CHAPTER 3: **NATURAL RESOURCES**

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KEY FINDINGS

Natural resources are an integral component of Canadian livelihoods and national and regional economies, and will continue to be in future. While the biophysical impacts of climate change of relevance to most natural resource sectors are well understood, integration of these impacts into business planning is generally lacking. Key findings arising from recent literature relating to forestry, mining and energy – the sectors considered in this chapter – include:

- Climate change will exacerbate existing climate risks related to the planning and management of natural resource sector industries, including activities associated with exploration, development, operation, distribution, closure and reclamation/rehabilitation. These risks relate to impacts and natural hazards associated with climate extremes (e.g. heat, cold, precipitation) and to slow-onset events such as permafrost degradation, sea level rise, and plant species migration. Climate change will also present new opportunities for the natural resource sectors, particularly in relation to northern economic development.

- Consideration of multiple stressors is critical to understanding adaptation in the natural resource sectors. Climate change itself is rarely identified as a priority concern, with industry focused on other immediate stressors, such as economic drivers. Nonetheless, there are opportunities to integrate consideration of climate change into existing planning processes.

- Environmental assessment, risk disclosure, and sustainable forest management reporting are examples of processes that can help advance adaptation actions in future. These processes allow governments, investors and the public to evaluate industry understanding of changing climate risks and influence the steps taken to address those risks.

- While awareness of climate change impacts and implementation of adaptation actions is most evident in sectors where there is a clear and direct relationship between climate and resource supply, notably forestry and hydroelectricity, the application of adaptive management approaches to address climate change impacts is seen across all natural resource sectors. Adaptive management approaches involve ongoing research, monitoring and evaluation with the intent of informing future management policy and practices, and allowing for flexibility in the face of the uncertainties inherent in climate change.

1. INTRODUCTION

Canada possesses an abundance of natural resources that are integral to Canada's history and identity, and that constitute a significant component of national, provincial and territorial economies. This chapter focuses on three natural resource sectors – forestry, mining and energy – which together directly account for 13.3% of Canada's gross domestic product and provide almost 950 000 jobs (Table 1; Natural Resources Canada, 2013a).

	Forestry	Mining	Energy	Total
GDP (2013)	1.1%	3.5%	9.1%	13.3%
Direct Employment	224 410	401 315	335 580	948 735
Domestic Exports	$25B	$90B	$119B	$224B

TABLE 1: Contribution of the natural resource sectors to the Canadian economy in 2012 *(Source: Natural Resources Canada, 2013a).*

The economic significance of natural resources is magnified at the local scale. Resource-reliant communities are mostly small and remote, but also include large and medium-sized cities like Calgary in Alberta, Hamilton and Sudbury in Ontario and Prince George and Kamloops in British Columbia. Some communities are considered to be solely reliant on natural resources, deriving 80% or more of employment income from natural resource activities (Natural Resources Canada, 2009).

The climate sensitivity of natural resource development depends on the sector considered. The impacts of changing climate on economic output and productivity are most evident for forestry and hydroelectricity. All natural resource sectors face climate risks, many of which are related to extreme weather events and associated natural hazards, during exploration, development, processing, transportation and rehabilitation/decommissioning activities (e.g. Lemmen et al., 2008a). Investments by natural resource industries over the next decade will provide an opportunity to integrate climate change considerations in order to enhance the climate resilience of future operations. Over 600 major resource projects are planned for development in Canada over the next decade, representing about $650 billion in investment (Natural Resources Canada, 2012a).

This chapter provides an overview of progress made in understanding the impacts of changing climate on forestry, mining and energy sectors in Canada, and on the sectors' advances in adapting to these impacts. This overview draws predominantly on material published since the release of *From Impacts to Adaptation: Canada in a Changing Climate* (Lemmen et al., 2008a). Following a brief review of key findings from previous assessments, this chapter presents individual sections on forestry, mining and energy. Recent research strengthens confidence in previous findings and provides new insights. Particular attention is paid to advancements in adaptation, recognizing the wide range in levels of engagement across sectors (from increasing awareness to implementing policy and operational changes). The chapter concludes by drawing together the findings pertaining to forestry, mining and energy for an integrated perspective of natural resources as an economic sector and the implications of climate change impacts and adaptation actions on economic competitiveness in the short and long term. Other aspects of natural resources are addressed in chapters 4 (Food Production), 5 (Industry) and 6 (Biodiversity and Protected Areas) of this report.

2. PAST ASSESSMENTS

Natural resources figure prominently in all regional chapters of *From Impacts to adaptation: Canada in a Changing Climate* (Lemmen et al., 2008a), as well as in Chapter 9 (Canada in an International Context) of that report (Table 2). The vulnerability of resource-reliant communities is a key conclusion of national significance emerging from that report. This vulnerability is a reflection of the high climate sensitivity of many natural resource-based industries, limited economic diversification and, in many cases, restricted access to services (Lemmen et al., 2008b). This vulnerability is magnified in the Arctic, where the magnitude of climate change has been and is projected to remain the greatest, and because of the remoteness of communities and many natural resource operations.

The fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC) addresses forestry and energy in thematic chapters (Easterling et al., 2007; Fischlin et al., 2007; Wilbanks et al., 2007), in the North America chapter (Field et al., 2007), and in the chapter exploring linkages between climate change adaptation and mitigation (Klein et al., 2007). While there is no integrated analysis of the vulnerability of the natural resource sectors, the report does highlight the importance of understanding multiple stressors on natural resource industries (Easterling et al., 2007).

	North	Atlantic Canada	Quebec	Ontario	Prairies	British Columbia	International
Forestry	X	X	X	X	X	X	X
Mining	X		X	X	X		X
Energy demand		X	X	X	X	X	X
Energy supply	X	X	X	X	X	X	X

TABLE 2: Content relating to natural resources within specific chapters of *From Impacts to Adaptation: Canada in a Changing Climate (Lemmen et al., 2008a)*.

FORESTRY

Due to their northern location, Canada's forests are exposed to greater increases in temperature than the global average (IPCC, 2007) with significant impacts varying across the country. Key findings of past assessments (Lemmen et al., 2008a; Lemprière et al., 2008, Johnston et al., 2009; Williamson et al., 2009) suggest that:

- Increases in disturbance regimes (e.g. forest fires, pest and disease outbreaks) are already evident and will become more pronounced in future.
- Forest composition will change due to shifting climatic and disturbance regimes.
- Forest access will be impacted by changes in disturbance regimes, shifting infrastructure costs, and shorter winter harvesting seasons due to reduced periods of frozen ground.
- Net impacts of climate change on forest productivity will be regionally and locally specific. Productivity could be positively impacted by warmer temperatures, longer growing seasons and increasing CO_2 levels where other factors (e.g. soil, water or nutrients) are not limiting, but will be negatively impacted by increased drought and more frequent and severe disturbances and extreme weather events.
- Social and economic impacts on forest-based communities (e.g. safety and security costs, forest sector jobs and tourism) will be significant in some regions.

MINING

Mining received less discussion than the other natural resource sectors in Lemmen et al. (2008a), reflecting the literature available at that time. Nonetheless, the report noted challenges to site selection, mine design, development and operations, and transport, as well as final closure and site remediation in a changing climate. Key findings suggested that:

- Extreme weather events have already negatively affected some mine operations.
- Significant vulnerabilities to climate change exist in post-operational mines, with implications for the environment and surrounding communities.
- Reductions in Arctic sea ice could lead to new opportunities for mining exploration and development in the North, related in part to decreased shipping costs. There are also challenges associated with operating in the Arctic environment, including issues surrounding environmental safeguards and social inclusion.
- Decreased viability of winter roads could affect access to many northern mine sites, and necessitate the development of alternative transport routes.
- Mine design and operational changes are likely necessary to manage the risks of environmental contamination related to permafrost degradation in the North, and the impacts of extreme weather events elsewhere.
- Many recent major mining developments in northern Canada have taken projected climate impacts into account in their design plans.

ENERGY

Adapting to climate-related changes in energy demand and supply is a challenge for the energy sector across Canada. Specific vulnerabilities vary by geographic setting, primary energy sources and projected changes in climate. Key findings from Lemmen et al. (2008a) indicate that:

- Seasonal energy demand will shift, with decreased demand for winter heating and increased demand for summer cooling.
- Supply-demand mismatches are possible since peak summer demand for cooling may coincide with decreased hydroelectric potential in some areas.
- Hydroelectricity generation may be affected by seasonal reductions in water supply, particularly in glacier-fed systems. Accommodating changes in timing of flow and peak events will likely require adjustments in reservoir management practices.

- Transmission of electricity is sensitive to increased temperature (greater energy losses) and extreme weather (infrastructure damage leading to distribution grid failure).
- Permafrost degradation and associated land instability will pose a risk to energy infrastructure (foundations, pipelines and roads) in northern Canada.

3. FORESTRY

Canada is a forest nation, with forests covering more than 50% of the country's landmass (Figure 1; Natural Resources Canada, 2011a). Change in Canada's forested land is driven primarily by large-scale disturbance regimes, with fire and pest outbreaks affecting 5% of the forested area annually (Natural Resources Canada, 2011a). Climate is a key determinant of forest distribution, composition, productivity, dynamics and disturbance regimes. As such, climate change is projected to have far-reaching consequences for Canada's forest sector.

In addition to the direct economic benefits provided by the harvest of timber and fibre (Natural Resources Canada, 2012a), forests provide recreational and cultural value, as well as non-timber forest products such as mushrooms and berries. Ecosystem services provided by forests, such as clean air and water, carbon storage and soil nutrients, also have social and economic value, although this is difficult to quantify.

Provincial and territorial governments have legislative authority over the land and resource management of 77% of Canada's forests, with each province and territory setting its own policies, legislation and other regulatory matters. The

FIGURE 1: Forest regions of Canada *(Source: Natural Resources Canada, 2000).*

federal government has jurisdiction over 16% of the forest, and the remaining 7% of forests are privately owned among more than 450 000 landowners. Less than 0.2% of Canada's forests are harvested annually (Natural Resources Canada, 2012b). The Canadian forest sector has made a commitment to sustainable forest management (SFM), and Canada is a global leader in forest certification with over 90% of the managed forest certified under one or more of the SFM standards (Natural Resources Canada, 2011b; Box 1).

This section provides an update of key findings related to climate change risks, opportunities and adaptation of importance to the forest sector. Other aspects of Canada's forest ecosystems are covered in Chapter 6 (Biodiversity and Protected Areas) of this report.

BOX 1

SUSTAINABLE FOREST MANAGEMENT (SFM) IN CANADA

Sustainable forest management (SFM) is defined as "management that maintains and enhances the long-term health of forest ecosystems for the benefit of all living things while providing environmental, economic, social and cultural opportunities for present and future generations" (Natural Resources Canada, 2012b). SFM promotes the responsible management of forests as a resource (e.g. for timber, services), while also protecting their continued health and diversity.

In Canada, a national framework consisting of a series of criteria and indicators has been developed by the Canadian Council of Forest Ministers (CCFM) to describe, monitor and report on trends and progress towards sustainable forest management. This includes measures pertaining to biological diversity, ecosystem condition and productivity, soil and water conditions, economic and societal benefits, and community involvement and responsibilities. Canada uses the Criteria and Indicators Framework at a national level to report on progress toward SFM in the State of Canada's Forests Annual Report (Natural Resources Canada, 2012b).

Sustainable forest management is also supported by the provinces and territories through policy and legislation, and by forestry organizations through voluntary third party certification. Canada leads the world in voluntary sustainable forest management certification; as of December 2011, close to 151 million hectares of forest had been certified through the three SFM certification programs in use in Canada (FPAC, 2012).

3.1 OBSERVED AND PROJECTED IMPACTS

Impacts of climate change on forests and the forest sector have already been observed in Canada. The most visible climate-related impacts are the changes in disturbance regimes, such as fire and pest outbreaks, and those associated with extreme climate events such as drought, windstorms and ice storms (Lemprière et al., 2008; Williamson et al., 2009), which can have immediate social and economic consequences. However, subtle impacts such as changes in tree species composition, phenology and productivity are increasingly being reported (Johnston et al., 2009) and will impact the forest sector on a longer time scale.

FIRE

Fires are a natural driver of Canada's forest dynamics, with over three million hectares of forested land burned in 2009 (Natural Resources Canada, 2011a). The occurrence, extent and severity of forest fires are projected to increase in most regions of Canada with continued climate change. Increases of between 75% and 140% in the number of fires have been projected by the end of the 21st century, with significant regional variation (Wotton et al., 2010), while projections of the area burned in western Canada show a three to five-fold increase by the end of the 21st century, relative to 1991-2000 (Balshi et al., 2009). Climate change will also affect the timing of the fire season, with an earlier onset and a later seasonal peak in fire weather (Le Goff et al., 2009). Changes in fire regimes have already been observed. Since the 1980s, large fires have increased significantly in northwestern (Kasischke and Turetsky, 2006; Girardin, 2007) and northeastern (Le Goff et al., 2007; Ali et al., 2012) Canada.

PEST EPIDEMICS AND DISEASES

Forest insects and pathogens are major disturbance agents that annually affect millions of hectares of forest in Canada (Natural Resources Canada, 2011a). The survival and spread of pests and pathogens is influenced by climate, and projected climate changes are anticipated to alter their geographical distribution and life cycle. Given that several pests and pathogens are currently limited by winter temperatures, the range and severity of diseases and pest outbreaks are likely to increase as winter temperatures rise (Lemprière et al., 2008; Johnston et al., 2009; Williamson et al., 2009).

The devastating mountain pine beetle outbreak in Canada's western forests has been widely attributed to higher winter temperatures along with other contributing factors (*see* Case Study 1). The forest tent caterpillar, spruce budworm, and spruce bark beetle are three additional forest pests that currently impact Canada's forests, and are likely to continue to damage forests in the future (Price et al., in review). The ability to predict the effects of climate change on forest diseases is limited due to the multiple factors involved: the disease organism, the method of spread (e.g. wind, insects), and the host species. However, pathogens that are currently widespread are likely to continue to affect Canada's forests in a warming climate (Sturrock et al., 2011).

DROUGHT AND OTHER EXTREME WEATHER EVENTS

Globally, the frequency, duration and severity of drought and heat stress are projected to increase with climate change (Price et al., *in review*). Forested ecosystems may already be showing a drought-related increase in tree mortality globally (Allen et al., 2010), in the United States Pacific Northwest (Van Mantgem et al., 2009) and in Canada's boreal forests (Peng

CASE STUDY 1

THE MOUNTAIN PINE BEETLE OUTBREAK

Among the most dramatic impacts of climate change on Canada's forests is the mountain pine beetle (*Dendroctonus ponderosae*) outbreak in the western part of the country. The mountain pine beetle is an endemic insect of western North American pine forests, whose populations periodically increase to create large-scale outbreaks. In Canada, mountain pine beetle populations have historically been controlled by extreme winter temperature events (colder than -35 °C over several days or weeks), especially in early winter (BCMFLNRO, 2012), resulting in relatively moderate impacts on western pine forests. These cold events have become less frequent in recent years, allowing beetle populations to expand to unprecedented numbers. The abundance of mature lodgepole pine following decades of reduced area burned by fire (linked to fire suppression practices and reduced fire weather) may also have contributed to the widespread outbreak, which in 2008 was evaluated as being one order of magnitude larger in area and severity than all previous recorded outbreaks (Kurz et al., 2008; Girardin and Wotton, 2009; BCMFLNRO, 2012).

As of 2012, approximately 18.1M hectares of mature lodgepole pine-dominated forest have been affected by the mountain pine beetle, and climate change is likely a key contributing factor to the extent and severity of this outbreak (BCMFLNRO, 2012). To address the salvage of dead pine, annual allowable cuts were initially increased in the severely impacted areas, and have subsequently been reduced in several Timber Supply Areas where the annual kill has declined rapidly. As the timber supply begins to decline, output from BC forests and manufacturing sector will also decline and could lead to the loss of jobs for thousands of workers, employed both directly and indirectly by the forest sector (e.g. International Wood Markets Group BC, 2010).

The primary host of the mountain pine beetle is lodgepole pine (*Pinus contorta*); however, the beetle can also attack jack pine (*Pinus banksiana*) which ranges from Alberta to Nova Scotia (Burns and Honkala, 1990). There is concern that if climatological barriers are further reduced, the beetle could spread across Canada's boreal forests. However, unlike lodgepole pine, jack pine populations are scattered across the landscape, which may limit the mountain pine beetle's capacity to migrate to new stands and thus reduce the potential for a massive outbreak expanding to the eastern part of the country (Cullingham et al., 2011). The peak of the current outbreak is generally considered to have passed, although the pest range is still expanding (BCMFLNRO, 2012). Since 2008, the expansion has continued both northward and eastward into the boreal forest (Figure 2). In 2011, the beetle was found about 80 km from the Yukon border, and newly-attacked trees have been reported in northern parts of Alberta, not far from the Saskatchewan border (Cullingham et al., 2011).

Over the ten year epidemic, the BC and federal governments invested hundreds of millions of dollars to reduce the impact of the outbreak, to develop new markets for salvaged pine, and to create economic strategies for the future (BCMFLNRO, 2012). Initially, the focus was on limiting the spread of infestation and harvesting infested and susceptible stands. As the outbreak continued, efforts to use the beetle-killed wood intensified (BCMFLNRO, 2012). An example is the use of wood stained blue by the fungus introduced by the beetle for interior panelling (Zaturecky and Chiu, 2005). Salvage wood is also used as a source of bioenergy (BCMFLNRO, 2012).

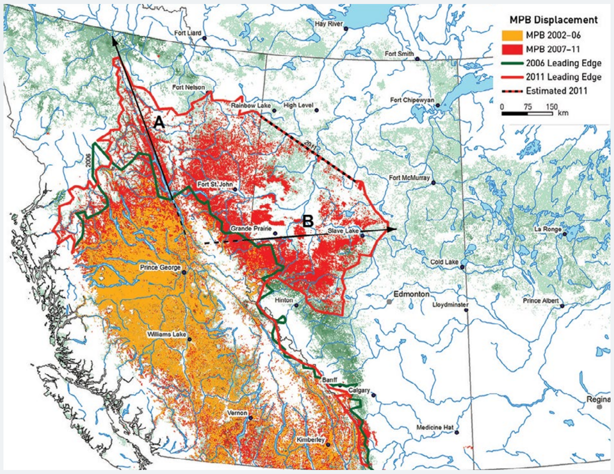

FIGURE 2: Map of Mountain Pine Beetle distribution, showing change for the 2002-06 and 2007-11 time periods and direction of change *(Source: Natural Resources Canada 2012c).*

et al., 2011). In the prairie region, drought was exceptionally severe during 2001-2002, resulting in dramatic dieback and decline in trembling aspen populations, with mortality increasing by over 20% compared to the long-term average (Michaelean et al., 2011). Moisture availability has also been linked to growth and productivity of forests, with moisture stress decreasing annual radial growth across a range of sites and species, including white spruce, black spruce, trembling aspen, and lodgepole pine (Barber et al., 2000; Chhin et al., 2008; Girardin et al., 2008; Hogg et al., 2008).

Extreme wind events are projected to increase with continued climate change (e.g. Haughian et al., 2012). Examples of forest impacts caused by extreme winds include widespread damage to both public forest land and private woodlots across Nova Scotia caused by Hurricane Juan in the fall of 2003 (McGrath and Ellingsen, 2009), and the destruction of old-growth and young forest stands across the lower mainland of British Columbia from a December 2006 windstorm that affected over 40 hectares in Stanley Park, a key outdoor recreation destination in Vancouver. While park restoration costs following the storm have exceeded $10 million, restoration efforts were used as an opportunity to increase public engagement and to replant for a more resilient forest (City of Vancouver, 2012).

CHANGES IN COMPOSITION

Species distribution is strongly influenced by climate. As climate changes, the climatic envelopes of Canadian tree species are shifting northward in latitude and upslope in altitude (*see* Chapter 6 – Biodiversity and Protected Areas). Although there is high uncertainty in range-shift projections (McKenney et al., 2011), the rate of shift in the climatic envelopes of most North American tree species could be at least one order of magnitude faster than their potential migration speeds (McKenney et al., 2007; McKenney et al., 2011), raising concerns that species will not be able to keep up with their climate niche. Additional local stress factors, such as drought, disturbance and competition with existing species, could interact with climatic factors to reduce their migration potential, creating an even greater discrepancy between the shift in climatic niche and actual species distribution (Mohan et al., 2009).

CHANGES IN PRODUCTIVITY

Growing seasons have lengthened over the past few decades, with spring phenological events such as bud burst and needle dehardening taking place earlier in the year. For example, trembling aspen bloom dates in Alberta advanced by two weeks between 1936 and 2006 (Beaubien and Hamann, 2011). Warmer climates and longer growing seasons may benefit populations in the northern portion of the species range, as evident in trembling aspen populations in eastern Canada (Lapointe-Garant et al., 2009). More southerly populations may show neutral or reduced growth under warming conditions (Ma et al., 2012), and may only show enhanced growth under ideal conditions and when trees are young (Girardin et al., 2012). Early growing seasons may also increase the risk of exposure to frost (Beaubien and Hamann, 2011), limiting productivity benefits. Increased atmospheric CO_2 concentrations may also result in moderate increases in productivity in very limited situations, such as sites where water and nutrients are not limiting and where competition is low (Soulé and Knapp, 2006; Wang et al., 2006).

SOCIO-ECONOMIC IMPACTS

The combined impacts of climate change on forests affect the quality and quantity of timber supply, with significant financial impacts on the forest industry (NRTEE, 2011). These impacts will exhibit strong regional variations, with potential costs resulting from reduced timber supply (Ochuodho et al., 2012) and shortened winter harvesting seasons (when operating costs are lower and soil disturbances are minimized; Johnston et al., 2009; Ogden and Innes, 2009). Economic consequences also extend beyond impacts on timber supply, as climate change will also affect industries that rely on forest harvests, such as manufacturing and construction. Lempriere et al. (2008) provided a summary of short, medium and long term climate change impacts on the quantity and quality of timber supply in Canada and on international supply and demand.

Forest fires threaten human health, safety and security (*see* Chapter 7 – Human Health). As an example of financial damages caused by wildfire, the 2011 Slave Lake, Alberta fire resulted in an estimated $742 million in insurance claims (Flat Top Complex Wildfire Review Committee, 2012). The projected increase in fire due to climate change will translate into extra cost for protection and community evacuations. There may be only a decade or two before increased fire activity exceeds the capacity of fire management agencies to maintain current levels of effectiveness (Flannigan et al., 2009).

Forest-based communities are highly dependent on the forest resource for jobs, income and other goods and services, such as outdoor recreation. Increased occurrence of fire, pest outbreaks, and extreme weather events will translate into a reduced number of forest stands that can be sustainably managed. Monitoring and protection costs may become prohibitive in certain areas, and contribute to the reduction or elimination of local forestry economies.

Analyses of economy-wide impacts of climate change on the forest sector need to integrate consideration of non-climate stressors, including consumer demand, labour and capital supply, and markets for production inputs and outputs (NRTEE, 2011).

IMPACT ON CARBON STORAGE

Climate change also impacts the ecological services that forests provide, such as water conservation and purification, biodiversity and carbon storage. The importance of forest ecosystems in mitigating climate change by storing carbon is increasingly recognized and valued (Pan et al., 2011). Disturbances can have major impacts on forest carbon stocks and fluxes (Hicke et al., 2012), and projected increases in drought, fire and pest disturbances would reduce the carbon storage capacity of Canada's forests (Amiro et al., 2009; Michaelian et al., 2011). For example, Kurz et al. (2008) concluded that by 2020, trees killed by the mountain pine beetle in western Canada will have released nearly one billion tonnes of carbon dioxide into the atmosphere, roughly equivalent to five years of emissions from Canada's transportation sector.

3.2 ADAPTATION

Climate change presents challenges to Canada's forest managers. Decisions made today will impact the forest for over 100 years, given the long generation times of tree species. Trees can cope with a certain amount of change in their environment through physiological or genetic adaptation (Aitken et al., 2008), but the rate of future climate change is likely to exceed the ability of forests to adapt sufficiently to maintain the current levels of goods and services provided to society. Therefore, planned forest adaptation will be required to maintain the competitiveness and sustainability of Canada's forest sector. The Canadian forest industry has been facing significant economic challenges, resulting in lost jobs, mill closures, and a general downturn in the forest sector. Effective adaptation must address all of these drivers of change in the forest sector.

Many papers and reports (e.g. Millar et al., 2007; Ogden and Innes, 2007; Bernier and Schoene, 2009; Johnston et al., 2009; Gauthier et al., *in review*) explore options for forest sector adaptation, and there are several examples of specific measures being implemented (e.g. *see* Case Study 2).

Forest sector adaptation in Canada has gained political attention, with the Canadian Council of Forest Ministers (CCFM, 2008) identifying climate change as one of two national priorities, and stating that consideration of climate change and future climatic variability is needed in all aspects of sustainable forest management. Subsequent work by the CCFM included case studies of vulnerability and resilience assessments covering a range of forest landscapes, management activities and policy environments (Johnston and Edwards, in press; *see* Case Study 3).

CASE STUDY 2

ASSISTED MIGRATION

Assisted migration is the human-assisted movement of species in response to climate change (Ste-Marie et al., 2011). It is an adaptation option that is increasingly being considered to maintain the biodiversity, health and productivity of Canada's forests in a changing climate. Assisted migration can be used for both conservation goals (e.g. to save a species) and forestry goals (e.g. to maintain healthy and productive forest stands). Given existing knowledge and established best practices, assisted migration is more feasible for major commercial tree species than for rare species of conservation concern (Pedlar et al., 2012).

Many jurisdictions have seed transfer guidelines that recommend where seeds from specific geographical areas should be planted to ensure that they are suited to their planting environment. Some Canadian jurisdictions have begun to implement assisted migration of tree populations and species on a small scale by modifying these guidelines in response to observed and projected climate change. Current implementation of assisted migration of commercial tree species usually involves seed movements within, or slightly outside, current range limits. For example, British Columbia has extended seed transfer zones 100 or 200 metres upward in elevation for most species (BCMLFNRO, 2008), and introduced a new policy to allow for the limited planting of western larch in specific locations outside of its current range (BCMLFNRO, 2010). Through a variance application system, Alberta has extended conifer seed transfer zones by 200 metres higher in elevation and 2 degrees of latitude northward for most species (S. Kavalinas, ESRD, personal communication). In the northern part of the commercial forest of Quebec, seeds from southern seed orchards may represent up to 20% of the reforestation material (André Deshaies, Ministère des Ressources naturelles, personal communication).

CASE STUDY 3

ANALYSIS OF FOREST SECTOR VULNERABILITY ASSESSMENTS

In 2008-2012, the Canadian Council of Forest Ministers (CCFM) conducted a study of the Canadian forest sector's vulnerability to climate change. One component of the study was a summary and synthesis of twelve vulnerability case studies across the country (Figure 3). The objectives of the case studies varied widely, from a focus on biophysical modeling, to policy analysis, to community-based assessments, to integration of climate change into forest management planning. The perceived importance of climate change relative to other issues also varied considerably among the case studies, from unimportant to extremely important.

FIGURE 3: Locations of vulnerability assessment case studies included in the CCFM climate change adaptation initiative. ESRD = Environment and Sustainable Resource Development (Alberta), RAC = Regional Adaptation Collaborative (Natural Resources Canada) *(Source: Johnston and Edwards, 2013)*.

Key outcomes of the vulnerability assessments, in additional to technical analysis, include:

- enhanced awareness of climate change among the wide range of players involved, and the development of strong linkages between practitioners and modellers;
- forest management capacity building and increased understanding of vulnerabilities, as a foundation for future work focused on adaptation. While some case studies did include adaptation options, in general the concept of adaptation is not yet well understood;
- the development of integrated, multi-scale modeling approaches, informed by stakeholder groups, which will enhance the science base for forest management in the future;
- enhanced participant understanding of the uncertainty associated with future climate projections.

Analysis of the suite of case studies also allowed Johnston and Edwards (*in press*) to identify factors that enabled successful vulnerability assessments. These factors, which can be applied to future initiatives, include:

- adequate funding and human resources, including experts and local leaders;
- previous analyses that provide some indication of the likely impacts and pre-existing concerns of local decision makers regarding the effects of climate change and what they can do to reduce the impacts;
- synthesized "off-the-shelf" technical data (climate, ecosystems, etc.) that assist vulnerability assessment teams to move forward quickly;
- availability of natural science and social science expertise to link the biophysical and human systems;
- a champion – someone personally dedicated to the project, often a local community leader – who can bridge the gaps between scientists, stakeholders and practitioners;
- mechanisms to integrate local and/or traditional knowledge with science; and
- an initial focus on current vulnerabilities, which helps identify and address lack of knowledge at the start of the process.

ADAPTATION BARRIERS AND CHALLENGES

Large-scale and high-profile examples of climate change impacts, such as the mountain pine beetle outbreak, and extreme climate-related events, such as the severe wild fires in Kelowna, British Columbia in 2003 and Slave Lake, Alberta in 2011 have increased awareness of climate change adaptation among forestry practitioners. Both government and industry are moving from a 'crisis management' strategy to an 'adaptive management' approach, working to proactively address the risks and take advantage of the opportunities presented by climate change (Johnston and Hesseln, 2012). However, a lack of economic incentives for adaptation can make it difficult for companies to absorb short-term costs despite potential long-term gains (NRTEE, 2012a, b). While economic pressures in the Canadian forest sector may limit the capacity of industry to focus on, and invest in, adaptation to address future climate impacts, many adaptive management strategies are also appropriate for dealing with other non-climatic stresses and to help increase system resilience.

Significant uncertainty remains about future climate conditions (Trenberth, 2010), the multiple, interacting impacts of climate change on complex forest ecosystems, and forest response to those changes. Scientific understanding of past and future climate change impacts on Canada's forests has increased substantively over the past decade, but this information is not always available, accessible, and/or applicable to prospective end-users (Johnston and Hesseln, 2012). In fact, understanding of prospective adaptation options has been identified as a knowledge gap and barrier to action by some in the Canadian forestry industry (NRTEE, 2012a, b). Networks of climate change adaptation stakeholders, such as the Forestry Adaptation Community of Practice (www.ccadaptation.ca/forestry), have emerged to help address this barrier through sharing knowledge and best practices.

The difficulty of unequivocally attributing impacts to climate change in forest systems that are subject to multiple stressors is sometimes viewed as a barrier to adaptation (Lemprière et al., 2008). Generating long time-series measurements that use multi-scale monitoring allows detection and quantification of climate-related forest changes, which facilitate the validation of models and informing of adaptation decisions. The integration of on-the-ground measurements and remote sensing data greatly increases the breadth and depth of Canada's capacity to monitor forest changes. Integration of scientific knowledge across disciplines will also allow development of a more integrated understanding of the vulnerabilities of the forest and the forest sector to a changing climate.

Because climate change significantly challenges the attainment of sustainable forest management goals, adaptation should be considered as essential to sustainable forest management. For example, the criteria and indicators of sustainable forest management adopted by the CCFM (2006) may prove to be difficult, if not impossible, to achieve because they do not factor in the impacts of a changing climate. Analysis of the criteria and indicators system by Steenberg et al. (2012) suggests that indicators may have to be revisited, adjusted and added in the context of climate change. Established sustainable forest management certification standards could provide a vehicle for mainstreaming climate change into forestry decision making. Redefining sustainable forest management to incorporate climate change is likely to be a complex process involving many players and will require detailed trade-off analyses to clarify the range of forest values represented.

4. MINING

The Canadian mining sector employed approximately 401 315 people in mineral extraction and in value-added smelting, fabrication and manufacturing, and contributed about $60 billion to Canada's gross domestic product in 2012 (NRCan, 2013a). In 2010, there were approximately 968 mining establishments, including 71 metal mines and 897 non-metal mines, operated in clusters in and around over 120 medium and small communities across Canada, primarily in Quebec and British Columbia (Figure 4). Mining also contributes to the economies of large cities. The Toronto Stock Exchange handled 83% of the world's mining equity transactions in the past six years; Vancouver is home to several clusters of exploration companies, Montreal to major aluminum and iron ore firms, and Saskatoon to uranium and potash ventures (Stothart, 2011).

Mining contributes to the economies of all provinces and territories (Table 3). This economic contribution varies considerably over time depending on the number of mines operating and the value of the commodity produced. According to the Mining Association of Canada the industry plans to invest over $140 billion in projects over the next decade (Marshall, 2012). This planned growth represents a potential opportunity to integrate adaptation as part of mineral exploration activities, mine construction, operations, transportation and closure.

Mining operations in Canada have long dealt with climate variability, but in recent years they have been affected by an increasing incidence of climatic hazards, several of which are likely sensitive to climate change (Lemmen et

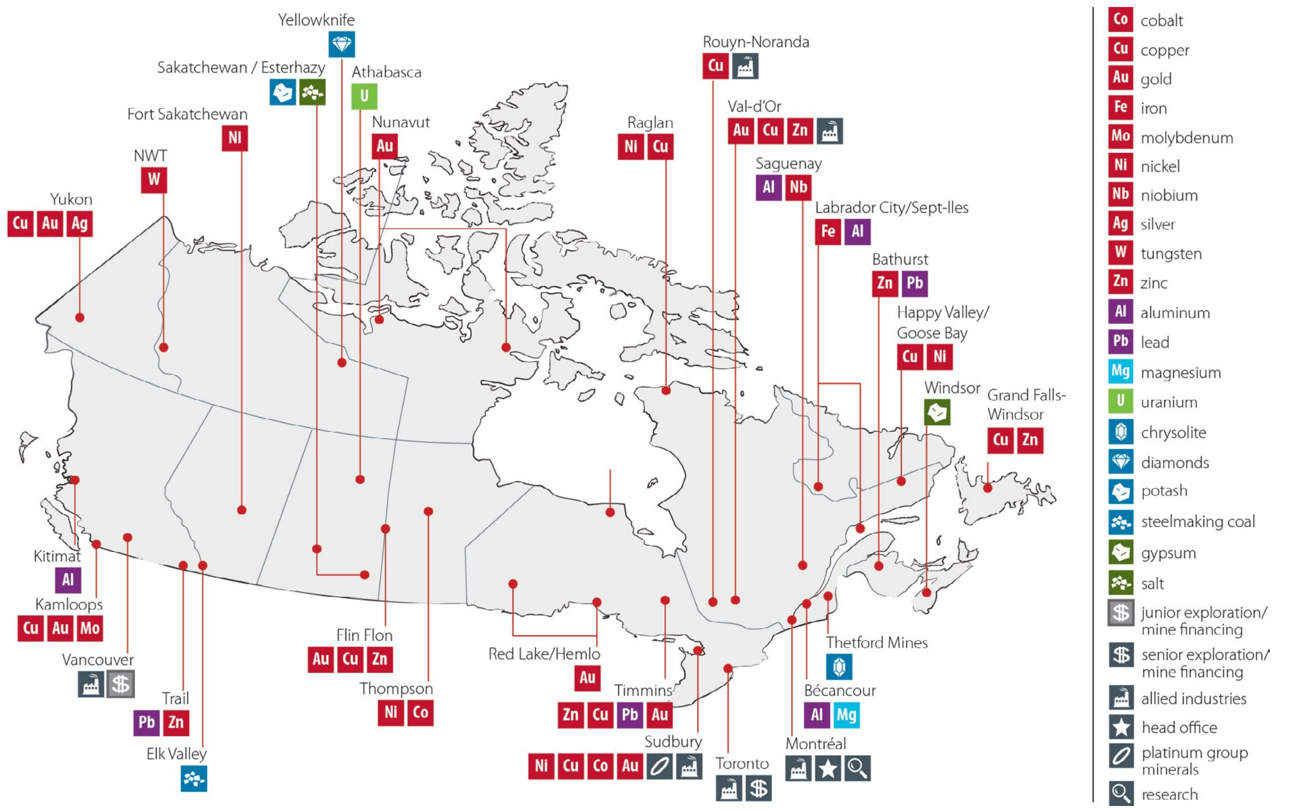

FIGURE 4: Canadian mining industry clusters *(modified from Stothart, 2011).*

al., 2008a; Pearce et al., 2011; Stratos, 2011; IMG-Golder Corporation, 2012; NRTEE, 2012a). Climate change presents a business risk, including public perception of a company's commitment to addressing climate change mitigation (Pearce et al., 2009). Climate change also presents new opportunities for mining exploration and development resulting from improved access to resources and new transportation options (Lemmen et al., 2008a; Prowse et al., 2009; Pearce et al., 2011; NRTEE, 2012a). The extent to which the mining sector is able to reduce its own impact on climate, adapt to climate change and take advantage of new opportunities will affect its long-term success, with economic and environmental consequences for host communities and the country.

The majority of available research on climate change impacts and adaptation in the mining sector focuses on operations located in northern regions and on issues like permafrost integrity, winter transportation networks, water management and the potential for Arctic seaways as sea ice melts. Limited information exists on climate change impacts and adaptation with regard to mining operations in southern Canada, despite the concentration of mines south of 60° (of 196 "Principal producing mines" listed in Natural Resources Canada (2012d), only 8 are located in the northern territories). The discussion in this section reflects the limitations of the information available.

Province/Teritory	Value of mineral production by province and territory, 2000 and 2010 ($M)	
	2000	2010
Newfoundland and Labrador	967.1	4584.0
Prince Edward Island	5.5	3.4
Nova Scotia	295.2	294.2
New Brunswick	772.5	1154.6
Quebec	3653.2	6770.5
Ontario	5711.4	7691.7
Manitoba	1268.8	1663.5
Saskatchewan	2282.6	7084.0
Alberta	1064.4	2347.3
British Columbia	2891.5	7073.8
Yukon	56.2	284.1
Northwest Territories	681.7	2032.7
Nunavut	384.6	305.1
TOTAL	20 034.7	41 288.9

TABLE 3: Value (millions of dollars) of mineral production by province and territory, 2000 and 2010 *(from Stothart, 2011).*

4.1 CLIMATE CHANGE IMPACTS AND OPTIONS TO ADAPT

Climate change affects all stages in the mining cycle, including planning, current and future operations, and post-operation. Studies have identified several aspects of mining operations that are currently affected by changing climatic conditions, including: a) built infrastructure; b) transportation infrastructure; c) extraction and processing; and d) daily operations.

BUILT INFRASTRUCTURE

Permafrost degradation and resulting soil instabilities, changes in the hydrological cycle, and extreme weather events present challenges for the design, construction, operation and closure of mine infrastructure (Instanes et al., 2005; Furgal and Prowse, 2008; Prowse et al., 2009). In the past, engineering design did not consider a changing climate and most mine infrastructure was built to withstand the climate norms and conditions at the time of construction. Structures built prior to the late 1990s and some after (e.g. roads, airstrips, buildings, berms, tailings dams and containment ponds) may be susceptible to increased thaw depth and settlement beyond the original design values due to climate change, which could increase maintenance costs and require remedial work to ensure structural integrity (Prowse et al., 2009). Permafrost degradation could also compromise the stability and performance of structures such as dams and waste covers, leading to the release of contaminants into the environment (Pearce et al., 2011; Stratos, 2011).

Extreme climate events have already exceeded the ability of some mine infrastructure to operate as intended. Changes in the hydrological cycle – especially extreme precipitation events and melt patterns – have led to high river flows that can exceed the capacity of water management structures. For example, torrential rains in the Yukon Territory forced a copper-gold mine to release untreated water into the Yukon River system on multiple occasions, breaching Yukon water license standards (Pearce et al., 2011). Slope stability and the integrity of engineered berms can also be compromised by extreme precipitation (Chiotti and Lavender, 2008). Erosion of dam slopes or gullying at the base of impoundment structures can occur, causing weaknesses in dams and increasing risk of failure. Tailings dam failures, triggered by heavy rain and flood events, have been documented internationally (ICOLD, 2001; WISE Uranium Project, 2006).

There are also risks of structural failure due to climate change and weather extremes for several post-operation mines across Canada, particularly in the North. Waste containment facilities constructed several decades ago were not designed for today's warmer conditions. Failures of frozen-core dams on tailing ponds at some mine sites and degradation of permafrost underlying spoil heaps have already resulted in unanticipated erosion and contaminants being released into the surrounding environment (Stratos, 2011). The potential exists for this to happen at other mine sites across the country (Pearce et al., 2011).

Adaptation of mine infrastructure to climate change involves addressing design features of new mines and remedial work at existing and post-operation mines to ensure structural integrity. Considering climate change in the design phase of mines is commonly part of the Canadian environmental assessment process, and resources such as the Environmental Code of Practice for Metal Mines (Environment Canada, 2009) are available to help mining operations plan for climate change (Prowse et al., 2009). For example, the report suggests that surface drainage facilities should be designed to handle peak conditions at least equivalent to a once in 100-year flood event in order to account for projected increases in extreme weather events due to climate change (Environment Canada, 2009). The Canadian Standards Association has also developed a technical guide for building infrastructure on permafrost (Auld et al., 2010). This guide pertains to new infrastructure projects and addresses how to estimate and account for the potential effects of future climate on permafrost and on foundations at sites where permafrost may be present.

A number of engineering and management techniques are being employed to protect infrastructure from the impacts of permafrost warming, including the use of deeper pile foundations, thicker gravel pads (insulation of the surface), adjustable foundations, artificial cooling, thermosyphons (to remove warm air from the ground around foundations and promote cooler ground temperatures), clearance of snow around foundations (to promote colder winter ground temperatures) and use of more resilient tailings cover designs (cover thickness, use of geosynthetics) (Pearce et al., 2009; Prowse et al., 2009). Monitoring the performance of these adaptive responses and adjusting accordingly helps ensure durability and effectiveness.

Mines have a lifespan long after operations cease and structures left onsite after closure will need to withstand future changes in climate. It is likely that infrastructure that has already been abandoned, including tailings ponds and waste rock stacks, have not been designed for the full range of changing climatic conditions, and if left unaddressed some of these sites could pose serious risks to the environment and the health of surrounding communities (Pearce et al., 2011).

TRANSPORTATION INFRASTRUCTURE

Mining operations that depend on climate-sensitive transportation infrastructure, such as winter roads and marine and freshwater transport, are especially susceptible to the warming trends documented across Canada, particularly in the north (Furgal and Prowse, 2008; Prowse et al., 2009). Warmer winters have rendered seasonal ice roads in the Northwest Territories less reliable than in the past (Prowse et al., 2009; Stratos, 2009; Pearce et al., 2011; *see also* Chapter 8 – Water and Transportation Infrastructure). The Tibbitt to Contwoyto Winter Road located north and east of Yellowknife (Northwest Territories) is the longest winter road in Canada at 600 km long, with more than 80% (495 km) located on frozen lakes. It is the main supply road for the Ekati, Diavik, Jericho and Snap Lake diamond mines, the Lupin gold mine (currently inactive) and several other mineral exploration projects (Prowse et al., 2009). In recent years the winter road has experienced shortened operating seasons as well as reduced ice thickness, which constrains the load volumes that can be safely transported (Prowse et al., 2009). The financial costs of a shortened ice-road season are significant. For example, in 2006 the road was open for only 42 days (compared to about 70 days of operation the previous season), requiring the Diavik diamond mine to spend an extra $11.25 million to fly in 15 million liters of fuel (Pearce et al., 2011).

Adaptive responses developed by road operators include the purchase of new, lighter-weight and amphibious machinery to facilitate road construction earlier in the season. In addition, alternative road routings have been developed and operational efficiencies have been achieved through measures such as concentrating truck shipping into the portion of winter when ice is thickest (Pearce et al., 2009). Alternatives to the ice road are also being explored, including construction of a seasonal overland route to the diamond mines, and the proposed Bathurst Inlet Port and Road Project which would link mine sites in Northwest Territories and Nunavut to the northern mainland coast.

Mining companies view changing climatic conditions as an opportunity with regards to changes in sea ice and marine shipping. Increased duration of the summer shipping season and opening of new Arctic shipping routes may enhance the economic viability of some northern mine developments. For example, continued warming is expected to lead to further opening of the Northwest Passage, resulting in longer or eventually year-round shipping seasons (Leong et al., 2005; Prowse et al., 2009). However, in the near term, ice hazards will remain high due to the more rapid drift of multiyear ice through the Arctic Archipelago (Prowse et al., 2009; *see also* Chapter 2). Non-climatic factors such as insurance costs, reduced shipping speeds and lack of supporting infrastructure, may also limit the use of the Northwest Passage for marine shipping. More specific issues related to transportation are likely to be identified as specific sites are developed (*see* Case Study 4).

CASE STUDY 4

VOISEY'S BAY NICKEL-COPPER-COBALT MINE, NUNATSIAVUT

The Voisey's Bay Nickel-Copper-Cobalt Mine, owned and operated by Vale, is located roughly 35 km southwest of the community of Nain on the northern coast of Labrador. It is a remote, sub-arctic location on land subject to Aboriginal land claims by the Innu and Inuit of Nunatsiavut. The main ore body of the project contains nickel, copper and cobalt, and is recognized as one of the largest nickel deposits in the world. The mine ships mining concentrate to its processing facilities in Long Harbour, Newfoundland during the ice-free open water season and also through sea ice between January and March (Vale, 2013).

During the environmental impact assessment (EIA) of the mine, the Labrador Inuit Association and the Innu Nation raised concerns over the mine shipping through landfast ice, and the potential for disruption to people travelling over the ice to other communities or to hunting grounds. Agreements were reached with these groups to help address these issues by not shipping during the initial freeze-up period or during the seal-hunting period in the early spring (April and May). The mine also allows the initial ice to become 20 cm thick before beginning icebreaking, in order to avoid disturbing travel routes on the sea ice used by local people and wildlife (Bell et al., 2008).

When the EIA of the Voisey's Bay mine was conducted in 1997, the climate models used projected minimal changes in climate over the approximately 25-year lifespan of the mine. The environmental impact statement acknowledged that changes to ice and sea conditions could occur over the mine's lifespan, but that these changes were difficult to predict (Bell et al., 2008). Over the last decade, global sea ice cover has declined at rates far exceeding climate model projections (Stroeve et al., 2012). Although reduced sea ice cover and associated later freeze-up and earlier break-up dates may be beneficial for some marine shipping operations, this could negatively affect the Voisey's Bay mine with regards to its agreement with local communities to maintain access to sea-ice routes and traditional hunting grounds. If sea ice continues to take longer to freeze up and achieve thicknesses suitable for icebreaking as per the agreement with the Inuit and Innu, mine shipping may be stalled during winter months (Pearce et al., 2009).

Vale recognizes the issue of climate change and the need to reduce greenhouse gas emissions, but the Voisey's Bay mine does not currently have a proactive plan for adapting to likely future climatic changes, including changing sea ice dynamics (CVRD Inco, 2006). The mine undertakes adaptive management practices by conducting monitoring, observation and risk assessment to track the implications of sea ice changes on the coastal and social activities of local Aboriginal people, and plans to respond when documented climatic changes begin to have a discernible impact on company operations (CVRD Inco, 2006). This approach to adaptation appears typical of the strategies employed by most mining operations in Canada to deal with changing climatic conditions, and has sometimes resulted in financial costs to companies, environmental damage or both, as described previously. A challenge in planning for adaptation is determining the correct balance between collecting new data to better understand the likely negative future impacts of changing climatic conditions and achieving the best short-term outcome based on current knowledge (Allan and Stankey, 2009).

EXTRACTION AND PROCESSING

Climate conditions also impact the extraction and processing of some minerals. Dust emissions and associated dust control regulations are of particular concern for sand, gravel, limestone and dolomite mines. Warm, dry conditions exacerbate dust emissions, requiring mine operators to employ dust control measures, such as water spraying and covered storage areas. Increased precipitation associated with climate change in some areas could be beneficial to these mining operations in that it helps to control dust emissions. Conversely, too much precipitation impedes the drying of the mined materials, which subsequently requires more energy, resulting in higher costs (Pearce et al., 2009; Case Study 5).

DAILY OPERATIONS

Daily operations at mine sites are sensitive to extreme weather conditions, including intense rain and snowfall, flooding, drought, changing ice conditions, extreme cold and forest fires, all of which can reduce operational capacity (Pearce et al., 2009; NRTEE, 2012a). Mining operations are often located in remote areas with limited services and access infrastructure, which are also climate sensitive. For example, in May 2012 several gold mining operations located near Timmins, Ontario halted operations due to forest fires which caused power outages, blocked highway access to the mines, and threatened the mine sites themselves (CBC, 2012). Mine operations located in mountainous terrain in British Columbia are sensitive to rainfall-initiated mud and debris flows, and transportation routes are at risk of washout, particularly if heavy rainfall occurs during spring melt. Freezing rain, flooding, and extreme cold and storms have interrupted production at mine operations in central Canada, and changes in the frequency and intensity of these conditions are projected to continue in the future with implications for mine operations (Pearce et al., 2009).

4.2 STATUS OF ADAPTATION IN THE CANADIAN MINING INDUSTRY

The attention given to climate change adaptation – long-term planning that considers present and projected climate change impacts – varies considerably within the mining

CASE STUDY 5

SODIUM SULPHATE MINING, CHAPLIN, SASKATCHEWAN

Sodium sulphate is mined and sold for use in powdered laundry detergents, glass making, textiles, modified corn starches, carpet deodorants, kraft pulp mills and mineral feeds for livestock. In ideal climate conditions, sodium sulphate mining utilizes heat from the sun to evaporate water from a solution of sodium compounds until the compounds precipitate out and can be gathered from reservoir bottoms. This process requires sufficient water supply in spring, hot dry summers to optimize brine strength and cold winters to facilitate the collection of sodium sulphate from reservoir floors. Under these ideal conditions, energy inputs to the system are minimal, reducing production costs and increasing the competitiveness of the mine. Variable climate conditions pose several operational challenges. For example, too much summer precipitation can necessitate the use of pumps to remove excess water, increasing production costs. Warmer winters, in which freezing of ground beneath the reservoir is delayed, limit the operation of heavy equipment and increase the cost of recovering the sodium sulphate.

The Saskatchewan Mining and Minerals Inc. mine at Chaplin, Saskatchewan is an example of a small sodium sulphate mine. Its success is related to favourable temperature, precipitation and runoff conditions, and to access to Chaplin Lake, an 18 km^2 saline lake (Figure 5).

The primary sources of water for the Chaplin mine are local precipitation and spring runoff. Access to a secondary source of water has been developed to aid in times of water shortages; water can be diverted from the Wood River to the Chaplin Creek and then used by the mine in Chaplin Lake. This delivery system is managed in partnership with Ducks Unlimited Canada and also benefits local waterfowl. In addition, the mine has built water storage areas that can be used during dry years. Water use efficiencies have also increased over the last twenty years through the development of small dikes throughout Chaplin Lake, which divide it into smaller sections and increase the control that mine operators have over water levels, allowing them to optimize brine concentrations during extraction. The sections allow operators to add water only where it is needed, improving water-use efficiency. In times of excess moisture, pumps can be used to remove surplus water and control brining concentrations. These techniques allow the mine to enhance its brining and recovery processes under variable and changing climate conditions.

FIGURE 5: Chaplin sodium sulphate mine site, southwest Saskatchewan *(Photo courtesy of Saskatchewan Mining and Minerals Inc)*.

sector. The apparent lack of proactive adaptation planning for climate change in the mining sector suggests that some mine stakeholders view it as a minor concern in relation to immediate issues, such as meeting regulatory and human resource requirements, and managing fluctuating market conditions (Ford et al., 2011). In some instances, limited understanding and knowledge of current and projected future climate change among mine decision makers may be constraining adaptation planning. Additionally, climate change is sometimes viewed as something that may occur beyond the operational lifespan of the mine, and therefore is of limited immediate importance (Ford et al., 2010).

Environmental impact assessment is one mechanism that has served to increase awareness of climate change impacts and adaptations in the mining sector as companies move from advanced exploration into production. These assessments often use climate scenarios to identify potential impacts on mine site infrastructure and the surrounding environment. Monitoring and adaptation strategies are then identified. However, the extent to which mining projects implement adaptation strategies and make operational adjustments remains limited (Bell et al., 2008).

Actions such as strengthening or redesigning infrastructure can be costly and are sometimes deemed unnecessary by mine operators due to the short operating lives of many mines. Furthermore, uncertainty about future climate change projections is considered a barrier in making investment decisions regarding adaptation (Ford et al., 2010). Nonetheless, advances have been made, and some mine designers have included climate change parameters into their plans (Ford et al., 2011). Proactive adaptation planning, however, takes place in a select few mining operations, primarily those located in the North (Ford et al., 2011).

A number of factors shape the ability of mining operations to adapt to a changing climate. These include climate change information, regulations, and access to engineering solutions.

Climate change information – Decision makers responsible for designing, building, maintaining and decommissioning mining infrastructure need improved understanding of the likely impacts of future climate changes at mine sites, and how engineering techniques can be adopted to manage these changes. There are concerns that available climate scenarios are not sufficiently refined to inform decision making. Needs include ensuring climate information is available in a format that is readily usable by mine developers and operators, as well as guidance for interpreting a range of climate change scenarios and factoring them into infrastructure and closure design (Ford et al., 2011).

Regulations – Adaptation planning in the mining sector has been largely voluntary. Despite recent attention to climate change as part of the environmental assessment process for many mine developments, there are no widespread requirements to consider climate change in mine planning or in mine closure plans. Regulations, developed in consultation with mine proponents, could be utilized to help ensure that available knowledge of current and expected future climate change is integrated into mine planning (NRTEE, 2012a).

Engineering solutions – In many instances the technologies and engineering strategies necessary for adapting mining operations to address changing climate conditions already exist. For example, in operations where maintaining frozen conditions is necessary, thermosyphon technology is commonly employed (Pearce et al., 2011). Similarly, tailings covers can be modified to ensure below-ground materials stay frozen, and ground-based transportation networks can be built in ways to minimize disturbance to the frozen soil layers below. In other cases, holding ponds, berms and other containment infrastructure can be strengthened to withstand more frequent extreme precipitation during the life of the mine and beyond. Engineering solutions that could reduce the negative impacts of climate change on mine operations exist, however, they are not always cost-effective and there are limited financial or regulatory incentives to encourage their uptake.

5. ENERGY

Canada's abundant and diverse energy resources are integral to the country's economy. Canada has the world's third largest proven reserves of crude oil, the fourth largest proven reserves of uranium, and is the second largest producer of uranium. In addition, Canada is the world's third largest producer of hydroelectricity, the fifth largest producer of both oil and natural gas, and the second largest net exporter of uranium (Natural Resources Canada, 2013b). In 2012, the energy sector contributed approximately $155 billion, or 9%, to Canada's GDP. Energy exports in 2012, 90% of which went to the United States, comprised more than 27% of Canada's total exports (Natural Resources Canada, 2013b). Canada's primary energy production is dominated by crude oil and natural gas (Figure 6). Alberta is by far the largest producer of primary energy in Canada (Figure 7).

Many aspects of energy supply, transmission and demand are sensitive to climate variability and will be impacted by various dimensions of climate change, including higher temperatures, changing frequency and intensity of extreme events and changes in water availability (Figure 8). However, with the exception of the hydroelectricity subsector, adaptation to climate change in the energy sector has received much less attention by industry and researchers than have issues of greenhouse gas mitigation (Wilbanks et al., 2007; ICF Marbek, 2012).

5.1 ENERGY DEMAND

Long-term trends in energy demand are influenced primarily by changes in population, economic activity, energy prices and energy efficiency (IEA, 2011a; Natural Resources Canada, 2011b). In Canada and worldwide, climate change will mean reduced energy demand for winter heating and increased demand for summer cooling (where other factors are held constant, e.g. Zmeureanu and Renaud, 2008; Isaac and van Vuuren, 2009; Schaeffer et al., 2012). The net annual result of climate change-induced shifts in energy demand will be country and region specific (Schaeffer et al., 2012).

The reduced demand for heating will primarily impact fuels such as natural gas and heating oil, while the increased demand for cooling will increase electricity consumption (the main energy source for space cooling; Wilbanks et al., 2007). This impact will be felt mainly in the residential and commercial sectors (Mideksa and Kallbekken, 2010). Capacity to meet the higher summer peak load associated with climate change-related shifts in energy demand is a significant challenge for the energy sector (ICF Marbek, 2012), and could require significant investments in new generating capacity (Mills, 2007).

Ontario is the only province where the current annual peak load occurs in summer (NERC, 2012). While recent studies continue to show the sensitivity of electricity demand in Ontario to climate variability and change, as well as a trend toward more frequent extreme heat days in several cities (*see* Chapter 7 – Human Health), the magnitude of impacts on energy demand may not be high (e.g. Lin et al., 2011). Furthermore, peak load in Ontario has declined substantially after reaching record levels in 2004-2006 (IESO, 2009), suggesting that the province may be less vulnerable to changes in annual peak load than previously thought. While Ontario's electricity system is believed to have a sufficient reserve margin to remain reliable under unexpected stress, including severe weather (NERC, 2012), the Environmental Commissioner of Ontario (ECO, 2012) has called for an in-depth assessment of the matter to ensure that the grid remains reliable in a changing climate.

The potential influence of climate change on electricity trade between Canada and the United States is recognized (e.g. Scott and Huang, 2007; Hamlet et al., 2009; Ouranos, 2010), but quantitative analyses are lacking. Summer electricity demand in the US is projected to increase as a result of climate change, but it is unclear whether Canadian utilities will be able to respond to this export opportunity since they will also be facing a higher domestic demand in the summer (Scott and Huang, 2007).

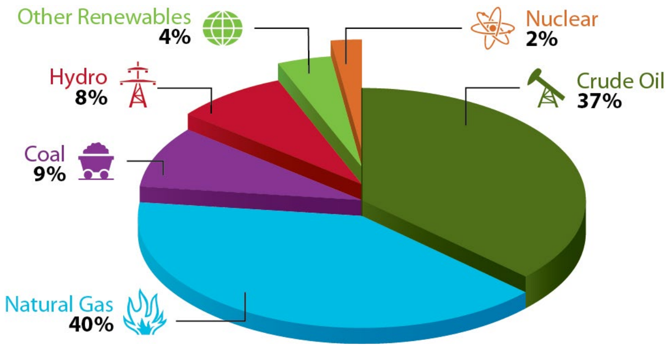

FIGURE 6: Canada's primary energy production. All numbers refer to 2010 production *(Source: Natural Resources Canada, 2012e)*.

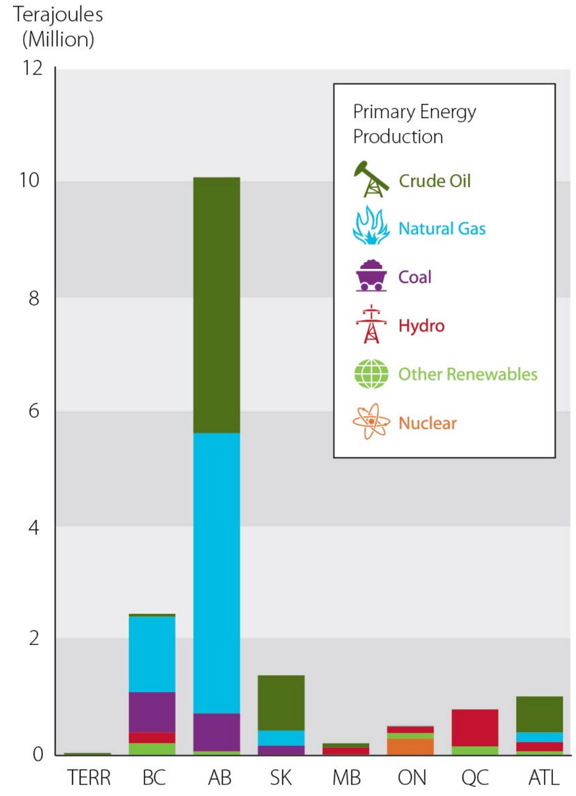

FIGURE 7: Primary energy production by province (note that the Northwest Territories are combined, as are the four Atlantic provinces; *data from Natural Resources Canada, 2012e*).

BOX 2

KEY DEFINITIONS OF ENERGY TERMINOLOGY

Energy sector – industries involved in the production, transformation and transportation of energy (Natural Resources Canada, 2012e).

Energy source – any substance that supplies heat or power (modified from Natural Resources Canada, 2011b).

Renewable energy – energy obtained from natural resources that can be naturally replenished or renewed within a human lifespan (Natural Resources Canada, 2012f).

Non-renewable energy – energy generated from finite resources, the stocks of which could deplete or become too costly or challenging to access. This includes oil and petroleum products, natural gas, coal and uranium (modified from Natural Resources Canada, 2012g).

Primary energy – energy that has not yet been transformed (modified from OECD, 2012).

Secondary energy – energy generated by conversion of primary energies, e.g. electricity from gas, nuclear energy, coal, oil, fuel oil, and gasoline from mineral oil.

Primary energy production – all primary energy that is produced in a country, including energy that will be exported (modified from Natural Resources Canada, 2011b).

Peak load – the maximum load consumed or produced by an electricity-generating unit or group of units over a measure of time (daily, monthly or yearly). As electricity generally cannot be stored, some generating capacity must exist exclusively for meeting periods of peak demand (modified from National Energy Board, 2004).

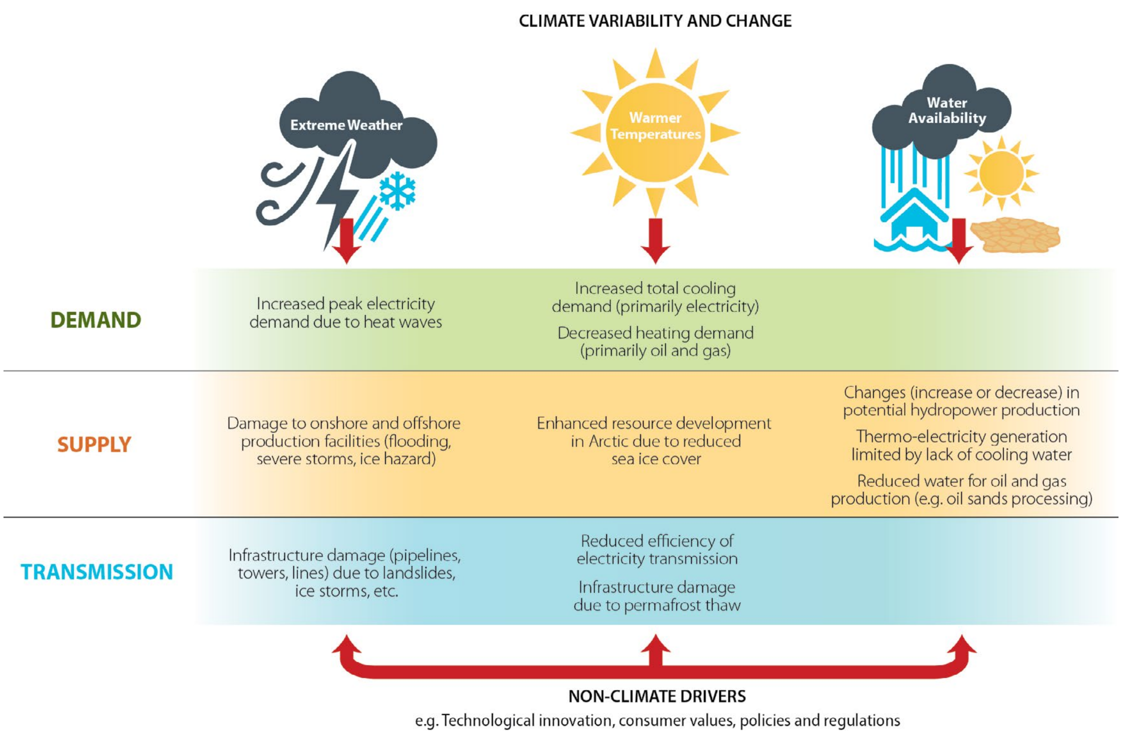

FIGURE 8: Key climate change impacts in the energy sector, recognizing the importance of non-climate drivers in determining adaptation actions.

ADAPTATION

Measures to reduce future electricity consumption include programs and standards that promote energy efficiency in buildings, appliances and equipment (Geller et al., 2006), and energy conservation practices such as user-controlled shading, enhanced natural ventilation, or accepting higher indoor temperatures in the summer (Levine et al., 2007; Gupta and Gregg, 2012). Projected increases in the use and market penetration of air conditioning units with climate change suggests that improving the efficiency of these units will be particularly valuable (Scott et al., 2008). Smart grid technologies, which facilitate enhanced coordination of electricity networks to respond to changing supply and demand, may also be an important adaptation measure as they maximize system reliability and stability (Newsham et al., 2011; Lilley et al., 2012). A high level of deployment of smart grid technologies has the potential to keep peak load in North America at today's level until 2050 (IEA, 2011b). Urban design measures that reduce heat island effects can also help to reduce electricity demand for cooling (Smith and Levermore, 2008; Xu et al., 2012). All of these measures provide adaptive benefits and many contribute to, or may be triggered by, other policy goals, such as economic competiveness, energy security and health and well-being (e.g. Levine et al., 2007; Sathaye et al., 2007; Ürge-Vorsatz and Tirado Herrero, 2012).

5.2 ENERGY SOURCES

Canada's energy supply includes both renewable and non-renewable sources. Most renewable energy sources (e.g. hydroelectricity, wind, solar, and biomass) are inherently sensitive to climate variability and change, whereas non-renewable sources (e.g. oil, natural gas, uranium and coal) are intrinsically less sensitive. However, energy supply derived from all sources is affected by changing climate when the full process from exploration to development and distribution is considered. Increasing the diversity of energy sources, by using varied types of renewable and non-renewable energy sources, as well as multiple sources of the same type of energy, can increase the climate resilience of energy supply.

5.2.1 RENEWABLE ENERGY

Renewable energy sources provide about 12% of Canada's total primary energy supply, with hydroelectricity being by far the most significant renewable energy source (Natural Resources Canada, 2012e).

HYDROELECTRICITY

Hydroelectricity currently accounts for 59% of Canada's electricity generation (Statistics Canada, 2013). More than 90% of total electricity production in Quebec, British Columbia, Manitoba and Newfoundland and Labrador comes from hydro. Ontario, Alberta and New Brunswick also produce significant quantities of hydroelectricity, while the Yukon and Northwest Territories rely on hydro to help meet local energy demand. The majority of Canada's hydro production comes from large reservoir systems (Figure 9), with additional capacity provided by small run-of-river power stations. Transboundary electricity markets, both inter-provincial and international (United States) are large. The availability of abundant sources of hydro power allows Canada to support industries reliant on high energy consumption, such as aluminum smelters (*see* Case Study 6).

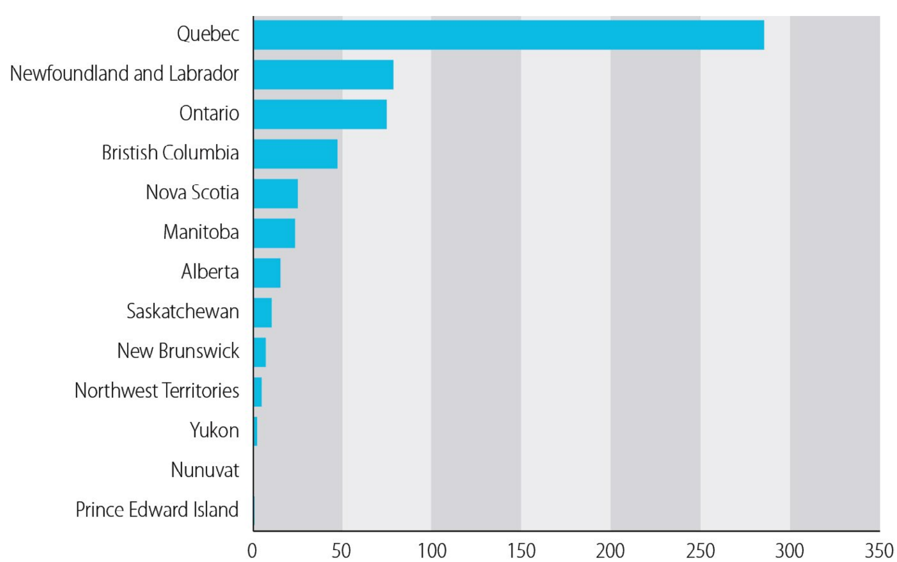

FIGURE 9: Large (higher than 15 m) dams associated with hydropower reservoirs in Canada *(Source: Global Forest Watch, 2012)*.

To date, most Canadian research relating to climate change and hydroelectricity has focused on the hydrological consequences of a changing climate, such as shifts in the timing and magnitude of river flows. Climate projections and hydrological modeling indicate a likely decrease in summer flows, an increase in winter flows, a decrease in spring water levels, and changes in the timing of peak flows for most Canadian watersheds, due in large part to increased frequency of winter rain and reduced snowfall amounts (e.g. Fortin et al., 2007; Boyer et al., 2010; Rodenhuis et al., 2011; Kienzle et al., 2012). The magnitude of projected changes varies significantly between regions and within drainage basins. In some regions, such as northern Quebec, increasing mean annual runoff (Figure 10) could present opportunities for established hydro generation facilities. However, greater hydrologic variability linked to climate change will likely increase the risk of overflows (non-productive discharge), particularly during winter and spring melt, with greatest impacts on run-of-river power plants (e.g. Minville et al., 2010b).

Important differences will occur within individual drainage basins where significant hydroelectric generation occurs (*see* Table 4). Even where increases in annual average precipitation are projected, increased evaporation and evapotranspiration may lead to lower water levels and negatively impact hydropower generation (e.g. Buttle et al., 2004). Increased winter rainfall could cause difficulties in basins where reservoir storage capacity is limited (e.g. Fortin et al., 2007; Shrestha et al., 2012). Rivers fed by glaciers will also see regime changes affecting late summer and fall flows. For example, glacier extent in the Columbia River basin of British Columbia is projected to be reduced by 40% by 2060 (Jost et al., 2012). In northern Canada, integration of permafrost and hydrological modeling is needed to enhance understanding of the potential impacts for hydroelectricity generation in this region (Goulding, 2011).

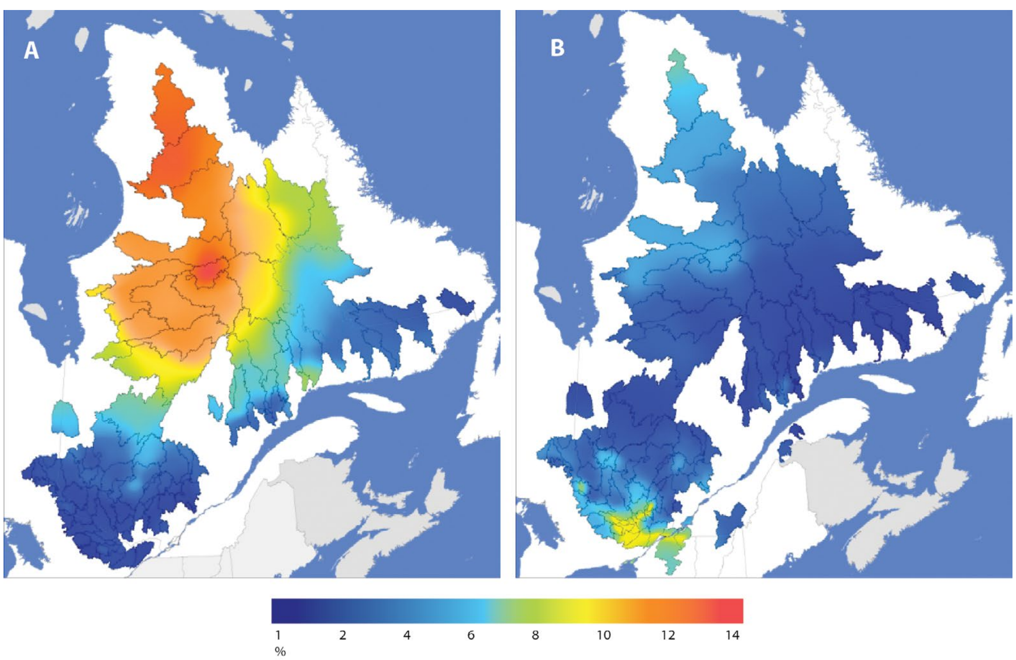

FIGURE 10: a) Average increase in annual runoff in Quebec watersheds between 2040-2070 relative to 1961-1990. b) Standard deviation for change in runoff. Average increase is statistically significant when it surpasses uncertainty associated with projections, represented by standard deviation *(from Desrochers et al., 2009)*.

Province	River basin	Significance	Methodology - observations / models / assumptions	Climate trends and projections	Key references
British Columbia	Upper Columbia	• 12 hydro facilities in total • Mica and Revelstoke dams produce 25% of BC hydro requirement	• Baseline period 1961-1990 • Future period 2041-2070 • Scenarios: A1B, A2, B1 • 8 Global Climate models	• General increase in flows except for end of summer and fall • Peak flows one month earlier (June rather than July)	Zweirs et al. (2011); Shrestha et al. (2011)
British Columbia	Upper Peace	• 2 facilities • G.M. Shrum (WAC Bennett Dam) and Peace Canyon produce 29% of BC hydro requirement		• Increase in annual flow up to 12%, greatest increase in winter • Decreased flows end of summer and fall • Spring floods not significantly earlier	Zweirs et al. (2011); Shrestha et al. (2011)
British Columbia	Fraser	• Home to 63% of BC population • Two tributaries important for hydro generation, several smaller facilities		• Increase total annual flow • Decrease annual maximum flow • Earlier spring floods	Shrestha et al. (2012)
British Columbia	Campbell	• Strathcona dam – largest facility on Vancouver Island		• Average flow unchanged • Increase in winter flow, reduction in spring and summer flows	Shrestha et al. (2012)
Alberta	Cline	• Tributary that generates 40% of North Saskatchewan River flows • Upstream of Bighorn Dam, TransAlta's highest performing hydro plant	• Baseline period 1961-1990 • Future periods 2010-2039, 2040-2069 and 2070-2099. • Scenarios: A1B, A2, B1 • 5 Global Climate models	• Decreased annual flows – 25% by 2020, 30% by 2080 • Peak flows to occur one month earlier by 2050	Zweirs et al. (2011)
Manitoba	Winnipeg	• Directly or indirectly influences the production of 4600 MW	• Streamflow observation period 1924-2003 • 9 gauging stations	• Historic trend (80 years) of increased summer and fall flows	Kienzle et al. (2012)
Ontario	Nipigon, Abitibi, Mattagami	• Identified as priority basins by Ontario Power Generation	• Baseline period 1961-1990 • Future period 2041-2070 • 24 Regional Climate Models • 4 Global Climate Models • Scenarios A2 and A1B	• Historic trend (80 years) of increased summer and fall flows	St. George (2007)
Quebec	North of 49° N	• Region contains most of Quebec's large hydroelectric generation facilities	• Baseline period 1961-1990 • Future period 2041-2070 • 2 Regional Climate Model	• Historic trend (80 years) of increased summer and fall flows	Music and Sykes (2011)

TABLE 4: Findings of recent studies concerning hydrologic impacts on river basins of importance for hydroelectricity generation in Canada.

Although many of the studies summarized in Table 4 conclude that there will be no change or an increase in total annual flow, the need for hydropower operations to adapt to climate change is crucial (*see* Case Study 6). While increased flow could be beneficial, it may also lead to flooding if reservoirs are not managed properly. Most importantly, projected climate impacts almost always involve major changes in the distribution of flow throughout the year, which presents challenges to most current dams and reservoir management. For instance, reservoirs are currently kept very low during winter in order to store melt water in spring. With increasing winter flows and earlier and lower spring flows, a new strategy could involve storing water throughout the winter as well, to help offset the impacts of lower summer flows.

Recent research has expanded beyond hydrologic analysis to multi-criteria analysis, which involves consideration of economic, political, social and environmental aspects to analyze potential adaptation measures and associated costs and benefits (Webster et al., 2008). A few published studies (e.g. Raje and Mujumdar, 2010; Soito and Freitas, 2011; Georgakakos et al., 2012) have examined how adaptation strategies for the hydropower industry can integrate perspectives of multiple water users and changing resource demands. Adaptive management is a powerful tool in addressing water-related conflicts and can both provide a more robust performance than traditional management approaches, and significantly reduce negative impacts resulting from climate change (Georgakakos et al., 2012). Adaptive management can include risk analysis and re-optimizing of regulations for reservoir operation to account for variability and uncertainty of hydrologic input forecasts (Georgakakos et al., 2012; *see* Case Study 6).

Adaptation measures related to hydro power can involve structural and non-structural approaches. Structural approaches refer to physical modifications of infrastructure and assets to reduce their climate vulnerability, whereas non-structural (or soft) approaches involve modifications to the way energy systems operate. Examples of structural measures include expanding the capacity of existing hydro power plants and revising design criteria for new facilities. Increasing the current capacity of power plants should help reduce non-productive discharge. However, this approach can be costly to implement or even technically impossible for existing power plants that were not designed for capacity expansion. Construction and maintenance costs, as well as the benefits resulting from increased hydroelectric generation, are considerations in assessing the value of applying structural approaches (Webster et al., 2008; Beauchamp, 2010).

Examples of non-structural approaches include use of resource management to adjust to hydrologic changes, as well as to policy or regulatory reforms. Ongoing studies suggest that taking into account the seasonal variability of flows and the uncertainty of future hydrological projections should lead to management approaches capable of increasing hydroelectric generation (Haguma, 2012). For example, Côté et al. (2011) showed that using a variety of climate scenarios allowed for better efficiency in power plants compared to classic methods that only rely on current climate (and which are usually recommended and used for establishing management regulations for hydroelectric systems). Non-structural adaptation also includes the protection or restoration of natural flow regulators such as wetlands to provide buffering capacity during times of low and peak flows (e.g. Jones et al., 2012).

OTHER RENEWABLE SOURCES

Together, non-hydro (alternative) renewable energy sources contribute about 4% of Canada's primary energy production. Wood and wood waste are the main source, with smaller contributions from biogasoline, wind, municipal waste and landfill gas, industrial and other waste, and solar and tidal sources. Few Canadian studies have examined the impacts of a changing climate on these energy sources (*see* Yao et al. (2012) for analysis of projected climate changes on wind power generation in Ontario).

Research outside of Canada has tended to focus on the impact of extreme weather, including wind and precipitation, on alternative renewable energy production (Wilbanks et al., 2007; Ebinger and Vergara, 2011; McColl et al., 2012). For example, where increased wind speeds exceed the maximum design value for turbines, equipment could be damaged or shut down, resulting in reduced effective generating capacity (Ebinger and Vergara, 2011; McColl et al., 2012). An increase in average air temperatures beyond certain thresholds negatively affects wind (decreased air density) and solar production (decreased efficiency of panels) (Ebinger and Vergara, 2011), but the magnitude of these impacts is unclear. Changes in cloud cover and wind regimes also affect solar and wind energy production, either negatively or positively, depending on the direction of change. Assessing the impacts of climate change on wind, solar and biomass energy production in Canada requires further research.

5.2.2 NON-RENEWABLE ENERGY

OIL AND GAS

The oil and gas industry operates across Canada. The remote nature of much of the sector's activity, including sites in the far north and offshore, presents challenges for the sector value chain. Canadian literature on climate impacts in this sector emphasizes risks to, and opportunities for, upstream activities (e.g. exploration, extraction and production), with

CASE STUDY 6

ADDRESSING CLIMATE CHANGE IMPACTS THROUGH ADAPTIVE MANAGEMENT: HYDROPOWER PRODUCTION IN THE PERIBONKA RIVER BASIN

Minville et al. (2008, 2009, 2010b and 2012) have undertaken extensive analysis of hydroelectricity generation along the Peribonka River, in south-central Quebec. The watershed is 27 000 km^2 and runoff is snowmelt dominated; spring melt produces 43% of the annual runoff volume. The existing hydro facilities include two large reservoirs (Lake Manouane and Passes Dangereuses) that store water and feed three hydropower generating stations (Figure 11). The electricity generated is used to meet the energy requirements of Rio Tinto Alcan's aluminum smelters.

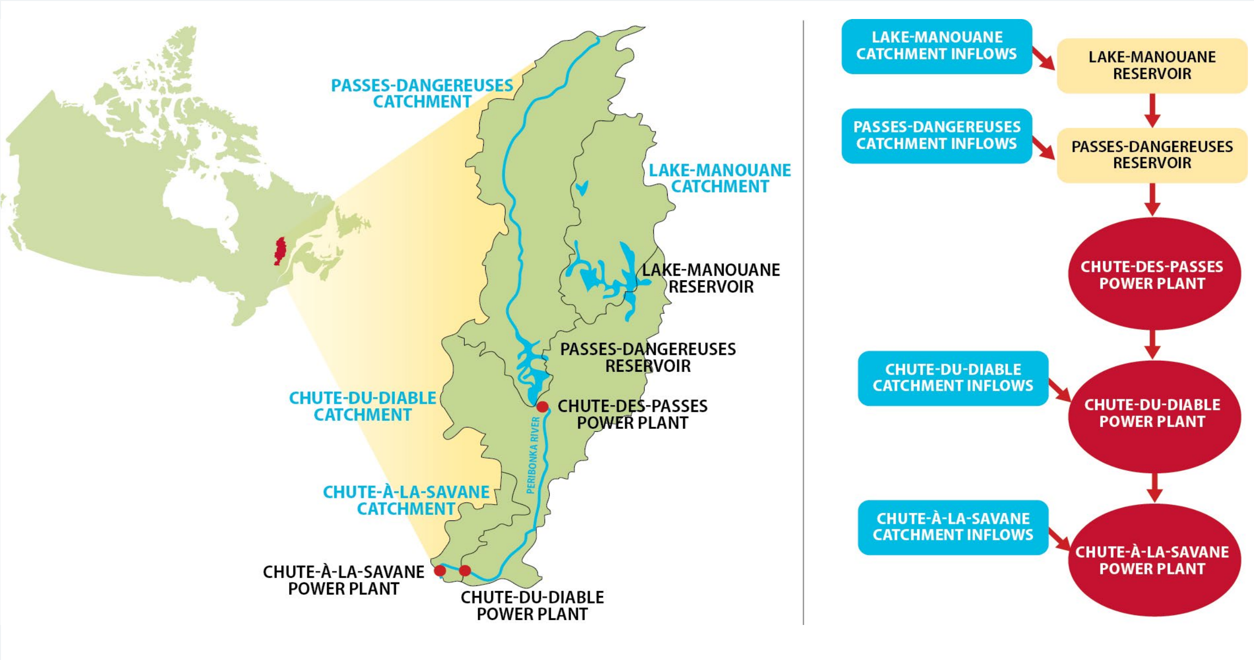

FIGURE 11: The Peribonka River watershed and hydrological system *(Source: Minville et al., 2010a)*.

The impact of climate change on the hydrology of the Peribonka River watershed was investigated by developing temperature and precipitation projections from combinations of five global climate models and three emission scenarios downscaled to the watershed level, as well as from the Canadian Regional Climate Model (CRCM; Caya and Laprise, 1999), to simulate hydrologic regimes under current and projected climates. Results indicate earlier spring floods, increased winter flows and reduced flows during summer and fall as a result of a changing climate. These shifts are accentuated over time and vary between northern and southern sub-basins (Figure 12). Uncertainty in these projections largely relates to changes in the snowpack and is, correspondingly, of most significance during winter and spring flooding.

Analysis also involved developing optimal management policies for the system reservoirs by simulating and assessing system performance under current and projected future climate conditions. Modelling results show higher spring water levels at Lake Manouane for all future periods relative to the baseline period (Figure 13). Summer water levels at Manouane tend to decrease by 2070-2099 as a result of reduced inflow and the need to maintain the Passes-Dangereuses reservoir at its highest level to maximize the hydroelectric generation. The behaviour of the Passes-Dangereuses reservoir is similar to that of Lake Manouane, except that the shift in the reservoir lowering period is more pronounced as a result of earlier spring flooding.

Case Study 6 continued on next page

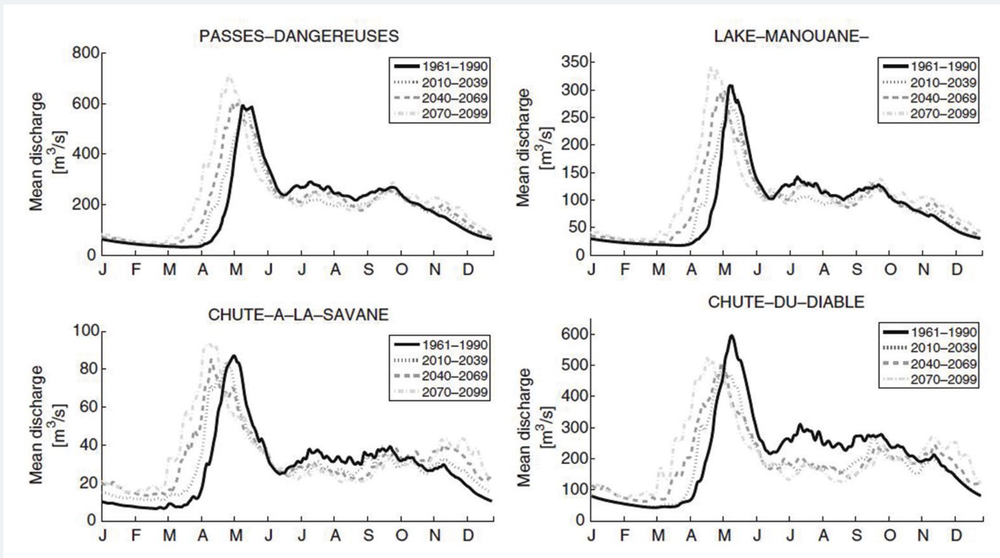

FIGURE 12: Average annual hydrographs for the Peribonka River sub-basins for the future periods 2010-2039, 2040-2069 and 2070-2099, compared to the 1961-1990 baseline, simulated using CRCM projections with SRES A2 (*from Minville et al., 2009*).

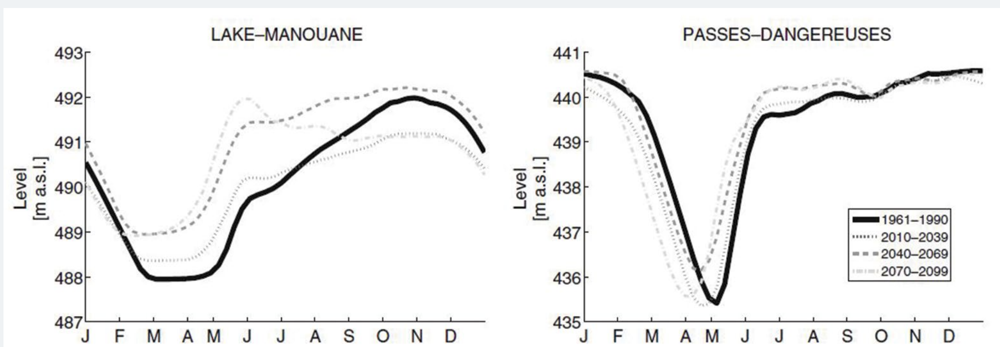

FIGURE 13: Reservoir water level for the future periods 2010-2039, 2040-2069 and 2070-2099, compared to the 1961-1990 baseline *(from Minville et al., 2009)*.

All climate projections indicate a future increase in annual runoff, so average hydroelectric generation should also increase. This increase could range from 1 to 15% in the period 2040-2069 at the Chute-des-Passes power plant, depending on the climate scenario used and assuming optimal management. However, if the current management policies remain unchanged, hydroelectric generation would decrease by 1 to 14% due to the inability to contain earlier snowmelt and resulting unproductive spilling. By practicing adaptive management and non-structural adaptation approaches, such as updating management policies on a regular basis, producers should be able to capitalize on the effects of climate change on hydrologic regimes.

a particular focus on the North (e.g. Furgal and Prowse, 2008). Risks include a shortened season for both exploration activities reliant on frozen ground, and for transporting supplies via winter roads. Longer term risks of climate change at northern sites relate to effects of permafrost degradation on the stability of infrastructure (e.g. ground subsidence affecting access roads, buildings and pipelines) as well as on the management of drilling wastes (which commonly rely on storage in permanently frozen ground to prevent mobilization of contaminants; Furgal and Prowse, 2008). Risks to off-shore production facilities relate to increased storminess (including Atlantic hurricanes) and changes in ice-risk (icebergs and multi-year sea ice; e.g. Stantec, 2012), and potential environmental and human impacts associated with oil spills (e.g. NEB, 2011).

The oil and gas industry routinely undertakes actions to address climate risks, but these are rarely documented systematically in publically available sources. Where available, evidence indicates that industry generally feels the sector is well positioned to adapt to climate change, largely in a responsive manner (NRTEE, 2012a, also *see* Case Study 7).

Research in the past five years has highlighted that climate change impacts on water resources will have significant implications for the oil and gas sector (e.g. PRI, 2009). Many upstream and midstream (e.g. processing, upgrading, storage and transport) activities associated with the production of oil, gas and coal are water-intensive, and, unlike thermal power generation, are made up almost exclusively of consumptive uses (Natural Resources Canada, 2010). Regional impacts may be most significant in areas that are already water-stressed, such as the southwestern Prairies (e.g. Sauchyn and Kulshreshtha, 2008). Recent attention has focused on water usage for oil sands processing and hydraulic fracturing.

While 75 to 90% of the water used in oil sands processing is recycled, the remainder is derived from surface and groundwater sources. With respect to climate change impacts, attention has focused on the ability of the Athabasca River in Alberta to provide water for expanded oil sands development while maintaining sufficient downstream flows to avoid ecosystem impacts. Analysis of historic flow variability and trends concluded that short term ecosystem impacts would have occurred under historic low flow conditions, and that management responses are needed to avoid longer term impacts under projected climate change (Bruce, 2006; Schindler et al., 2007). An expert panel of the Royal Society of Canada (RSC, 2010) concluded that concerns about withdrawals during low-flow periods could be addressed through additional off-stream water storage captured during spring peak flows. The Panel's report notes that "substantial reductions in Athabasca River flow resulting from climate change would drive implementation of this option [additional off-stream water storage] to a great degree" (RSC, 2010, p. 284). A detailed analysis of projected climate changes on Athabasca River water flows was conducted as part of a multi-stakeholder committee analysis examining water withdrawls (Ohlson et al., 2010; *see also* Lebel et al., 2009) concluded that significant uncertainties and knowledge gaps on this and other topics highlighted the importance of adaptive and flexible management approaches.

To adapt to water availability risks, the oil sands industry emphasizes technological innovation and notes the significant gains in water-use efficiency in the past decade (CAPP, 2012). While off-stream water storage represents one possible adaptation, fundamental changes in the methods used to separate bitumen in ways that greatly reduce water use are also being investigated (CAPP, 2012). From a regulatory perspective, the Water Management Framework for the Lower Athabasca River, introduced by the Government of Alberta in 2007 to limit, monitor and adjust freshwater withdrawal from the river on a weekly basis, provides a mechanism to protect environmental integrity under both current and future climate conditions (ESRD, 2013).

ELECTRICITY GENERATION (FROM NON-RENEWABLE SOURCES)

Nuclear energy constitutes 15%, and coal-fired power plants represent 13%, of electricity generation in Canada (Statistics Canada 2012, 2013). Climate impacts of greatest concern to non-renewable electricity generation relate to possible impacts of extreme climate events on infrastructure, as well as impacts on the availability and temperature of cooling water (e.g. Wilbanks et al., 2008; Rübbelke and Vögele, 2011). While detailed information for Canadian facilities is publicly available through findings of regulatory hearings, this information has not been broadly captured by the scientific literature. The following discussion draws heavily on analyses from Europe and the United States.

Discussion of infrastructure risks for power plants focuses on intense storms and extreme precipitation, which can cause flooding of facilities or make access routes to them impassable, potentially leading to decreased generation, shutdowns or increased costs to handle drainage and clean-up (Wilbanks et al., 2007; Ebinger and Vergara, 2011). Both thermal and nuclear power plants also face the potential of reduced generation in the case of extremely low water levels (McColl et al., 2012). A rise in water temperatures reduces the cooling efficiency at power plants (Harrison et al., 2009), resulting in a proportionate increase in the demand for cooling water. European research has documented failures to meet the cooling needs of thermal power plants due to high water temperatures during summer heat waves (McColl et al.,

CASE STUDY 7

ADAPTATION TO CLIMATE CHANGE IN THE OIL AND GAS SECTOR

The Carbon Disclosure Project (CDP) is an international effort to track corporate progress on managing climate change risks and opportunities. Relying on voluntary responses to an annual survey targeting the largest firms based on market capitalization, the CDP has an extensive database of business responses dating back to 2003. The CDP's primary focus is on mitigation, but adaptation-relevant questions are also included. Recent reports illustrate a shift in how Canadian businesses perceive the physical impacts of climate change. For example, opportunities outnumbered risks stemming from a changing climate in the CDP Canada reports from 2008 to 2010 (CDP, 2010). Sectoral differences in perception of risk and opportunity are also evident. Of all the sectors represented in CDP, energy businesses were found to be the least likely to report on possible opportunities arising from climate change and the second least likely of all sectors to report on exposure to physical risks, based on analysis of responses in reports from 2003 to 2010 (NRTEE, 2012b).

The 2010 survey included questions addressing current and/or anticipated risks associated with physical impacts of climate change, the timescale of these risks, possible financial implications and actions planned or taken to manage the risks. Examples of adaptation actions identified by Canadian oil and gas companies to address current and anticipated future climate risks are presented in Table 5.

Internal policy, programs and operating standards
• Engineering and construction standards that ensure facilities can operate in extreme conditions, including potential temperature and weather-related shifts
• A capital approval process characterized by project evaluation that includes engineering, environment, and business risks; identification and sharing of key learnings from past capital projects; and incorporation of these learnings in plans to manage operational risks
• Programs that promote system integrity and ongoing preventive maintenance for each component of the gas system
• Business continuity planning and emergency preparedness to ensure the continued supply of transportation fuels
• An insurance program that includes coverage for physical damage, business interruption and third party liabilities, also serving to manage commercial risks of climate change-related hazards
Actions to build resilience
• Design and application of wooden mats so producers can drill during warm-weather months in muskeg and wet areas, while minimizing environmental disturbance
• System interconnectedness allowing redirection of gas from one plant to another in case of shut downs, minimizing revenue loss to the company and production losses to customers
• Enhancing water-use efficiency in the design and operation of existing and new facilities, including expanded recycling and reuse of water, reassessment of freshwater licence allocations for return to the Crown and collaboration with industry to reduce impacts on local water resources
Stakeholder engagement
• A Water Strategy that includes getting involved in policy and regulatory development, and working with local stakeholders on site-specific water issues as ways to address the potential impacts of climate change

TABLE 5: Selected examples of actions to manage the physical impacts of climate change highlighted by Canadian oil and gas companies in their 2010 responses to the Carbon Disclosure Project *(Source: CDP, 2010)*.

The limited number of respondents to the CDP prevents generalizations for the sector as a whole, but responses can provide insights on individual oil and gas companies' perceptions of risk and sense of urgency to adapt. For example, in its 2012 CDP response, Encana noted risks to water availability related to changes in precipitation and drought, as well as impacts of extreme weather on exploration and production activities. The risks were considered difficult to quantify, with timeframe and magnitude of impact stated as "unknown", and likelihood deemed "unlikely". In accompanying descriptions, the company notes that it currently operates in a range of extreme environments across North America, that its facilities are engineered and constructed to operate within wide ranges of weather conditions, and that they annually conduct a "look-back and learning" process that allows steps taken to address negative impacts at any one site to be shared across the company. With respect to risks associated with water availability, the company noted that if managed, this risk would have a negligible effect on exploration and production.

2012). In addition, temperatures of cooling water discharges from power plants could increase, with the risk of violating regulatory thresholds established to protect ecosystem services. Both regulatory and safety violations could result in shutdowns. Current Canadian nuclear power plants are cooled by very large bodies of water (Lake Huron, Lake Ontario and the Atlantic Ocean) so the same risks may not apply in Canada. Nonetheless the impact of climate change is one factor to be considered when locating future plants.

Adaptation responses to warmer water temperatures will depend in large part on the type of cooling technology currently deployed. Once-through cooling (OTC) systems, the most common type of system in Canada (Natural Resources Canada, 2010), feature a continuous intake and discharge of cooling water. One option to decrease the amount of cooling water used in lakeside OTC systems is relocating the water intake to a deeper (and colder) part of the lake. Where facilities are located on shallow lakes, such as in the Canadian prairies, there may be fewer options to deal with climate change and drought. New technologies to reduce water consumption, enhance water reuse, and develop dry cooling techniques are opportunities for innovation that will be partly driven by the need to adapt to climate change impacts (ICF Marbek, 2012).

5.3 ENERGY TRANSMISSION

Infrastructure for energy transmission is a major, long-lived and climate-sensitive investment for both the electricity and oil and gas sectors. Canada has over 140 000 km of electricity transmission grid, with Quebec, Ontario and Alberta representing about 60% of the national total. This infrastructure provides interconnections between energy markets in other provinces and in the United States (ICF Marbek, 2012). There are more than 825 000 km of oil, refined products and natural gas pipelines in Canada, including both delivery and transmission pipelines (CEPA, 2012). Major new pipelines have been proposed to enhance access to Canadian and US markets, and to expand into Asian markets. The distribution network for oil, gas and coal also includes road, rail, barge and tanker transport.

Severe weather is a common cause of interruptions in power supply. The 1998 ice storm in eastern Canada, which had estimated costs of more than $5 billion, provides an extreme example of the vulnerability of electricity transmission infrastructure. Extreme temperatures can affect the performance of a large amount of infrastructure, including electricity transmission (reduced efficiency and increased line drag), pipelines (reduced efficiency of compressors and fan coolers) and railroads (heat buckling), which are particularly important for coal transport (ICF Marbek, 2012). Climate-related natural hazards also present risks to energy transport. For example, extreme rainfall can cause flooding and trigger landslides that can interrupt road and rail transport. Permafrost thaw can lead to surface subsidence or destabilized slopes that can result in pipeline buckling or rupture. Engineering solutions exist to reduce many of these risks.

6. SYNTHESIS

The natural resources sector routinely manages climate risks. Adapting to the reality of a changing climate is in the best interest of both natural resource companies and the communities in which they operate. As with other sectors, governments, industry and non-government organizations all have a role to play in adaptation in the natural resource sectors. Since provincial governments have legislative authority for natural resources within their jurisdiction (PCO, 2010), there are differing approaches and levels of activity across Canada. Intergovernmental processes provide a mechanism for sharing experiences, tools and development of best practices for adaptation, as demonstrated by recent activities under the Canadian Council of Forest Ministers (CCFM, 2013a, 2013b, 2013c, 2013d). The federal government is responsible for cross-jurisdictional issues, including international trade, and plays a strong role in research and development. Industry associations are increasingly engaged in building awareness of climate change impacts and the value of adaptation. In instances where a strong link between climate variability and change and resource production exists, such as with hydroelectricity, there are several examples of industry being a leader in analyzing impacts and funding related research.

The first-order biophysical impacts of a changing climate on resource exploration, physical infrastructure and distribution systems – including impacts related to weather extremes, regional hydrologic changes, permafrost degradation, sea level rise and others – are fairly well understood for many aspects of natural resources, and have not evolved significantly in the past five years.

Application of this understanding is most developed in the forestry and hydroelectricity sectors. Significant gaps in biophysical impact research still remain, including understanding changes in wind patterns and cloud cover and the potential impacts on wind and solar power generation, the implications of reduced water availability on oil and gas activities, and the effect of novel climates on forest ecosystems. Detailed study of downstream impacts, including economic analysis related to international trade and global competitiveness, remains very limited. However, new insights have emerged on dealing with climate change impacts as part of business planning. Gauthier et al. (*in review*) offer four key principles for adaptation in the forest sector, which equally apply to other natural resource sectors. These are:

1. Efficient incorporation of climate change risks into planning and operations. Risk management approaches involve moving from optimal production targets to achieving the most robust outcome under a range of conditions.
2. Integration of no-regret options that provide benefits under a range of potential futures.
3. Adoption of an adaptive management framework. Given the uncertainty associated with climate change, management systems must be flexible and responsive to changes.
4. Monitoring to identify climate-related changes and potential deviation from management goals.

Many frameworks for adaptation exist; however, examples of their application and documentation of implemented measures remain relatively few. The adaptation that is occurring in the natural resources sector has been primarily through ad hoc, reactive responses to climatic events. Examples include flying supplies to northern mine sites when the ice road season is shortened due to warm temperatures, shifting of forest harvest operations to cope with unfrozen ground conditions, and making use of the increased quantity of salvage logging. Examples of proactive adaptation planning for future climate change are fewer. Case studies compiled by the National Roundtable on the Environment and Economy (NRTEE, 2012a) documented the climate change adaptation activities of a number of resource-based companies (J.D. Irving and Tolko Industries in the forestry sector, Rio Tinto Alcan in mining and Entergy Corporation, BC Hydro and Hydro Quebec in the energy sector). Those examples highlight that adaptation is starting to infiltrate the culture of the natural resource industry, as it has for other sectors of the Canadian economy.

A number of barriers and enablers of adaptation are evident across the natural resource sectors. Recent changes of significance to Canada primarily relate to near-term economic drivers such as global economic performance, commodity prices, and international trade issues. To remain competitive in both continental and global markets, investments in longer-term sustainability are sometimes viewed as a low priority. However, the fact that rapid changes are taking place in the natural resource sectors, particularly in the context of northern economic development, also provides opportunities for adaptation if climate change is integrated as part of broader decision-making processes.

Limited awareness in the natural resource sectors of the potential scope, scale and business relevance of climate change impacts, as well as uncertainties regarding the projection of specific climate changes, have been cited as reasons for limited progress on adaptation (NRTEE, 2012b). In addition, the fact that most of these industries operate in a wide range of climate extremes makes them comparatively resilient to many projected climate changes. Nonetheless, comprehensive risk assessments can identify new vulnerabilities, including those related to disruptions in public infrastructure.

Processes that are emerging as enablers of adaptation action in the natural resource sectors include environmental assessment, public risk disclosure, and reporting associated with sustainable forest management. The former is a legislated requirement (updated in 2012 for federal jurisdiction) for major development projects with the goal of reducing a project's potential impact on the environment before it begins and to ensure that measures to mitigate risks are applied once the project is initiated. Such assessments routinely consider the impacts of climate change on the proposed development, with guidance and case studies provided by the Federal-Provincial-Territorial Committee on Climate Change and Environmental Assessment (2003). Public disclosure, such as the Carbon Disclosure Project (*see* Case Study 7), exists to inform investors on how publicly traded companies evaluate and manage material risk in a changing climate (CDP, 2010). Although analysis of US Securities and Exchange Commission disclosures indicated that the quality of disclosure regarding climate risk is generally inadequate to allow investors to accurately assess future risks and performance (Ceres, 2012), it also highlights the potential value of this process for promoting adaptation, encouraging both investors and regulators to push for improvements in disclosure quality.

In many instances, the engineering and planning solutions to help natural resource companies and local communities prepare for and adapt to climate change exist. The potential for developing effective adaptation strategies in the Canadian natural resources sector is substantial, and collaboration among companies, regulators, scientists and other stakeholders to develop practical adaptation strategies that can be mainstreamed into existing planning and operations will greatly enhance likelihood of success. There is an opportunity for Canadian natural resource managers to share their experiences in climate change adaptation with planners and managers in other sectors in Canada and internationally.

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