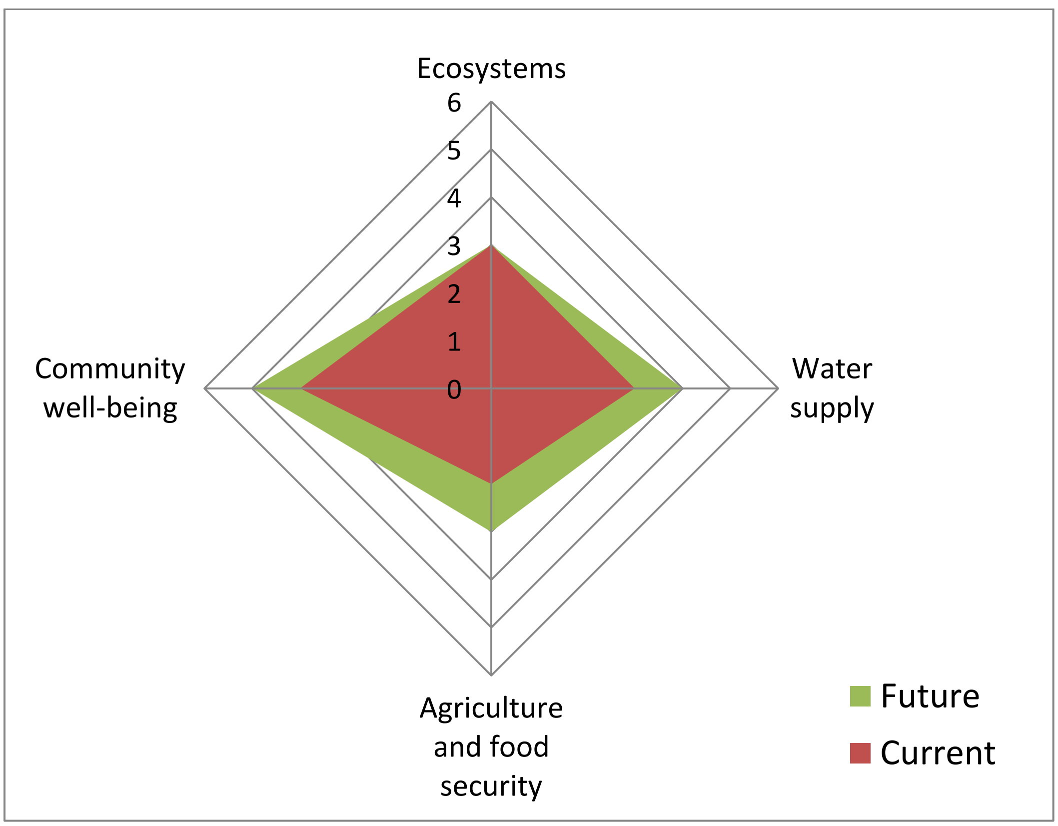

Figure 11 Spider diagram depicting the interaction between mining and climate impacts in the NRB. The red area depicts the current interaction and green areas indicate any projected increases.

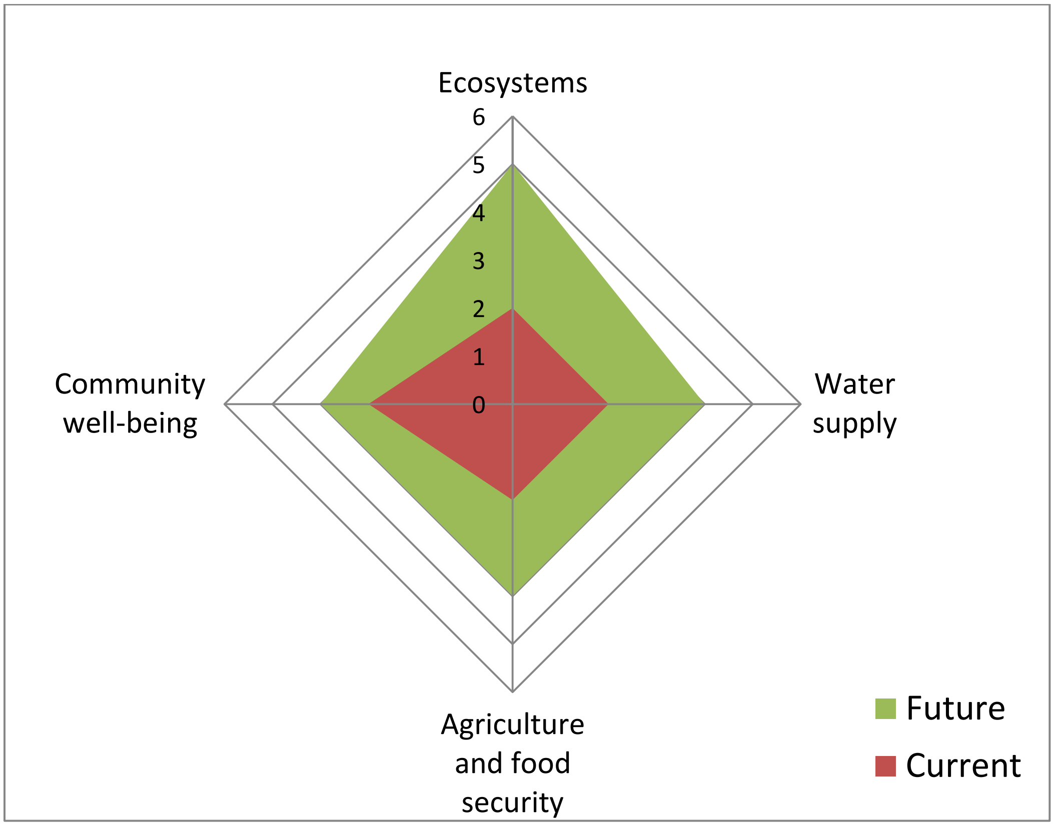

Figure 12 Spider diagram depicting the interaction between oil and gas and climate impacts in the NRB. The red area depicts the current interaction and green areas indicate any projected increases.

Both the current and future degrees of interraction show that all of the major types of resource development in the region have a close relationship and a large interraction with the impacts of climate change. Ongoing research on this subject should include a more comprehensive assessment of future interractions. Particularly, any future decreases in interraction could also be noted and represented.

6. Discussion: Understanding climate change and resource impacts in the Nechako

Thinking about the '*big picture*' can be challenging. For many people climate change is a strange idea and/or distant, global phenomenon that is so '*big'* and so confusing that it is hard to imagine how it impacts their daily lives. This report has focused on '*grounding'* the realities of climate change within the practical day-to-day realities of changing landscapes of the Nechako River Basin. We have explored ways in which climate change has the potential to affect everything around those of us who live and work within the NRB. Climate change directly influences what is important in our daily lives via impacts to ecosystems, water supply, agriculture and food security, and community well-being.

Understanding these interactions help to show how the '*big picture'* of climate change is also relevant to all aspects of natural resources management. Although individuals, industries and governments may tend to view developments and projects (and even climate change) as separate events or issues, it is extremely important that we do not forget how single projects (or single issues) will combine and influence each other over time. This is particularly true in large, relatively unpopulated areas like northern BC: how could one project have an impact on such a great wilderness? In the past, when resource development was beginning in the region, considering projects or issues in isolation was not a major problem. These days, when we consider the speed of change and development all around us, it is especially important to be mindful of all of our actions and their direct and indirect consequences.

This way of thinking has recently led to a focus on considering the **cumulative** (or combined) **effects** of our actions and their resultant **cumulative impacts**. This report has highlighted how individual projects or activities could have a *cumulative* effect when considered along with other past, existing and future changes or activities. Even areas with small human populations, it is important to consider the combined effects of air pollution, water pollution, climate change, tourism and other human activities. Actions that occur in northern BC can also have implications in different regions and other parts of the world, and vice versa. A large amount of the hydro-power generated in BC is sold to the United States to fulfill electricity demands at peak times. The Kemano project itself is owned by an Australian company. Oil from Alberta may pass through the NRB to be shipped across the Pacific Ocean to China.

Climate change is a case-in-point example of how difficult it is for humans to consider and acknowledge the effects of our actions across time and space. Although the concepts of past and future climate change and climate impacts are relatively new, over the last 30 years the scientific consensus on climate change has strengthened. Along with this growing understanding is increasing attention to the importance of responding to climate change through both adaptation and mitigation (e.g., Picketts, 2013; Déry et al., 2012; Rodenhus et al., 2009; Walker and Sydneysmith, 2008; Stern, 2006). In this report, we have sought to highlight how important it is to understand climate change in relation to other influences on landscape change. In earlier tables we made a preliminary assessment of the interrelationships between different resource-related activities and climate change (Table 5-hydro-power and climate impacts; Table 6-forestry and climate impacts; Table 7-agriculture and climate impacts; Table 8-mining and climate impacts; and Table 9-oil and gas and climate impacts). Table 10 provides a summary of these interactions.

Table 10 Overview of relationships between types of climate impacts and types of resource development in the Nechako River Basin.

	A: Ecosystems	B: Water Supply	C: Agriculture and Food Security	D: Community Well-being
Hydro-electric power	Very High*	Very High*	Medium*	Very High
Forestry	Very High	High*	Medium	Very High
Agriculture	Medium	High *	Very High	High
Mining	Medium	Medium*	Low*	High*
Oil and gas	Low*	Low*	Low*	Medium*

*These values are all projected to increase in the future.

The purpose of Table 10 is to help to identify and discuss some '*pinch points*' or topics of concern. Through this exercise we can begin to better understand what is at risk, how we can proactively minimize negative impacts and how we can capitalize on any opportunities. It can also serve to help prioritize short term and long term actions. This is an exploratory exercise: therefore, these topics have to be further analyzed and studied. Even a simple table (such as Table 10) highlights the need to focus on the interactions among these sectors, and the benefits of proactive approaches that take the interactions among different resource development into account prior to making decisions about the future. Moving forward there needs to be further engagement and research to identify and prioritize thresholds and acceptable levels of change. One potential course of action is to develop future scenarios that could help establish understand the future consequences of growth, development and climate change in the changing landscapes of the Nechako.

If we begin to consider the Nechako watershed as a whole, we can understand the types of resource-related development that have occurred and their implications. We also now have information available to understand climate change and its impacts on the Nechako watershed. The purpose of this report has been to explore these complex ideas, and to ponder about how they may interrelate. This information should be applied and built upon by citizens, scientists and managers to strengthen the understanding of what the cumulative effects of resource development and climate change may be, and to plan accordingly. Decision makers must be proactive in thinking about how change, growth and development in the region can and should proceed so that the Nechako Watershed is environmentally, socially, culturally and economically sustainable.

Glossary:

Adaptation: responding to (or preparing for) the effects of climate change. Adaptations can be made by natural systems, individuals, communities and/or higher orders of government.

Climate change: long term changes (generally over at least 30 years) in temperature and precipitation regimes, and/or the number of and severity of events.

Climatic variability: changes in temperature and precipitation regimes, and/or the number of and severity of events, over periods of weeks to years.

Community well-being: the general state of the quality of life of people in a community. Many interrelated factors determine well-being including environmental factors (e.g., clean water and access to nature), economic factors (e.g., secure jobs and access to resources), socio-cultural factors (e.g., community cohesion, identity, freedom of choice and respect) and health (which also depends on all factors). Community well-being therefore combines security, basic material for a good life, freedom and choice, good social relations and health (MEA, 2005).

Cumulative effects: the combined results or outcomes of activities. These can include past, present and future activities and effects on economic, social, environmental or cultural systems.

Cumulative impacts: changes or influences on economic, social, environmental or cultural systems caused by the combination of actions.

El Niño Southern Oscillation (ENSO): a source of climate variability that affects BC on scales of about 2-7 years. It is associated with warm waters in the southern Pacific Ocean (El Niño) or cool waters (La Nina).

Greenhouse gases (GHGs): atmospheric gases that absorb and emit solar radiation, and affect the temperatures of earth. The primary GHGs are water vapour, carbon dioxide, methane, nitrous oxide and ozone.

Intergovernmental Panel on Climate Change (IPCC): an international scientific body that studies and encourages responsible action on climate change. It was established by the World Meteorological Organization (WMO) and the United Nations Environmental Programme (UNEP) in 1988, and is releasing its 5th assessment report in late 2013 and 2014.

Interior Plateau Region: A large, heavily forested and rolling area in the interior of BC that lies between the Caribou Mountains on the east and the Coast Mountains on the west. (Please note that not everyone defines the interior plateau region in the same way.

Mitigation: refers to actions the limit long term climate change by reducing the concentration of GHGs in the atmosphere. This is done reducing the amount of GHGs emitted, or by enhancing earth's ability to sequester GHGs by increasing the capacity of carbon sinks (such as forests).

Omineca region: refers to the north central interior section of BC: and can be generally considered to be the area northwest of Prince George. Its boundaries are similar to the interior plateau. It is named after the Omineca River, and is named and defined after the Omineca gold rush in the 1860s.

Pacific Climate Impacts Consortium (PCIC): is a group based out of the University of Victoria that specializes in using, and helping people to use, climate information and climate models to help make decisions about climate variability and climate change.

Projection: a description of the future that allows for certain conditions to develop (such as increases in GHG emissions). Therefore, projections are expectations that are conditional on certain things happening.

Prediction: a statement that something will happen or has a chance of happening in the future based on what is known today. A prediction is very similar to a forecast

Pacific Decadal Oscillation (PDO): a source of climate variability that affects BC on a scale of about 20 to 30 years. It is associated with cool temperatures in the west Pacific Ocean and warm temperatures in the East Pacific Ocean (warm PDO phase) or warm temperature in the West Pacific Ocean and cool temperatures in the East Pacific Ocean (cool PDO phase).

Scenario: A plausible description of a possible future. Scenarios are often based on a range of projections.

Snow water equivalent (SWE): is a common measurement of the amount of water, expressed as the depth, contained in a snowpack. It is a product of the snowpack depth and the snow density.

Traditional Ecological Knowledge: is commonly referred to as 'TEK'. It refers to the knowledge, beliefs and practices that are passed down through generations by indigenous peoples of a region.

University of Northern BC (UNBC): a university that was established in BC in 1990. Its main campus is in Prince George, and regional campuses are located in Prince Rupert, Terrace, Quesnel and Fort St. John. The university's mandate is 'in the north for the north', and it is committed to teaching and research that benefits northern peoples and communities.

Variable Infiltration Capacity (VIC) model: is a complex hydrologic model that considers interactions between soil, vegetation and the atmosphere. The VIC model calculates water and energy balances in a grid cell with variability of the soil column, land surface vegetation classes and topography represented statistically.

Vulnerability: generally refers to the susceptibility of a system. It is a common term in climate change studies that refers to the extent to which climate change may affect a system (or community). Vulnerability depends on how sensitive a community is to changes, and also how able they are to adapt to new conditions.

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