climate change and Canadian mining

OPPORTUNITIES FOR ADAPTATION

David Suzuki Foundation

SOLUTIONS ARE IN OUR NATURE

CLIMATE CHANGE AND CANADIAN MINING: OPPORTUNITIES FOR ADAPTATION

Prepared by ArcticNorth Consulting

Prepared for: The David Suzuki Foundation

Lead Authors: Tristan Pearce (tristan.pearce@arctic-north.com), James D. Ford (james.ford@arctic-north.com), Jason Prno, Frank Duerden,

Contributing Authors: Lea Berrang-Ford, Tanya R. Smith, Jeremy Pittman, Andrew Reid, Maude Beaumier, Dale Marshall

August 2009

ACKNOWLEDGEMENTS

We acknowledge the intellectual contributions made by Dr. Barry Smit and the Global Environmental Change Group in the Department of Geography at the University of Guelph. We would like to thank the following people and organizations who assisted us in this project:

Al Douglas (Coordinator, Ontario Center for Climate Impacts and Adaptation Resources
Alun Richards (Manger, Communications, AREVA Resources Canada Inc.)
Andrea Foster (Outreach Coordinator, David Suzuki Foundation)
Andrew Reid (Global Governance, University of Waterloo)
Andy Fyon (Director, Ontario Geological Survey)
Andy Philips (Senior Engineer, Knight Piésold Ltd.)
Bob Powell (Specialist Geotechnical Engineer, Knight Piésold Ltd.)
Cheryl Wray (Environmental Superintendent, Baffinland Iron Mines)
Dave Taylor (Environment Department (Sudbury), Vale Inco)
David Putnam (Director, Safety, Health and Environment, De Beers Canada)
Edward Cocchiarella (Manager – Environment, Ontario operations, Vale Inco)
Erik Madsen (Director, Winter Road Operations, Joint Venture)
Erik Sparling (Project Manager-Infrastructure & Climate Change, Canadian Standards Association)
Erica Beasley (Department of Geography, Ryerson University)
Glen Jackle (Sr. Quality & Process Engineer, Saskatchewan Minerals Inc.)
Gord Macdonald (Sustainable Development Manager, Diavik Diamond Mines Inc.)
Greg Cousineau (Senior Transportation Planner, Department of Transportation, Government of the Northwest Territories)
Guy Frechette (Senior Electrical Engineer, Xstrata Copper, Kidd Mine)
Ian Horne (Director, Environmental Affairs, FNX Mining)
Igor Holubec (Consultant)
Jacques Gérin (Independent Consultant)
Jim Millard (Environmental Superintendent, Baffinland Iron Mines)
Jonathan Fowler (Vice President, Aboriginal Affairs and Sustainability, De Beers Canada)
Joana Marques (Department of Geography, Ryerson University)
Ken Embree (Managing Director, Knight Piésold Ltd.)
Kit Vaughan (Head of Climate Change Adaptation, WWF-UK)
Kristen Ostling (Communications Specialist, David Suzuki Foundation)
László Götz (Environmental Manager, Goldcorp, Porcupine Gold Mines)
Marc Butler (Superintendent of Environment, Xstrata)
Mark Getzlaf (Environmental Director, PotashCorp)
Melodi Moini (Department of Geography, Ryerson University)
Morag Carter (Director of Climate Change, David Suzuki Foundation)
Nicholas Bourque (First Nations Liaison, Sandvik Mining and Construction)
Paul Stothart (Vice President, Economic Affairs, Mining Association of Canada)
Rick Hoos (Principal Consultant, EBA Engineering Consultants Ltd.)
Ryan Kadowaki (Program Coordinator, David Suzuki Foundation)
Steven Aiken (Manager, Environmental Services, Knight Piésold Ltd.)
Steven Scott (Department of Geography, University of Guelph)

Tina Neale (Adaptation & Impacts Research Division, Environment Canada)
Anonymous representatives of Voisey's Bay mine Labrador
The Prospectors and Developers Association of Canada
Greg Birchfield, Natural Resources Canada
Anonymous interviewees in Labrador and south-western Quebec

We would also like to thank the Prospectors and Developers Association of Canada (PDAC) for permission to survey at their 2008 annual conference. Finally, we would like to thank five reviewers who provided detailed comments on the report.

The project was funded by the David Suzuki Foundation and also benefited from in-kind from the following:

The International Polar Year CAVIAR Project
ArcticNet
Social Sciences and Humanities Research Council

CONTENTS

FIGURES

TABLES

ABBREVIATIONS

AOGM	Atmosphere-Ocean General Circulation Models
GCM	General Circulation Models
GDP	Gross Domestic Product
GHG	Greenhouse Gas
ICMM	International Council on Mining and Metals
ICOLD	International Commission of Large Dams
IJC	International Joint Commission
IPCC	Intergovernmental Panel on Climate Change
IPCC AR4	Intergovernmental Panel on Climate Change Fourth Assessment Report
MAC	Mining Association of Canada
NRCan	Natural Resources Canada
PDAC	Prospectors and Developers Association of Canada
SRES	Special Report on Emission Scenarios
TSM	Towards Sustainable Mining

CHAPTER 1

1.1 INTRODUCTION

The scientific evidence that the climate is changing is now beyond doubt and a link to human emissions is well established (IPCC, 2007c, b). Acknowledging this fact, research has broadened from focusing solely on the causes and nature of change to its implications for human activity. For individual sectors, and regional and national economies, identifying and characterising impacts and vulnerabilities is of tremendous value because changing environmental conditions have major implications for economic viability and social and cultural well-being. It is increasingly recognised that by identifying and anticipating potential vulnerabilities stake-holders, practitioners and regulators can take pro-active approaches to reducing future uncertainties. Our understanding of the implications of climate change for major industrial activities in Canada, however, remains limited (Health Canada, 2008, Lemmen et al., 2008).

Primary economic activities, which are the mainstay of local economies in much of Canada, are particularly exposed and sensitive to the consequences of climate change because of their immediate dependency on the natural environment (Lemmen et al., 2008, Ford et al., 2008a). The potential vulnerability of many of these economic activities to climate change has considerable regional significance because they are often the dominant economic activity for large regions and the well being of tertiary activities and local populations often depend on their viability. Such regionalization is typified by the Canadian mining industry, which, tied to the nation's diverse geology is based in hundreds of widely dispersed, often rural locations.

The question of the vulnerability of the mining sector is not new: mineral resources are finite, the viability of mines and associated communities is primarily determined by global mineral prices, and the question of the vulnerability of the mining sector to global economic conditions has long been a pre-occupation of economists. From a business perspective it is an expectation that climate change would be a serious consideration because its impact could lead to increased costs; for many operations factors related to distance, climate, and landscape are already significant cost variables. Despite this, few, if any, Canada-wide studies of the vulnerability of the Canadian mining sector to climate change have been conducted (Ford et al., 2008a, b, Ford & Pearce, 2007).

This report documents and describes the vulnerability of the Canadian mining industry to climate change, highlights opportunities for adaptation, and examines experience with reducing greenhouse gas emissions. Specifically, the report:

- Characterizes how the Canadian mining sector is sensitive to climate change and assesses how climate change is perceived among different operators.
- Documents strategies the sector has adopted to deal with changes in climate and assesses how these strategies differ across Canada.
- Identifies what risks and/or opportunities the mining sector perceives future climate change will bring.
- Documents strategies to deal with expected future climate change and investigates potential costs of adaptation.

- Identifies greenhouse gas mitigation strategies currently used by the mining sector and perceptions of mitigation as a response to climate change.

The research was guided by a vulnerability assessment framework and employed a ‘mixed methods’ approach that used both qualitative and quantitative analyses including surveys, interviews with industry stakeholders, and case studies. The research involved mining operations dealing with metallic and non-metallic minerals, including coal and diamonds, but excluding oil and gas.

The report has 8 chapters, beginning with an assessment of the importance of mining in Canada, analysis of climate change scenarios for Canada, and review of the literature on climate change impacts, adaptation, vulnerability and mitigation in the Canadian mining sector before outlining the research approach and key research questions guiding the study. Three chapters then profile the primary research contributions of the report, namely a survey of mining sector practitioners at the Prospectors and Developers Association of Canada mining conference, a Canada-wide survey of mine-site practitioners, and in-depth case studies from six regions of Canada. The report finishes by synthesizing the research findings. It is noteworthy that each chapter is organized as a separate research project with specific aims, objectives and deliverables. This reflects the iterative nature of the project with the research completed in distinct phases, each phase providing a baseline for the next step. Thus the second survey built upon the results of the first survey, and the case studies built upon the survey results. Moreover, this organization reflects an overriding objective in the study to do research to help the mine sector reduce vulnerability to climate change and plan to reduce greenhouse gas emissions. To this end, we endeavoured to publish each chapter upon completion in the popular press and trade journal outlets. The research approach chapter, survey chapter, and some of the case study chapters have already been published (Appendix 1). One downside to this organization is that there is repetition in places, particularly in the discussion sections of the primary research chapters; however, we believe the organizational benefits significantly outweigh the drawbacks.

CHAPTER 2

2.1 MINING IN CANADA

2.1.1 Overview

Mining is the act of extracting valuable minerals or other geological materials from the Earth to satisfy a range of human wants and needs. In Canada, mining has a long history and continues to be an important activity today. The contributions of mining to the Canadian economy are manifest at a number of stages in the mining process including mineral exploration and mine development, resource extraction, material transportation, processing, fabrication, and mine decommissioning. This chapter documents the importance of mining to the Canadian economy in terms of the jobs it directly and indirectly supports, its contribution to the Gross Domestic Product (GDP), importance to the export sector, and role in attracting foreign direct investment. Some key contributions of the mining industry are summarized below (MAC, 2007b).

2.1.2 Contribution to Canadian Economies

As of January 2007 there were 801 mining establishments in Canada, including 55 producing metals and 746 producing non-metals. These operations exist in more than 115 communities across Canada and procured external goods and services from approximately 2360 firms based in all Canadian regions (MAC, 2007b) (Figure 2.1).

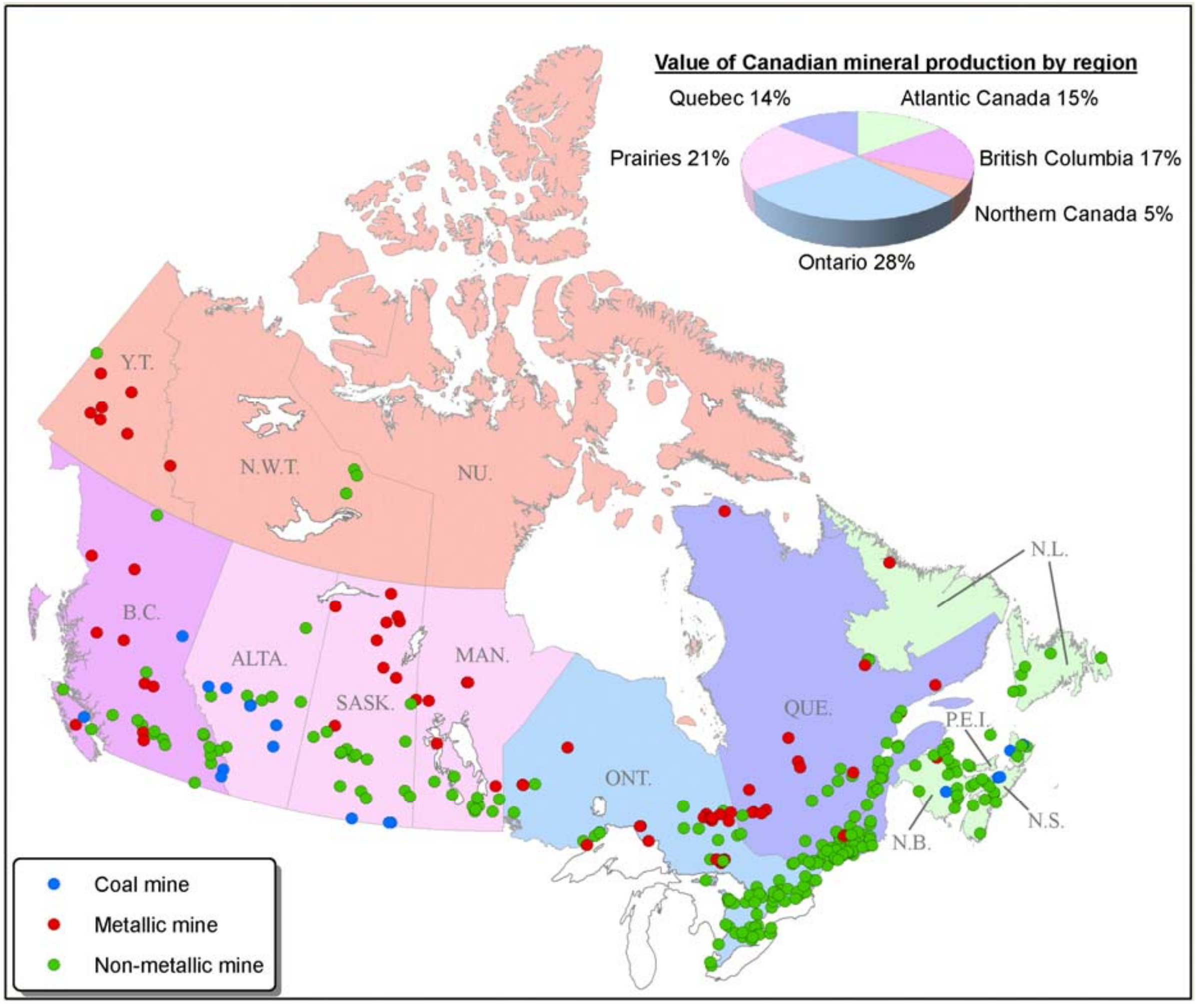

Figure 2.1: Map of mine operations in Canada (MAC, 2007b)

In 2007 the total value of all mineral production in Canada, including metals, non-metals and coal, was $40.4 billion, up 19% from the 2006 total of $33.6 billion. This growth was based largely upon a marked increase in the value of metallic and non-metallic minerals globally. Of this 2007 total value, metallic mineral commodities accounted for $26.3 billion, up 25.1% from the year before, with notable increases made by uranium and nickel. Non-metallic mineral commodities were valued at $11.3 billion and coal commodities at $2.8 billion (NRCan, 2007a). When broken down by province and territory, 28% of the value of all mineral production was generated in Ontario, British Columbia had the next highest share of production value at 17%, while Quebec had 14%, and Saskatchewan 11% (Figure 2.2) (MAC, 2007b).

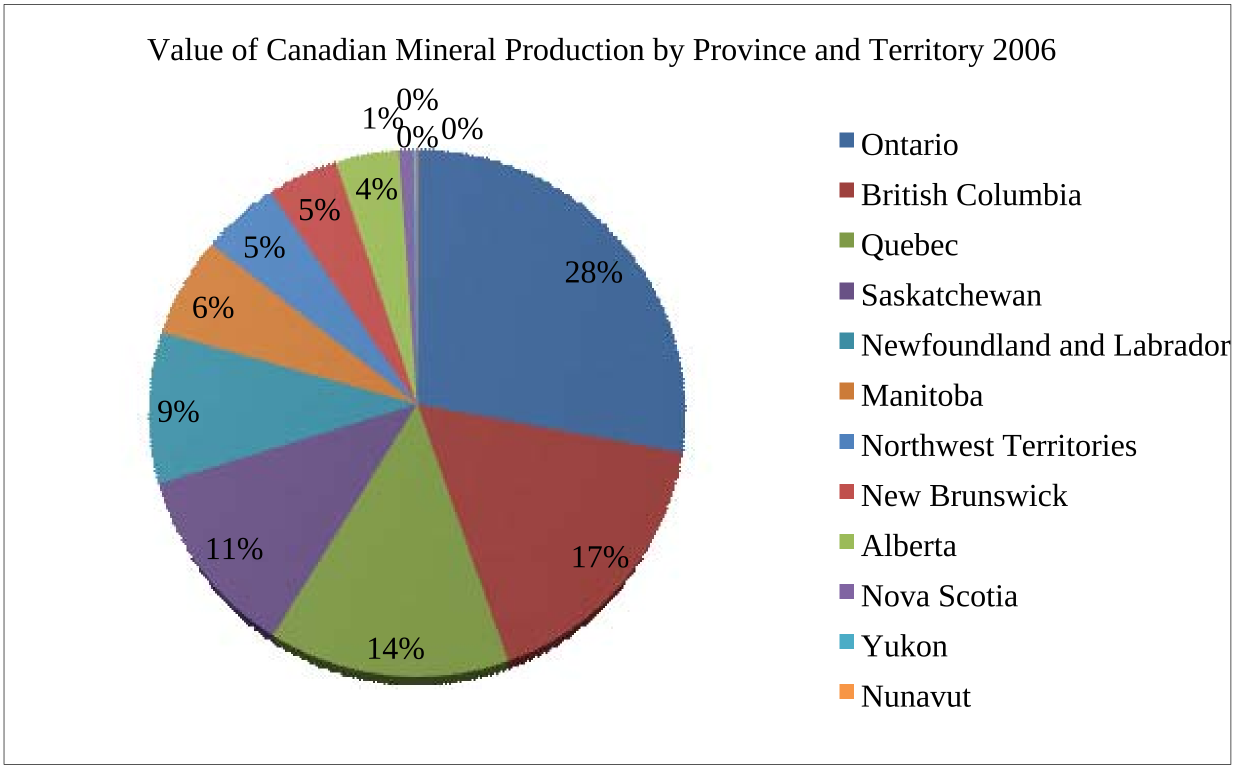

Figure 2.2: Total value of all mineral production in Canada, 2007**.**

In 2006 the Canadian mining industry provided $39.6 billion (or 3.7%) of the country's total GDP (NRCan, 2006). By this measurement, the mining sector was worth as much as the forestry industry, the agricultural industry and the electric power, gas and water utilities industries together (

Figure 2.3). Furthermore, the mining industry has demonstrated stable growth in line with trends in the Canadian economy; over the past 20 years the value of the Canadian mining industry has consistently averaged between 3.5% and 4.5% of Canada's GDP (MAC, 2007b).

In 2006, stage 1 (primary mineral extraction activities of mining and concentrating) activities contributed $9.8 billion to Canada's GDP, stage 2 (production of primary metals through smelting and refining of minerals) activities contributed $12.0 billion, stage 3 (processing of non-metallic mineral products) contributed $5.2 billion and stage 4 (fabrication of primary metal products) contributed $13 billion (MAC, 2007b).

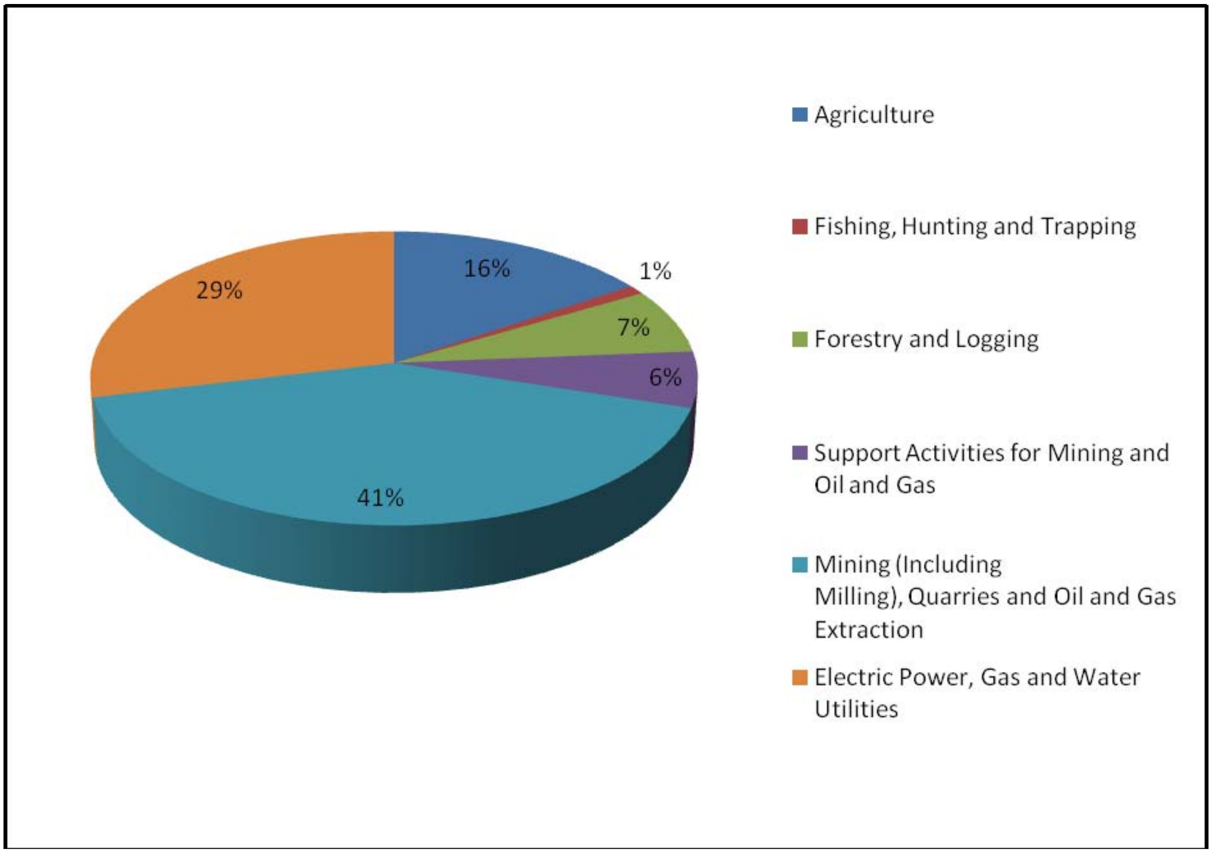

Figure 2.3: Percentage Contribution of Selected Industries to Canada's GDP, 2006**.**

2.1.3 Employment

The mining and mineral processing industries employ approximately 369 000 people, or almost 3% of all full-time employees in Canada. This number does not include exploration, contract drilling and other mining-related support activities that are directly and indirectly responsible for many other employment opportunities. Stage 1 operations accounted for 49,173 jobs. Of this number, metallic mineral extraction employed 24,791, non-metallic mineral extraction employed 19,663 and coal extraction employed 4,719 people. Employees in mineral extraction earned average weekly wages of $1,109, which is $362 more than the national average of $747. In terms of provincial and territorial breakdown of Stage 1 operations, Ontario had the largest share of employment, at 29%. The next five largest were Quebec (18.9%), British Columbia (13.7%), Saskatchewan (12.5%), Alberta (5.8%) and Newfoundland and Labrador (5.4%). Stage 2 operations in Canada employed 79 740 people, while Stage 3 operations employed 55,521 people. Stage 4 operations employed the majority of workers in the mining and mineral processing industries, accounting for 184,311 jobs (NRCan, 2007b).

2.1.4 Imports, Exports and Foreign Investments

The Canadian mining industry is also important internationally. Canada is one of the largest mineral and metal producers in the world, and is a leading producer of a number of minerals that are currently in high global demand. Canada ranks first globally in production of potash and uranium; second in nickel and cobalt; third in titanium concentrate, aluminum, magnesium, gypsum and platinum-group metals; fourth in chrysolite and cadmium; and fifth in zinc and molybdenum (MAC, 2007b) (Table 2.1).

Table 2.1: Significant minerals for which Canada was one of the top three global producers (2006).

Mineral	World Ranking	Canadian Production (t)	Percentage of Global Output
Potash (K2O equivalent)	1	10 700 000	34.5%
Uranium (metal content)	1	11 627	27.8%
Nickel (mine production)	2	198 000	13.7%
Cobalt (mine production)	2	5533	10.2%
Magnesium (metal)	3	65 000	9.0%
Titanium concentrate (ilmenite)	3	809 000	16.9%
Platinum group metals (metal content)	3	21 456	5.6%
Aluminum (primary metal)	3	2 894 000	9.1%
Gypsum (mine production)	3	9 500 000	8.6%

Note: Data from Canadian Mining Association, P. (2007a). Facts and Figures: A Report on the State of the Canadian Mining Industry. Mining Association of Canada.

In 2006 the Canadian mining industry exported $72 billion in metals, non-metals and coal, which was equivalent to 16% of all of Canadian exports. Of this, metals accounted for $57 billion, non-metals $11 billion and coal $3.4 billion. The most significant exports included iron and steel ($13.5 billion), aluminum ($12.3 billion), copper ($6.3 billion), gold ($5.6 billion), coal ($3.4 billion) potash ($2.4 billion), iron ore ($1.9 billion), uranium ($1.8 billion), diamonds ($1.7 billion) and nitrogen ($1.4 billion). In 2006, Canada also experienced approximately $38 billion in foreign direct investment in the metallic minerals and metal products sector, representing 8.5% of total foreign direct investment stocks in Canada that year (MAC, 2007a).

2.1.5 Exploration Activities

The purpose of mining exploration is to locate large, high-grade reserves for potential future development. Exploration requires healthy levels of investment to ensure success. In 2007 roughly 808 project operators reported expenditures for mineral exploration on approximately 3,000 properties across Canada. In that year, expenditures in Canadian mineral exploration grew for the 8th consecutive year, reaching $2.6 billion. This was up 34% from the 2006 total of $1.9 billion. The combination of high commodity prices and the availability of tax incentives in various Canadian jurisdictions combined to foster this growth, as did the decline in many Canadian mineral reserves. Almost 50% of exploration expenditures in 2007 related to drilling activities, where approximately 6.6 million meters were drilled, including underground, surface, diamond and other types of drilling. Rock work was the next largest area, accounting for 9% of expenditure ($233 million), followed by geophysics ($213 million), geology ($204 million) and the combined total of engineering, economic and pre-production feasibility studies ($186 million).

The top five provincial or territorial recipients of exploration[1] and deposit appraisal[2] expenditures in 2006 were Ontario ($342 million), British Columbia ($304 million), Quebec ($260.2 million), Saskatchewan ($236.3 million), and Nunavut ($199.7 million). In terms of expenditure by mineral commodities, precious metals had the highest share ($933 million), followed by base metals ($613 million), uranium ($354 million) and diamonds ($308 million) (NRCan, 2008b) (Table 2.2).

Table 2.2: Mineral Exploration and Deposit Appraisal Expenditures, by Province, 2002-2007.

Province ($ millions)	2002	2003	2004	2005	2006[p]	2007[i]	% Change from 2006 to 2007
British Columbia	39.2	62.5	151.9	218.1	304.0	319.2	5.0
Alberta	5.6	4.9	6.3	6.6	16.0	9.3	41.9
Saskatchewan	41.4	47.7	71.8	133.9	236.3	245.2	3.8
Manitoba	29.8	27.2	36.0	52.9	46.9	49.5	5.5
Ontario	139.0	219.4	306.9	294.0	341.6	371.4	8.7
Quebec	111.2	134.0	227.2	205.1	260.2	293.3	12.7
New Brunswick	3.2	2.6	13.4	10.1	12.8	25.2	96.9
Nova Scotia	3.4	6.4	9.1	6.5	6.7	18.0	168.7
Prince Edward Island	-	-	-	-	-	-	-
Newfoundland and Labrador	44.2	23.1	33.2	48.7	97.6	115.8	18.6
Yukon	7.8	12.7	22.0	54.0	76.2	103.7	36.1
Northwest Territories	72.7	53.6	112.4	96.3	129.8	112.2	13.6
Nunavut	75.9	92.7	187.5	178.7	199.7	225.2	12.8
Total	573.4	686.7	1177.8	1304.8	1727.8	1888.0	9.3

- = Nil or insignificant   I = intentions   p = preliminary

Note: Data from Canadian Mining Association(MAC, 2007a). Facts and Figures: A Report on the State of the Canadian Mining Industry. Mining Association of Canada: pp 21.

A strong majority - approximately 75% - of Canadian exploration and appraisal spending occurs off-site in greenfield areas (a rural area that has not been previously built on), rather than close to existing mine sites. This may be a result, for example, of federal tax policy that disadvantages on-site exploration spending together with the high cost of such exploration and exploitation of known deposits (MAC, 2007b).

2.1.6 Recent Global Economic Events

While the mining sector has long been known to experience pronounced 'boom' and 'bust' cycles (i.e. marked periods of economic gain and slowdown) and has weathered these events in the past, the current economic downturn has been altogether unique. The rapidity, severity, and breadth of the downturn have had major implications for the Canadian mining sector. Commencing in fall 2008, commodity prices dropped sharply around the world, access to vital credit markets became increasingly difficult, and the viability of certain mining operations

[1] *exploration expenditure:* spending on activities up to and including the first delineation of a previously unknown mineral deposit.
[2] *deposit appraisal expenditure:* spending on activities that bring delineated deposits to the stage of detailed knowledge required for a production feasibility study.

increasingly came into question. While these dramatic changes have presented mining companies with significant economic challenges – in the worst cases resulting in mine closure – the implications for climate change vulnerability have not yet been identified. Worryingly, these tough economic times may render the sector less willing and/or capable to invest in climate change adaptation strategies. Fiscal restraints and uncertain economic outlooks may cause mining companies to focus on maintaining profitability rather than pursuing environmental programs that are viewed as an extra cost.

It is also unknown if the recent acquisition of large Canadian mining companies by foreign interests will affect the vulnerability of mining operations to climate change. In cases where decision centers are moved out of Canada, for example, mining operations could become less responsive to changing local conditions and increasingly sensitive to matters of climate change. This, too, will need to be assessed in coming years.

CHAPTER 3

3.1 PROJECTIONS OF FUTURE CLIMATE CHANGE IN CANADA

3.1.1 Overview

This chapter outlines climate change projections for three time periods (2011 to 2040, 2041 to 2070 and 2071 to 2100) for six regions in Canada (Northern Canada, Atlantic Canada, Quebec, Ontario, the Prairies and British Columbia), with the aim of highlighting the magnitude of the climate change problem and outlining the kinds of changes mines will be exposed to. Based on a review of the latest climate change projections, we focus on the three most common emission storylines to assess how future climate might evolve. Common across all emission scenarios are projections of changing temperature and precipitation regimes (the two climate variables commonly accounted for in climate models), with changes more pronounced towards the end of the century. Northern – particularly Arctic regions – have already and are expected to experience the most dramatic changes. Change in average temperature for Canada as whole by the end of the century range from 1.1°C to 6.4°C.

3.1.2 Background

General projected future climate change trends are provided here and more detailed analyses are available in Natural Resource Canada’s, “From Impacts to Adaptation: Canada in a Changing Climate 2007” (Lemmen et al., 2008).

1.) Global Climate Models

Global climate models or General Circulation Models (GCMs) are three-dimensional computer representations of the various interacting components of the Earth's climate system, and use mathematical equations to predict future climate behaviour. There are different types of GCMs, and each focuses on different elements of the climate system: (1) *Atmosphere General Circulation Models* simulate the dynamics of the atmosphere interacting with the Earth's surface and the cryosphere; (2) *Ocean General Circulation Models* work on a similar principle but model the ocean and sea ice; and *(3) Atmosphere-Ocean General Circulation Models* (AOGCMs) are the most complex models and couple atmosphere general circulation models and ocean general circulation models to predict future climatic conditions. AOGCMs have been used in a number of major climate change reports including, the United Nation's Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4) and Natural Resource Canada's national assessment of climate change impacts and adaptation (Lemmen et al., 2008, IPCC, 2007b, c). The climate change scenarios developed in the NRCan national assessment report provide the basis of this chapter’s assessment of projected future climate trends in Canada.

2.) Emission Scenarios

To predict future climatic conditions, an AOGCM requires data on future atmospheric concentrations of greenhouse gases which cause climate change. This is achieved by using *emission scenarios*. An emission scenario is a description of a potential future, consisting of a plausible set of demographic, technological, social, economic, and environmental circumstances which determine greenhouse gas (GHG) emissions. Emission scenarios are not predictions – it is impossible to say with certainty whether a particular scenario will come to pass – but can be thought of as 'storylines' which offer possible future emission pathways. Because of the inherent uncertainty in projecting future emissions, studies often utilize several emission scenarios. The IPCC commissioned a 'Special Report on Emission Scenarios' (SRES) for its Third Assessment Report, which identified four distinct scenario 'storylines.' Each emission scenario varied in projected change in greenhouse gas emissions depending on different trajectories of social, economic, political, and technological development (IPCC, 2000). These four storylines were further divided into 40 more specific emission scenarios, representing a broad range of possible futures. Six of these scenarios were identified as the main, or ‘marker', scenarios and were used in combination with AOGCMs as the basis of the Natural Resource Canada's national assessment of climate change impacts and adaptation.

3.) Emission Scenarios Examined in this Report

Three emission scenarios, used in (NRCan, 2008a) Canadian Mineral Exploration and Deposit Appraisal are described in this chapter and referred to in this study: B1, A1B and A2. The *B1 scenario* represents a future with substantially decreased greenhouse gas emission levels; the *A2 scenario* represents a future with relatively high emission levels; and the *A1B scenario* represents a future with emission levels at a moderate point between the B1 and A2 scenarios.

B1 scenario- The B1 scenario depicts a future with a socially and environmentally conscious public, government, business, and media. It is marked by the introduction of clean, resource-friendly technology, and a transition to alternative energy sources. Under the B1 scenario, global population peaks at 9 billion in 2050 and decreases to 7 billion by 2100. In this scenario, average global temperatures are estimated to increase by 1.8° by 2090-2099, with a likely increase range of 1.1° to 2.9° (IPCC, 2007a, b).

A1B scenario - The A1B scenarios depicts a future with rapid economic growth, the introduction of new and more efficient technology and, as in the B1 scenario, a global population that peaks at 9 billion in 2050 before decreasing to 7 billion by 2100. It features increased international cooperation, and increased global movement of ideas, people and technology. The key feature of the A1B scenario is that it depicts a world with a balance of energy resources, including both fossil fuels and cleaner, alternative sources. Under the A1B scenario average global temperatures are estimated to increase 2.8° (with a likely range of 1.7°-4.4°) by 2090-2099 (IPCC, 2007c).

A2 scenario - The A2 scenario is marked by lower flows of trade, slower technological change and uneven economic growth. Global average per capita income is lower than either the A1B or B1 scenarios, with areas of lower incomes heavily reliant upon fossil-fuels for their energy. The A2 scenario also features the highest population, reaching 15 billion by 2100 because of increased regionalization that places an emphasis upon family and community life. Under the A2 scenario, average global temperatures are estimated to increase by 3.4° by 2090-2099 (with a likely range of 2.4° to 6.4°) (IPCC, 2007c). The A2 scenario does not represent the upper limit of potential emission levels. There are several scenarios, most notably the A1F1 marker scenario, that depict a future with an even higher reliance on fossil fuels and consequently even higher average global temperatures.

3.2 REGIONAL CLIMATE CHANGE SCENARIOS

This section applies the B1, A1B, and A2 emission scenarios using the AR4 GCM of the Canadian Centre for Climate Modeling and Analysis to describe potential future trends in temperature and precipitation in six regions in Canada: Northern Canada, Atlantic Canada, Quebec, Ontario, the Prairies and British Columbia. Each region is examined by scenario over three 30 year periods: 2011 to 2040, 2041 to 2070, and 2071 to 2100. These time periods will be referred to by their middle decade as per standard practice in the climate change literature: 2020 period, 2050 period, and 2080. General trends are presented for winter and summer periods.
It is noteworthy that the data used in this assessment was obtained using the AR4 GCM of the Canadian Centre for Climate Modeling and Analysis, available through the Canadian Climate Change Scenarios Network (www.cccsn.ca). All references to 'temperature' refer to average air temperature at a height of 2m, and all projections are referenced to a baseline period of 1961-1990. Any decrease in temperature or precipitation is denoted by the use of negative values.

3.2.1 Northern Canada

Temperature

- Temperatures are projected to increase across Northern Canada in the winter and summer in all three scenarios and time periods, and temperature increases are most pronounced in the winter (the largest of anywhere in Canada).
- In the winter, the region of Hudson Bay and the southern portion of the Foxe Basin are projected to see the largest winter temperature increases of any region in Canada.
- In the summer, the temperatures in the Foxe Basin and Hudson Bay regions are projected to increase less than the rest of Northern Canada.
- The greatest increases in summer temperatures are projected for the border between Nunavut and the Northwest Territories, running from Victoria Island, down to the Saskatchewan border, the Boothia Peninsula, Ukkusiksalik National Park, and the southern Yukon (this trend was only significant under the A1B and A2 scenarios).

Precipitation

- Precipitation will generally increase across Northern Canada, more so in the winter and increasing over time.
- While the three scenarios project comparable increases in total precipitation, the distribution of these increases differed by scenario.

3.2.2 Atlantic Canada

Temperature

- Temperatures are projected to increase across Atlantic Canada in the winter and summer in all three scenarios and time periods, and temperature increases are expected to be the largest in the winter.
- Smaller increases in temperature are projected for the south coast of Newfoundland and the northeastern coast of Nova Scotia compared to other areas in Atlantic Canada, and temperature increases are projected to be the greatest in the northern region of Labrador.
- In the summer, the region of New Brunswick, PEI, Nova Scotia and the southwest corner of Labrador are projected to have the largest temperature increases in Atlantic Canada.

Precipitation

- In all three scenarios, increases in precipitation are projected to be larger in the winter than in the summer. Increases are projected to be the largest under the A2 scenario, followed by the A1B. The B1 scenario projected the smallest increase, with some regions seeing slight decreases in precipitation by 2080.
- In the winter, precipitation increases are projected to be smaller along the coastline than inland. Under the B1 scenario the coastline is projected to see slight decreases in precipitation over the 2080 period.
- In the summer, precipitation is projected to decrease in the southern region of Atlantic Canada (New Brunswick, PEI, Nova Scotia and the southern coast of Newfoundland). The northern regions of Newfoundland and Labrador are projected to see increases in precipitation.

3.2.3 Quebec

Temperature

- Temperatures are projected to increase across Quebec in the winter and summer in all three scenarios and time periods, and temperature increases are most pronounced in the winter. Temperatures are projected to increase the most under the A2 scenario, followed by the A1B and the B1 scenarios.
- Winter temperatures are projected to increase the most in the northern half of the province, specifically along the coasts of James Bay and Hudson Bay. The south of the province, particularly along the St. Lawrence River and along the southern half of the Ontario border is generally projected to see significantly smaller increases in temperature.
- In the summer, the inverse is generally true, with the largest temperature increases projected for the regions near the St. Lawrence River and the Ontario border. These temperature increases are projected to be some of the highest in Canada. Lower summer temperatures are projected for the north.

Precipitation

- In the winter, significant increases in precipitation are projected in the St. Lawrence River region and along the eastern and northern coastline. Smaller increases are generally projected across the rest of the province. Increases in winter precipitation are projected to be higher under the A2 and A1B scenario than for the B1 scenario.
- In the summer, precipitation is expected to increase in the northern region of Quebec. In contrast, the southern region of the province, particularly along the St. Lawrence River and along the southern half of the Ontario border, is projected to see a decrease in precipitation. This trend is most pronounced under the B1 scenario and least pronounced under the A1B scenario.

3.2.4 Ontario

Temperature

- Temperatures are projected to increase across Ontario in the winter and summer in all three scenarios and time periods, and temperature increases are most pronounced in the winter. In the winter and summer, temperature increases are projected to be the largest under the A2 scenario, followed by the A1B and B1 scenarios.
- In the summer, Ontario as a whole is generally projected to see the highest summertime temperature increases of any region of Canada, with the exception of southern Manitoba, which is projected to see similar increases. These increases are uniformly distributed across the province, with the exception of the northernmost section of the Hudson Bay coast, which is generally projected to see smaller increases.

Precipitation

- In the summer, precipitation is projected to decrease in southern Ontario and the southern half of province along the Manitoba border. Summer precipitation is expected to increase in Northern Ontario. These trends are most pronounced under the A2 and A1B scenarios.

3.2.5 The Prairies

Temperature

- Temperatures are projected to increase across the prairies in the winter and summer in all three scenarios and time periods, and temperature increases are most pronounced in the winter.
- Temperatures are generally expected to increase uniformly across the Prairies, with the exception of two regions: the southern half of the Alberta - British Columbia border is projected to see smaller increases compared with the rest of the Prairies; and the coast of Hudson Bay is projected to see larger increases.
- In the summer, temperatures are projected to increase across the southeastern half of the Prairies, with the largest increases in temperature occurring in southern Manitoba. The

increases close to the Ontario border are projected to be among the highest summertime increases in Canada.

Precipitation

- Precipitation trends varied for each scenario. In the summer, precipitation levels are projected to be the lowest under the B1 scenario. In the winter, the A1B and A2 scenarios project large precipitation increases in Alberta. The B1 scenario projects decreases in precipitation in southern Alberta and the rest of the Prairies.
- Precipitation levels are projected to decrease in the summer, particularly in the southern prairies.

3.2.6 British Columbia

Temperature

- Temperatures are projected to increase across B.C. in the winter and summer in all three scenarios and time periods, and temperature increases are most pronounced in the winter. Temperature increases are projected to be the largest under the A2 scenario, followed by the A1B and B1 scenarios. Generally, B.C. is expected to experience smaller temperature increases than other regions in Canada.
- Temperature increases in the summer are generally uniform across the province with the exception of the Pacific coast which is projected to see smaller increases.

Precipitation

- In the summer and under the A1B and A2 scenarios, precipitation levels are projected to decrease in the southern parts of the province, specifically in the Vancouver region and Vancouver Island. Under the B1 scenario, precipitation is expected to increase, particularly along the coast.
- In the winter, and under the A1B and A2 scenarios, precipitation levels are projected to increase in the north of the province along the Yukon border. Precipitation increases are expected to be smaller in the south. Under the B1 scenario much of the province is projected to see decreases or negligible increases in winter precipitation.

CHAPTER 4

4.1 CLIMATE CHANGE AND THE CANADIAN MINING INDUSTRY: A LITERATURE REVIEW

4.1.1 Overview

This chapter assesses what we know and don't know about climate change and the Canadian mining sector based on a literature review of trade and scientific publications, identifying key questions for the research described in this report. Key findings include:

- There is an emerging literature in trade journals on climate change impacts, with a strong focus on mitigation.
- Trade journals present comparably less information on climate change impacts and adaptations compared to scientific publications.
- While some trade journal articles have debated the science and validity of climate change, the majority of articles reviewed note that climate change is a problem with relevance to the Canadian mining sector.
- The scientific literature on climate change impacts and adaptations in the mining sector is emerging, although few studies have been conducted to date.
- Key mining activities which the scientific literature indentifies as specifically at risk from climate change include mining and transportation infrastructure, and processing operations.
- The scientific literature on climate change adaptation in the mining sector is limited, although research has established broad principles for mainstreaming no-regrets adaptation and future planning.
- There is currently a deficit in the Canadian mining sector in terms of what we know about climate change impacts and how to adapt, and what we need know for the future.

4.1.2 Trade Journals

Mining industry trade journals, websites, and publications by Canadian and non-Canadian mining associations were reviewed to investigate what has been reported about the vulnerability of the mining sector to climate change. Given the rapid development in climate science and impact assessment, only sources of information published since 2002 were considered. The main mining journals with relevance to Canada were selected along with mining associations representing Canadian mining companies, with searches performed using the following key words: 'climate change', 'global warming', 'greenhouse effect' and 'greenhouse gases'. Table 4.1 highlights the trade journals and mining associations that were investigated:

Table 4.1: Trade journals and mining associations reviewed

Trade Journals	Mining Associations
Canadian Mining Journal CIM Bulletin Coal Age Engineering and Mining Journal Mine Water and the Environment Mining and Quarry World Mining Journal Mining Magazine Sudbury Mining Solutions Journal The Northern Miner	Alberta Chamber of Resources Association for Mineral Exploration British Columbia European Association of Mining Industries International Council on Mining and Metals Minerals Council of Australia Mining Association of British Columbia Mining Association of Canada National Mining Association (USA) NWT and Nunavut Chamber of Mines Ontario Mining Association Prospectors and Developers Association of Canada Quebec Mining Association Saskatchewan Mining Association Yukon Chamber of Mines

The review reveals that the Canadian mining sector is aware of climate change and that they have begun to prepare for it in a number of ways. For example, The International Council on Mining and Metals recognizes "the significance of climate change as a global issue, requiring a global response" (ICMM, 2006) and the Mining Association of Canada has stated that they are "…firmly committed to being part of the climate change solution. Our Association takes climate change and the reduction of greenhouse gas emissions very seriously" (MAC, 2004). There have been a number of climate change-related presentations at major mining conferences including the Prospectors and Developers Association of Canada (PDAC) annual conference, Sudbury's international 'Mining and the Environment' conference, the World Mines Ministries Forum, and at the Canadian Institute of Mining, Metallurgy and Petroleum annual conference, with the majority focusing on mitigation initiatives.

Climate change has also been discussed in trade journals, with the majority of coverage relating to greenhouse gas reduction and energy management initiatives. For example, there have been reports on proposed carbon emissions caps in Canada and other carbon emissions-related legislation (e.g. Ednie, 2002, The Northern Miner, 2007), reports on the top Canadian emissions reducing companies (e.g. The Northern Miner, 2000) and discussions on the merits of voluntary vs. mandatory emissions reduction initiatives. Reports on initiatives to reduce greenhouse gases have focused on implementation of the Kyoto Protocol (e.g. Ion, 2004), carbon emissions trading schemes (e.g. Ednie, 2002) carbon offsetting for industry (e.g. Ednie, 2002, Wise, 2005), emissions reducing technologies (e.g. Ednie, 2002), and evaluation of carbon sequestration opportunities (e.g. Canadian Mining Journal, 2005, Coal Age, 2007, Ednie, 2002, Ion, 2004).

'Energy management' initiatives were also widely discussed in the trade journal literature. For example, energy management was reported by Ednie (2004) as a means "to meet environmental regulations, attain emissions reductions targets and lower operating costs". In many instances, climate change is often not the sole focus of these articles; often, energy management initiatives are viewed as a way of achieving multiple objectives, of which reducing greenhouse gas emissions was one. The Mining Association of Canada similarly views energy management as an important issue, even including ‘Energy and Greenhouse Gas Emissions’ as a key performance indicator for their ‘Towards Sustainable Mining’ (TSM) initiative.

TSM is a broader commitment by the Mining Association of Canada’s member companies to improve their performance in areas of sustainable development and to enhance the reputation and credibility of the Canadian mining industry with its communities of interest and the public. Six sub-indicators within TSM have been established and are reported on within the broader ‘Energy and Greenhouse Gas Emissions’ indicator:

1. Energy use management systems;
2. Energy use reporting systems;
3. Energy intensity performance target;
4. Greenhouse gas emissions management systems;
5. Greenhouse gas emissions reporting systems; and,
6. Greenhouse gas emissions intensity performance target.

For each of these sub-indicators, MAC members are categorized into one level on a six-level scale which most clearly represents the status of their operation. The intent of the assessment system is to provide a common basis for monitoring implementation progress for each of the indicators (MAC, 2004). MAC also reports on energy and GHG emissions data in its annual reports (see for example, MAC, 2007).

The literature also contains reports on the impacts of climate change on the physical aspects of mining projects, although there are fewer studies in this regard compared to those on mitigation. For example, the Canadian Mining Journal (2006) and Robertson (2006) both report on ice road closures which affected mining operations in the Northwest Territories and British Columbia; a major problem during the 2006 ice road season. Deloitte and Touche (2008) meanwhile, address risks to infrastructure for mining projects from climate change. In this study, climate change is viewed as posing a number of risks to mining projects and having implications for regulations, new technologies and changing public opinion. Jimena (2006) further discuss the role of the public, noting that investors and shareholders are now demanding companies address climate change and similarly disclose their emissions. This trend is consistent with broader moves in industry to develop a green advantage and appeal to shareholders.

Absent in the trade journal literature, however, is a *thorough* discussion and *rigorous evaluation* of what climate change will mean for the physical aspects of mine operations both today and in the future, and capacity of the sector to adapt to change. While this was briefly alluded to in reports on poor ice road conditions (e.g. Canadian Mining Journal, 2006, Robertson, 2006), comprehensive investigations into climate related risks to infrastructure, for example, were not noted. In some cases, trade journals reported on the ‘debate’ about the causes of climate change (i.e. anthropocentric vs. natural causes), reporting which in some instances downplayed the issue’s significance (e.g. Kaufman, 2007, Popovich, 2007, The Northern Miner, 2007, The Northern Miner, 2008). Overall, the physical risks likely to face mining companies in the future in the context of a changing climate were afforded little attention.

Climate change was more often than not viewed as a regulatory or ‘political’ risk in the trade journal literature as opposed to a physical one. Adaptations, in this regard, focused largely on reducing greenhouse gas emissions as a means to meet the threat of future legislation or to take advantage of carbon trading schemes. The potential effects on infrastructure of changing temperature and precipitation regimes, increased extreme weather events and melting permafrost were not considered in the majority of reports. Issues relating to water availability, emergency management and planning in a changing climate are also not discussed. Also noticeably absent was any discussion on the opportunities a changing climate may bring to mining projects. While climate change will undoubtedly have negative impacts, as the National Adaptation Assessment highlights (Lemmen et al., 2008), it will likely also produce opportunities; no discussion of these potential opportunities was noted in the literature.

Nevertheless, climate change is now a recognized and increasingly reported on issue in the mining sector. Although the significance of climate change has been established, a rigorous assessment of varied adaptation needs and risks is now needed. Indeed, there is currently a deficit in the Canadian mining sector in terms of what we know about climate change adaption and what we need to know in the future; a deficit which has been more generally noted for Canada as a whole (Burton, 2006).

4.1.3 Scientific Reports and Periodicals

This section reviews current scientific understandings of the Canadian mining industry’s vulnerability to climate change. Recent scientific reports from national and international institutions with environmental mandates, and academic periodicals were reviewed. Relevant climatic and environmental conditions affecting the mining industry were identified using the same key words as guided the review of trade journals, with particular attention given to climatic impacts on mine design, construction, and operation. Current and potential future adaptive strategies used by the mining sector to deal with climatic change were also documented. Table 4.2 highlights the sources reviewed for this section.

Table 4.2: Institutions with environmental mandates and scientific periodicals reviewed

Institutions with Environmental Mandates		Scientific Periodicals
International/Bilateral	**National**	
Intergovernmental Panel on Climate Change (IPCC) International Commission on Large Dams (ICLD) Arctic Climate Impact Assessment (ACIA) International Joint Commission United Nations Environmental Program	National Resources Canada Office of the Auditor General (Canada) US Global Change Research Program (USGCRP) US Department of Transport Canadian Climate Change Scenarios Network Environment Canada Infrastructure Canada Transport Canada Indian and Northern Affairs Canada Engineers Canada	Climatic Change Atmosphere-Ocean Journal of Organizational Change and Management Global Environmental Change Limnology and Oceanography Journal of Hydrology Ecotoxicology and Environmental Safety 2006 IEEE-EIC Climate Change Technology

The body of scientific literature addressing the relationship between climate change and mining is relatively recent. Few publications have specifically investigated this relationship. Despite this gap in knowledge it is evident from the literature that the scientific community perceives climate change to be a tangible concern for the mining industry in Canada. Specifically, the literature identifies a number of current and predicted future physical impacts of climate change on the mining sector. Climate change is expected to impact mining in terms of workforce, transportation, communication, building infrastructure, operations and mine decommissioning. Three aspects of the mining industry are believed to be particularly sensitive to climate change: mining infrastructure and transportation, processing operations, and site geography. Table 4.3 provides a detailed summary of the exposures and sensitivities of the sector, opportunities, and adaptation and mitigation strategies relevant to these aspects of the mining industry.

Table 4.3: Summary of exposure-sensitivities, opportunities, mitigation and adaptation strategies within the mining sector

Aspect of Industry	Sources	Exposure/Risk	Opportunity	Adaptation	Mitigation
Infrastructure	General sources relevant to climate change and Canadian mining infrastructure: • Infrastructure Canada			General adaptations applicable to most mining infrastructure as offered by (Auld et al., 2006): • Structural reinforcement, retrofitting, redundancy, and replacement • More intensive maintenance routines	
1. Transportation	General sources relevant to climate change and Canadian transportation infrastructure: • Transport Canada			General mitigation measures applicable to mining transportation as offered by IPCC, 2007: • Increase fuel efficiency of vehicles • Land-use/transport planning	
a) Roads	• (Auld et al., 2006:8) • (IJC, 2003:19) • (Lemmen et al., 2008:84-85) • (NRCan, 2004-143) • (Mills & Andrey, 2002:3) • (Instanes et al., 2005:928) • (The Northern Review, 2001:78) • (Alessa et al., 2008:266) • (Yamaguchi et al., 2005) • (IPCC, 2007a:2,15) • (Bonsal et al., 2001:5-6) • (Borrow, 2004)	• Permafrost thaw causing cracks, sinking, slumping of road bed • Lake-effect snow events block roads (Great Lakes region) • Warmer temperatures causing melting of Northern ice roads		• Terracing to create stability • Abandon and rebuild elsewhere • Increase all season road network • Enhance load bearing capacity through snow removal and compaction • Enhance thickness through surface flooding or spray-ice • Modified transport schedules to coincide with mid-winter months • Balloon transport (NRCan, 2004:	• To mitigate against affects of permafrost thaw: • Reduce ground warming in design and operation (insulation) • Reduce ground disturbance at design phase • Avoid thaw sensitive soil locations • Use permafrost preserving infra-structure

				144) • Increase in sea transport • Intelligent Transport Systems (automated traffic control and advisory) (NRCan, 2004: 144).	
b) Marine	• (Neale et al.:12) • (Lemmen et al, 2008: 81-85) • (IPCC, 2007c:2, 10-13) • (Bonsal et al., 2001:5-6) • (Instanes et al., 2005: 937)	• Stronger winds increasing risks to barge traffic from waves and surges • Increased variability in environmental conditions inhibiting on-route navigation.	• Rising average temperatures causing reduced ice pack and allowing for longer shipping periods, shorter routes, greater exploration etc.		
c) Fresh Water	• (Neale et al.:11-12) • (Lemmen et al, 2008: 85) • (Quinn, 2002:6-7) • Lindeberg (Lindeberg and Albercook, 2000:39-42) • (IJC, 2003: 4-31) • (Mortsch and Quinn, 1996:906,910) • (Mortsch et al., 2006) • (Alessa et al.,	• Decreased water levels in rivers, lakes (incl. the Great Lakes) due to greater evaporation and variation in precipitation events creating shallower ports and shipping channels; unknown consequences for flat bottom barges.	• Rising average temperatures causing reduced ice pack and allowing for longer shipping period.	• Increase all season road network • Increase dredging • Reduce ship loads • Use of alternate transport methods (i.e. rail, road, etc.)	

	2008:166) • (Bonsal et al. 2001: 5-6) • (Borrow et al., 2004)				
2. Containment Facilities (Tailings)	• (Instanes, 2005: 926-927) • (Lemmen et al, 2008: 259) • (Neale et al.,: 8) • ICOLD, 2001 • (ICOLD, 2001) • (Kyhn and Elberling, 2001:131, 137-141) • (Zhang et al., 2000) • (Bjelkevik, 2005) • (Romano et al., 2003) • (Yamaguchi, 2005) • (Lemly, 1994: 230,235) • (Bonsal et al. 2001: 5-6) • (Borrow et al., 2004)	• Warmer average temperatures leading to Acid mine drainage • altered freeze-thaw cycles exposing previously frozen tailings • evaporation of water covers on tailing pond exposing raw tailings • High intensity precipitation causing saturation of tailings impoundment, overtopping, and erosion leading to risk of failure • Wind and wave action of extreme weather events causing re-suspension of tailings and formation of ice dams		• Research and development of new cover materials (Auld et al., 2006:5)	• (See 1.a) • Reduce quantity and size of tailing ponds exposed to climatic conditions by: • Re-circulating waste water for reuse in mine operations • return mine waste underground through backfilling (Lemly, 1994:235-236)
3. Buildings	• (Auld et al., 2006:4,6) • (Fernandez, 2002) • (The Northern Review, 2001: 69) • (Alessa, 2008: 266) • (Yamaguchi, 2005) • (IPCC, 2007c:2,15) • (Borrow et al., 2004)	• Permafrost thaw jeopardizing structural integrity via ground instability • (partial or entire collapse, sinking, etc.)		• Climate relevant building codes and standards • Build according to the Diversified Lifetimes Strategy (Fernandez, 2003)	• (See 1.a) • Structural forensic disaster investigations to inform future building development

4. Energy				General adaptation/mitigation measures applicable to most mining operations as offered by IPCC, 2007 and Auld, 2006b: backup power sources, decrease energy requirements, disaster resistant energy service systems (renewable energy), self sufficient technology	
a) Communications	• (Lemmen et al, 2008: 313) • (Neale et al.:7)	• Extreme weather events isolating mine operations from people, goods and services			
b) Powered facilities/equipment (buildings, machinery, etc.)	• (Auld et al., 2006:7)	• Extreme weather events causing power failures therefore altering activity timing			
5. Mine Site Drainage	• (Neale et al.:11) (Bjelkevik, 2005: 33-34) • (Zhang et al., 2000) • (Borrow et al., 2004)	• Greater precipitation frequency and intensity may cause flooding and/or dilution of effluent. • Altered freeze-thaw cycles forming ice dams		• Alter drainage system design	
Operations					
1. Processing	• (Lemmen et al, 2008: 308, 259) • (Brown et al., 2006:42) • (IPCC, 2007c:10)	• Water scarcity limiting production rates, dust suppression, tailing pond covering options, and jeopardizing drainage effluents etc.		• Reduce water intake • Recycle process water • Move water from tailing ponds/ pits/quarries to underground use	
Mine Site Geography (condition of property)					

1. Environment	• (Instanes, 2005; 927) • (NRCan, 2004:138) • (Zhang et al., 2000) • (Borrow et al., 2004) • (Kyhn and Elberling, 2001: 139)	• Erosion induced by greater frequency and intensity of precipitation and/or permafrost thaw of slopes, berms, and mine pit walls. • Rising average temperatures and extreme weather events (wind storms) damage Northern snow fences protecting tailing ponds from oxidation and re-suspension			

Infrastructure and Transportation: It is generally accepted that “under changing climate conditions, it is likely that risks of infrastructure failure will increase … as weather patterns shift and extreme weather conditions become more variable and regionally more intense” (Auld and MacIver, 2006) This is a primary concern for Infrastructure Canada: “due to climate change, Canada’s infrastructure is increasingly forced to withstand more frequent and extreme weather events, more climate variability, and changes in climate norms (average conditions)” (2006)Transportation, containment facilities, buildings, energy, and mine site drainage are highly susceptible to permafrost thaw, rising average temperatures, stronger winds, changing water levels and ice composition, and greater intensity and frequency of precipitation. Consequently, the scientific community is concerned with declining structural integrity, reduced time efficiency of altered activity methods, and limited access to relevant markets. The Arctic Climate Impact Assessment (ACIA), for example, highlights the effect that permafrost thaw has on Arctic transportation infrastructure. Melting ice and weakening ground subsistence pose risks to the seasonal availability and safety of ice roads, and the structural integrity of overland roads, bridges, pipelines, and airstrips (Instanes et al., 2005). Melting sea ice also presents a number of potential opportunities for the mining sector including longer shipping seasons, shorter transportation routes, and increased exploration opportunities (Instanes et al., 2005, Lemmen et al., 2008).

Processing Operations: The scientific community recognizes mine processing operations as being especially vulnerable to the changing climate. As mining is in many instances a “heavily water dependent” industry, increased water scarcity presents a significant challenge (Lemmen et al., 2008, UNEP FI & SIWI, 2005). Water scarcity can impact production rates, dust suppression activities, mine drainage composition, and the covering of tailing ponds, amongst other issues. Furthermore, managing issues associated with water scarcity will occupy valuable resources (e.g. personnel) that would otherwise be devoted to mine processing tasks (Brown et al., 2006).

Other Site Features: Other features integral to a mines’ functionality have been noted as being vulnerable to climate change. For example, “the stability of open-pit mine walls will possibly be affected where steep slopes in permafrost overburden have been exposed for long periods of time” (Instanes, 2005). In Northern Canada, snow piles are maintained by snow fences to prevent wind erosion of tailing ponds. These piles are at risk of melting from rising average temperatures or blowing away themselves in extreme weather events, exposing tailing ponds and allowing for the oxidization of contaminants (Kyhn and Elberling, 2001). More generally permafrost thaw is a risk across northern regions, especially where containment structures have not been designed to withstand the accelerated melting predicted with climate change, or designed to facilitate long term maintenance (Furgal and Prowse, 2008, Prno, 2008a). Flooding and extreme precipitation also threaten to expose sink holes and induce/exacerbate acid rock drainage which potential impacts on water resources. These are but a few of the vulnerabilities mine sites could face.

Adaptive Strategies: The scientific community considers current and future adaptability of the mining sector a feasible and necessary task to ensure the viability of some mining operations. The Northern Review reports that “private sector industries such as … mining … need to include climate change considerations in research, planning and design of projects” (2001). Others have also re-affirmed the need to “mainstream” adaptation by integrating adaptive strategies into everyday business planning and focusing on adaptations which bring benefits regardless of the impacts of climate change (so called win-win, or no-regrets adaptation) (Smit & Wandel, 2006, Ford et al., 2007, Ford, 2008a). Auld et al. (2006), for example, suggest a two-pronged approach to increasing infrastructural adaptive capacity. First, they suggest employing “no regrets” measures which include activities such as strictly enforcing engineering codes and standards, “consistent forensic analyses of infrastructure failures”, and “maintenance of the quality and length of climate change records and networks”, amongst others. Other strategies could involve the derivation of new methods for determining climate design values, and the provision of design-specific advice relating to climate change based risk factors. Second, they suggest continued “adaptation learning” whereby adaptation options are developed through progressive and on-going research; this research is often suggested to be participatory in nature. “No regrets” and “adaptation learning” have been applied to other aspects of mining as discussed in: The 2006 Report of the Commissioner of the Environment and Sustainable Development (Government of Canada, 2006); Natural Resources Canada’s report ‘From Impacts to Adaptation’(Lemmen et al., 2008) Infrastructure Canada’s adaptation literature review (Infrastructure Canada, 2006); the Arctic Climate Impact Assessment (ACIA, 2005) and; Mills and Andrey (2002).

4.1.4 Gaps in Knowledge

This literature review has revealed that climate change is a significant concern for the mining industry. However, the following gaps and observations are apparent, and help guide this research:

- When comparing the scientific literature with information from mining industry trade journals, a strong discrepancy exists. The mining industry perceives climate change to be foremost a political or regulatory risk yet the scientific community views it as primarily a physical risk. This discrepancy will likely affect discussions on adaption and mitigation and requires further inquiry.
- The mining industry’s vulnerability to climate change is generally treated as being discrete from its greenhouse gas emissions. A select few publications have called for greater integration of mitigation and adaptation measures yet even fewer provide concrete suggestions for how to accomplish this; initiatives that reduce GHGs and also increase adaptability are particularly desirable.
- Several industry-wide barriers to adaptation have been identified. These include lack of technical information, high capital costs, configuration of current operations, competitive pressures and existing industry regulations (Post and Altama, 1994). Absent from this discussion is a thorough evaluation of the organizational barriers faced by mining companies in regards to climate change adaptation such as “employee attitudes, poor communications, past practice and inadequate top management leadership” (Post and Altama, 1994).
- Although Natural Resources Canada recognizes there are “an estimated twenty-seven thousand orphaned or abandoned mines” across the country, little scientific literature evaluates the role and impact of climate change in mine rehabilitation projects (NRCan, 2007).
- Due to the corporate nature of the mining industry and its wide geographic scope, adaptation to climate change is often discussed and implemented at an institutional scale (Lemmen et al, 2008). This may be technologically or economically efficient but previous research on adaptation to climate change suggests that “adaptive capacity is context specific” varying

through space and over time according to local resources and environmental conditions (Smit and Wandel, 2006). There is a need for more case-specific research to investigate the nature of vulnerability.

CHAPTER 5

5.1 RESEARCH APPROACH

5.1.1 Overview

This chapter describes the vulnerability approach and methods used to structure the data collection. We use a common conceptualization of vulnerability as a function of exposure-sensitivity to climate conditions and adaptive capacity to deal with exposure-sensitivity. Mixed methods including surveys and in-depth interviews are used to identify and characterize both current and future climate change vulnerability drawing upon the insights of mining sector stakeholders.

5.1.2 The Vulnerability Approach

5.1.2.1 Conceptual model

In this research, we use the conceptual model of Ford and Smit (2004) and Ford et al. (2008) to examine the vulnerability of the Canadian mining sector to climate change. This model conceptualizes vulnerability as a function of exposure-sensitivity to climatic conditions and the adaptive capacity to deal with those risks. Exposure-sensitivity refers to the propensity of mining operations to be negatively affected when exposed to certain climatic conditions. It is a joint property of both the characteristics of climatic conditions (e.g. magnitude, frequency, spatial dispersion, duration, speed of onset, and timing), and the nature of the mining operation in question (Smit & Wandel, 2006). *Adaptive capacity* refers to the ability of individual mines and the sector as a whole to address, plan for, and/or adapt to these conditions. In this conceptualization, vulnerability is viewed as being determined by economic, political, and climatic conditions and processes operating at multiple scales which affect mining sector exposure-sensitivity and adaptive capacity. This is consistent with other conceptualizations of vulnerability in the climate change literature (Berrang Ford et al., 2008, Smit et al., 2008, Smit and Wandel, 2006, Turner et al., 2003, Fussel and Klein, 2006, Schröter et al., 2005, Duerden, 2004).

Vulnerability based adaptation research broadens the scope of climate change adaptation planning to focus on measures that reduce sensitivity and exposure *and/or* increase adaptive capacity. This may include, for example, the prescription of conventional techno-engineering adaptive responses designed to reduce climate change exposure. More often, vulnerability based research also advocates the development of initiatives to strengthen adaptive capacity and/or reduce climate sensitivity which are not normally considered under impacts-driven research. Importantly, such recommendations usually target the reduction of current climate vulnerability, bringing immediate benefits alongside reduced vulnerability to future climate change, so called “no regrets” adaptation.

5.1.2.2 A two stage approach for assessing vulnerability

A two stage analytical framework is used to empirically employ the conceptual model to assess vulnerability of the mining sector to climate change (Fig. 5.1). Analysis begins by identifying current climate vulnerabilities faced by the sector which directly feeds into an assessment of vulnerability to future climate change. Potential adaptation responses are considered in all stages of the framework. The following provides a step-by-step guide to the framework.

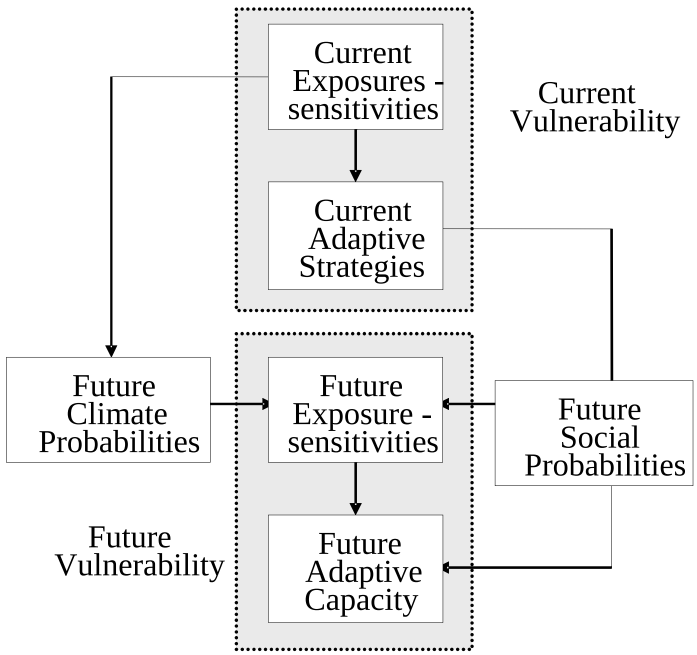

Figure 5.1: Conceptual framework for assessing vulnerability to climate change (adapted from Ford & Smit, 2004; Smit & Wandel, 2006)

5.1.2.2.1 Stage 1 Current Vulnerability

Assessment of current vulnerability is concerned with the present day, characterizing how current climatic conditions affect the mining sector, and identifying entry points to reduce risks on a *short term planning* horizon.

<u>Identify exposure-sensitivity to climatic conditions</u>

Characterization of current vulnerability begins by identifying *exposure-sensitivity* to climatic conditions. For example, temperatures, precipitation, and wind can have direct impacts on mines: strong winds can knock out power lines, high temperatures can cause heat stress among employees, and low precipitation can reduce water supply. These climatic conditions also influence the magnitude and frequency of natural hazards including flooding, avalanche, drought, landslides, ice storms, and forest fires. Questions of importance when identifying exposure-sensitivity include:

- What is the physical nature of climatic conditions that pose risks?
- What time of the year do they occur and how frequent are they?
- At what thresholds do they become a problem? For example, how much snowfall can engineering structures safely handle?
- What areas / operations are affected?
- The production of maps can be useful in identifying areas at risk of different hazards
- How is the impact determined by the severity of the climatic conditions?

At this stage it is also important to identify *why* exposure-sensitivity to climatic conditions exists. Understanding causal mechanisms can help identify entry points for planning to reduce exposure-sensitivity, which in turn will help reduce exposure-sensitivity to future climate change impacts.

<u>Evaluate the effectiveness of current management practices</u>

Characterization of current vulnerability finishes by identifying plans currently employed by the mining sector to manage climatic hazards before, during, and after they occur, to provide insights in adaptive capacity to deal with stress. Plans may directly relate to climate hazards. For example, mines may have detailed procedures in case of emergency situations including loss of power, reduced transportation access, or accidents. Other plans may be more indirect. Business contingency planning for instance, may not relate directly to climate risks, but the general procedures contained in these plans can help maintain operations during a flood or climate-related power outage. Once inventoried, assessment then examines the effectiveness of existing climate management strategies. This may involve looking at current and past experience of managing climatic hazards, which allows strengths and weaknesses to be identified on the basis of actual experience, and develops a greater understanding of factors that constrained or enabled management ability. For some climate hazards, however, there may be no past experience. In such instances, assessment can involve the creation of hypothetical scenarios during which response procedures are assessed.

The outcomes of the assessment of current management practices can feed directly into improved climate hazard planning. Common weaknesses revealed by such analysis include: conflict in jurisdiction over response strategies; lack of guidance and misunderstanding on how to respond among employees; conflicting emergency response guidelines; absence of contingency plans for worse case scenarios; poor communication within and across organizations, and departments; and limited knowledge of sensitivity to climatic stresses. Once identified, addressing these weaknesses can often be achieved within existing budgets, human resources, and decision making structures.

From a climate change planning perspective the benefits of systematically assessing climate management plans are well-recognized: enhancing capacity to deal with present climatic risks strengthens resilience to longer-term climate change. More importantly, such planning can bring immediate benefits in the form of reduced sensitivity and increased capacity to manage current climatic hazards.

5.1.2.3 Step 2 Future Vulnerability

Analysis of current vulnerability feeds directly into assessing vulnerability of the mining sector to future climate change. This stage forms the basis for longer term *strategic planning*.

Characterizing future climate exposure-sensitivity

Characterizing future climate exposure-sensitivity firstly involves identifying how climate change will affect climatic conditions to which exposure-sensitivity already exists. Questions of importance include:

- How will the magnitude, frequency, and timing of climatic hazards be affected by climate change?
- Will climate change make current problems more widespread?
- Will new problems emerge?

Once the impacts of climate change have been specified, it is then necessary to evaluate exposure-sensitivity of mining sector operations and activities to projected changes. This may involve producing maps showing areas that will become high risk (e.g. of flooding) with climate change, identification of infrastructure that is at risk, and evaluation of the sustainability of current mines in given locations. The output from this analysis can provide context for long term planning to reduce exposure-sensitivity to climatic risks.

Examine future management challenges

The vulnerability assessment is completed by evaluating the extent to which current management practices employed by the mining sector will enable future climate change impacts to be dealt with. This involves hypothetical simulations examining the strengths and weaknesses of existing plans to manage exposure-sensitivities that will emerge with climate change. It can also involve looking at how management systems have coped with similar climatic events to those projected, using this experience to guide the development of long term management plans.

5.1.3 Methods

5.1.3.1 Mixed methods

A mixed methods approach including quantitative and qualitative analyses was employed in this research to characterize the vulnerability of the Canadian mining sector to climate change. All the methods drew upon the observations, experience and knowledge of mining sector practitioners. This is particularly important: mining sector practitioners have significant expertise and knowledge of mining and how climate affects operations, built up through personal observation and hands-on management. Stakeholder input and insight can therefore be used to characterize current exposure-sensitivity and adaptive capacity, and is documented in this study using fixed question surveys, in-depth interviews, and focus groups. In conjunction, natural science data is utilized to characterize how climate and climate-related risks may change in the future. The methods are described in detail in subsequent results chapters.

5.1.3.2 Research Timeline

The project began with a fixed-question survey administered to participants at the Prospectors and Developers Association of Canada annual meeting in Toronto, March 2008 (chapter 6). A survey approach was chosen, as it allowed for the rapid collection of standardized data that could be analyzed using a number of statistical techniques. This was ideal in establishing a baseline understanding of climate change vulnerability in the mining sector. A second more detailed survey was then developed and administered by phone to mining practitioners selected by a random sample from the population of the entire Canadian mining sector (chapter 7). Case studies involving interviews and focus group discussion were then conducted with mining sector practitioners across Canada to develop an in-depth understanding of climate change vulnerability and opportunities for adaptation. Some of these interviews took place at mine sites and others at company headquarters. Case studies were utilized to further investigate key findings from the surveys, allowing practitioners to explain in detail how their companies are experiencing and responding to climate change. The narratives offer a rich description of climate vulnerability and its determinants. Climate data, models and scenarios were then used to provide insights on how climatic changes might affect each case study region.

CHAPTER 6

6.1 PERCEPTIONS OF CLIMATE CHANGE IMPACTS, ADAPTATION AND VULNERABILITY IN THE CANADIAN MINING SECTOR: THE PDAC SURVEY

6.1.1 Chapter Overview

Mining sector practitioners can play a key role in adaptation planning. Understanding how they perceive climate change, how they view opportunities and how they view limits to adaptation is important for understanding vulnerability of the mining sector to climate change, and outlining opportunities for policy (IPCC, 2007b, Ford and B. Smit, 2004, Keskitalo, 2008). Data on perceptions of climate change vulnerability and adaptation among mining sector practitioners were collected at the Prospectors and Developers Association of Canada (PDAC) International Convention in Toronto, March 2008, using a close-ended survey. 42 randomly selected conference delegates were surveyed over two days. Key findings include:

- The mining sector is sensitive to climatic hazards.
- Climate change is currently having a negative impact on some mining sector operations.
- Companies are taking action to manage the impacts of climate change using a number of strategies.
- Cost and uncertainty are the most commonly identified barriers to adaptation.
- Future climate change is expected to have impacts for company operations.
- Projected changes in climate are viewed as having potentially adverse impacts and are thought to bring few benefits.
- Despite the perceived threat of future climate change, companies are not currently taking action to plan for future climate change.
- Cost and uncertainty are the most commonly identified barriers for adapting to future climate change.
- The mining sector is making efforts to reduce GHGs.

The experience and results from this survey were used to design the follow-up survey described in chapter 7 and to develop the in-depth case studies described in chapter 8.

6.1.2 Survey Location

The Prospectors & Developers Association of Canada (PDAC) is a national association representing the interests of the mineral exploration and development industry in Canada. PDAC, which includes individual and corporate members, was established in March 1932 and currently has over 5000 members. PDAC exists to protect and promote the interests of the Canadian mineral exploration sector and to ensure a robust mining industry in Canada. The association encourages standards for technical, environmental, safety and social practices in Canada and internationally. PDAC's annual convention is held in March each year in Toronto, and is a major meeting for the mineral exploration and development community. For this reason, the annual meeting from the 2nd – 5th March 2008 was chosen as the venue to conduct the survey.

6.1.2.1 Aims & Objectives of the Survey

The overall objective of this survey was to develop a baseline characterization of perceptions of climate change impacts, adaptation and vulnerability in the Canadian mining sector. The survey consisted of three main components (Appendix 2);

a). Respondent information: the first section gathered respondent information about the experience of practitioners, the company they represented, their job description, and the geographic location in which their company has activities.

b). Current climate vulnerability: this section of the survey explored perspectives on current climate sensitivities and adaptive strategies being employed. Specific questions sought to: 1). *Identify* climate-related hazards affecting mining and *characterize* their importance; 2). *Evaluate* if the mining sector perceives climate change to be affecting operations; 3). *Document* impacts of current climate change and *characterize* severity of impacts; 4). *Identify* adaptations being used by the mining sector to cope with climate change and *document* barriers to adapting; and 5). *Explore* if action is being taken to reduce Greenhouse Gas Emissions (GHGs).

c). Future climate vulnerability: this section sought to document perspectives on the potential implications of future climate change for mining and opportunities for adaptation. Specific questions sought to: 1). *Explore* if the mining sector perceives future climate change as a problem and *identify* potential negative impacts and benefits; 2). *Identify* if the sector is already planning for future climate change and *document* the nature of those adaptations; 3). *Specify* barriers to future adaptation; and 4). *Explore* if action is being considered to reduce Greenhouse Gas Emissions in the future.

6.1.3 Survey Delivery

For the purposes of this research, eligibility criteria reflected the project aims: to examine current and potential impacts of climate change on mining in Canada and outline adaptation strategies that could be implemented to mitigate those impacts, where mining encompasses mines producing metals, non-metals and mineral fuels (i.e. coal). Of those eligible to be interviewed, a broad definition of mining practitioners was used and included individuals involved in any aspect of the management, planning, and servicing of mining activities in Canada. This included mining executives, government regulators, mine operators, mine service providers, consultants etc.

The survey was administered in-person to 42 delegates at the conference (Table 6.1) who were selected using a modified random sample. To reduce the potential for selection bias, the sampling method involved approaching every fifth person passing-by the sample location to ask if they would like to be interviewed. To avoid bias in location of sampling (e.g. standing by a presentation hall where only CEOs are meeting), the sample location was selected so that anyone at the conference had a*n equal opportunity* of being selected. The location was kept for the whole interview period. Participants were not remunerated for their time, with interviews lasting on average between 10 and 15 minutes. Participation was voluntary and confidential.

Table 6.1: Respondent characteristics

Respondent characteristic	Respondents (%)
Company	
Mining company	16 (38)
Consulting	9 (21)
Mine supplies	7 (17)
Industry association	3 (7)
Government	2 (5)
Financier	2 (5)
Legal	1 (2)
Type of mining	
Metal	39 (93)
Non-metal	11 (26)
Coal	10 (24)
Interviewee role in company	
Executive / Senior management	13 (31)
Operations management	7 (17)
Health & Safety	1 (2)
Office / Administration	8 (19)
Tradesperson	3 (7)
Scientist	7 (17)
Engineers	2 (5)
Average years of experience in the mining sector	13 years
Geographic region	
Western Canada	20 (48)
Central Canada	18 (43)
Eastern Canada	29 (69)
Maritime Canada	16 (38)
Northern Canada	20 (48)

6.1.4 Analysis

6.1.4.1 Analytical techniques

Basic descriptive statistics were used to describe the sample population, responses to each question, and to ascertain the distribution of responses by mining sector characteristics including mine type, role in the mining sector, and geographic location. Cross tabulations were used to explore how answers to specific questions varied by practitioner-reported characteristics (e.g. years of experience, company working for, location of company operations, etc.). Chi-squared (x^2) and Fischer's exact tests were conducted to assess statistical significance of variation in question response by respondent characteristic. When testing for significance of association a significance level of 95% was used. Unless otherwise marked, p-values refer to x^2 tests in both text and tables. It is noteworthy that for many questions multiple answers were permitted: cumulative question responses may therefore not add up to more than 100%.

6.1.4.2 A note on the statistics

Cross tabulations are used in this report to display the joint distribution of two or more variables simultaneously. Each cell shows the number of respondents that gave a specific combination of responses and are utilized to explore differences in how people respond to answers and to see if response differs by respondent characteristics. Chi-squared and Fischer’s exact test are examples of inferential statistics which are used to make judgments of the probability that observed associations are statistically significant, i.e. to ask if the association might have occurred by chance. Here we use a significance level of 95%, which indicates that 5% of the association could have occurred by chance (95% not by chance). Where associations are statistically significant the terms “more likely” and “less likely” are used following standard procedure. These terms are only used in such instances.

6.1.5 Results

6.1.5.1 Survey population distribution

Table 1 summarizes the characteristics of the respondent population. A total of 42 people answered the questionnaire. The majority of surveyed practitioners represented mining companies (38%) followed by consulting firms (21%). 17% of the sample were mine suppliers involved in providing transportation and other services to mine sites. Other companies and government regulators were less represented, as can be expected from a conference primarily aimed at mining operations and prospecting. Respondents were also asked to identify which types of mining their companies were involved in (multiple responses were allowed for this question). 93% of respondents companies were involved in metal mining in some capacity, 26% with non-metal mining, and 24% with coal. Respondents represented companies with operations in all regions of Canada, with 69% of companies having operations in Eastern Canada, 43% in Central Canada, 48% in Western Canada, 38% in the Maritimes, and 48% in Northern Canada.

The most common position for those surveyed was in senior / executive roles (31%), with those employed as administrators, scientists and operational managers forming between 15 and 20% of the survey population (Figure 6.1). Fewer than 10% of respondents had positions in industry associations, as legal advisors, or in finance. On average, respondents had 13 years experience working as practitioners in the mining sector, ranging from as high as 50 years experience to fewer than 2 years. The high percentage of senior executives in the sample and level of experience of respondents reflects the high profile nature of the PDAC conference. Importantly, the sample population can be viewed as capturing perspectives of a knowledgeable and highly influential section of the mining industry.

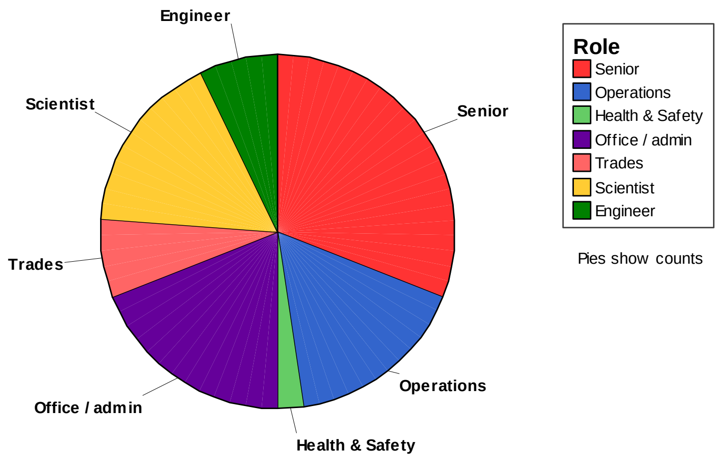

Figure 6.1: Pie chart showing job description on respondents

1.) The mining sector is sensitive to climatic hazards

The majority of practitioners surveyed identified mining sector operations to be sensitive to climatic hazards, with three quarters of respondents indicating that climate hazards have a negative impact on operations. 50% identified this impact as being moderate, and one quarter as being large (Table 6.2). Snowfall was noted as the most common event affecting mine operations (55%) with freezing rain having the least impact. 36% of respondents noted that forest fires and ice conditions affected operations. Interestingly – in the context of warming temperatures – only 21% of respondents noted that high temperatures had a direct impact on operations compared to 38% who identified cold temperatures as having an impact. Flooding, storms, and heavy rainfall were identified by between 20 and 26% of respondents as affecting operations. It is noteworthy that senior management were less likely (p=0.05) to perceive climatic hazards as negatively affecting operations compared to those performing other roles.

Table 6.2: Responses to selected questions

Question	% Answering question
Do climate hazards affect operations? (n = 42)	
Large impact	26 (11)
Moderate impact	50 (21)
Not a problem	21 (9)
Don’t know	2 (1)
Which conditions affect operations (n = 42)	
Snowfall	23 (55)
Rainfall	10 (24)
Freezing rain	7 (17)
Ice	16 (38)
Temp – heat	9 (21)
Temp – cold	16 (38)
Storms	11 (26)
Flooding	10 (24)
Fires	15 (36)
Is climate change currently affecting your operations? (n = 42)	
Yes	20 (48)
No	17 (41)
Don’t know	5 (11)
Nature of climate change impacts (of those answering yes to above) (n = 20)	
Bad for business	7 (35)
Very bad for business	2 (10)
Good for business	3 (15)
Very good for business	0 (0)
Neutral	3 (15)
Don’t know	1 (5)
Is your company taking action to manage the impacts of climate change? (n = 40)	
Yes	18 (45)
No	11 (28)
Don’t know	11 (28)
Characteristics of adaptive response (of those identifying adapting, which are the most common) (n = 40)	
Engineering	19 (47)
Administrative	13 (33)
Technological	13 (33)
Behavioural	11 (27)
Reducing GHGs	11 (27)
Taking advantage of benefits	5 (13)
What barriers (of those identifying barriers, which are most common) (n = 35)	
Cost	18 (43)
Uncertainty of climate projections	19 (45)
Uncertainty in regulatory regime	15 (36)
Market / economic uncertainty	10 (24)
Lack of skilled personnel	12 (29)
Short life span of mine	10 (24)
Do you expect future climate change to affect the operations of your company? (n = 41)	
Yes	21 (50)
No	19 (43)

Don't know	2 (5)
Nature of expected climate change impacts (n = 21)	
Bad for business	10 (48)
Very bad for business	2 (10)
Good for business	2 (10)
Very good for business	0 (0)
Neutral	4 (19)
Don' know	3 (14)
Problematic projections (n = 41)	
% see potential for problems with projections	36 (86)
Of those see problems, what problems are seen (n = 36)	
High temperatures	10 (28)
Shorter ice season	14 (39)
More snowfall	16 (44)
Less snowfall	4 (11)
More forest fires	17 (47)
More storms	9 (25)
More flooding	9 (25)
Beneficial projections (n = 38)	
% respondent seeing some benefits with projections	18 (48)
Of those seeing benefits, what benefits are seen (n =18)	
Higher temperatures	6 (32)
Short ice season	11 (64)
Less snowfall	12 (68)
Less flooding	0 (0)
Companies taking action to plan for future climate change (n = 40)	
Yes	12 (30)
No	19 (48)
Don't know	9 (23)
What planning are those companies taking action doing? (n = 8)	
Engineering	4 (50)
Administrative	3 (38)
Technological	0 (0)
Behavioural	0 (0)
Reducing GHGs	1 (13)
Taking advantage of benefits	0 (0)
What barriers to action are there (n = 31)	
Cost	17 (54)
Uncertainty of climate projections	20 (65)
Uncertainty in regulatory regime	9 (21)
Market / economic uncertainty	6 (14)
Lack of skilled personnel	8 (19)
Short life span of mine	4 (10)
Is your company reducing GHGs (n = 40)	
Yes	23 (58)
No	13 (33)
Don't know	4 (10)
Is your company thinking about reducing GHGs (n = 25)	
Yes	10 (40)
No	8 (32)
Don't know	7 (28)

Climate hazards affect mine operations in all regions of Canada. Significant differences between regions in terms of climatic conditions affecting operations are also evident in the data (Table 6.3). Those respondents with operations in Central (p=0.007, Fischer) and Western Canada (p=0.010 Fischer) were more likely to identify rainfall as negatively affecting operations; those with operations in the North (p=0.003, Fischer) and Central Canada (p=0.001, Fischer) were more likely to identify flooding as having negative impacts. Freezing rain (p=0.031, Fischer), extreme cold (p=0.008), fire (p=0.020) and storms (p=0.033) were all more likely to be identified by respondents with operations in Central Canada as negatively affecting operations. Given the large geographic zones of these regions, however, caution is required when interpreting these associations. Other climatic hazards are equally likely to be identified as problems across the geographic regions.

Table 6.3: Climatic hazards identified by respondents as having a negative impact on mine operations by geographic region

Region	Heavy Rainfall	Freezing rain	Extreme Cold	Fire	Storms	Flooding
Western	8 (40%)*	5 (25)	8 (40)	9 (45)	7 (35)	7 (35)
Central	8 (44%)*	6 (33) *	11 (61)*	10 (67)*	8 (44)*	9 (50)*
Eastern	9 (31%)	6 (21)	12 (41)	13 (45)	8 (28)	8 (28)
Maritime	6 (38%)	4 (25)	9 (56)	7 (44)	5 (31)	6 (38)
North	6 (30%)	4 (20)	10 (50)	10 (50)	7 (35)	8 (40)*

*Significant at p=<0.005

2.) Climate change is currently having a negative impact on some mining sector operations

48% of respondents identified climate change to be currently affecting mining sector operations, with 41% identifying no discernible impact (Table 6.2). Of those respondents identifying climate change to be currently affecting operations, 55% believe that current climate change impacts are bad for their business compared to only 15% who think they are good for their business. 10% of respondents believe current changes to be very bad, making a total of 65% who view climate change impacts to be negative. 15% identified no positive or negative impacts and no respondents identified the impacts to be very good (Figure 6.2). All practitioners were equally likely to identify climate change as having a negative impact, and equally likely to note good or bad impacts.

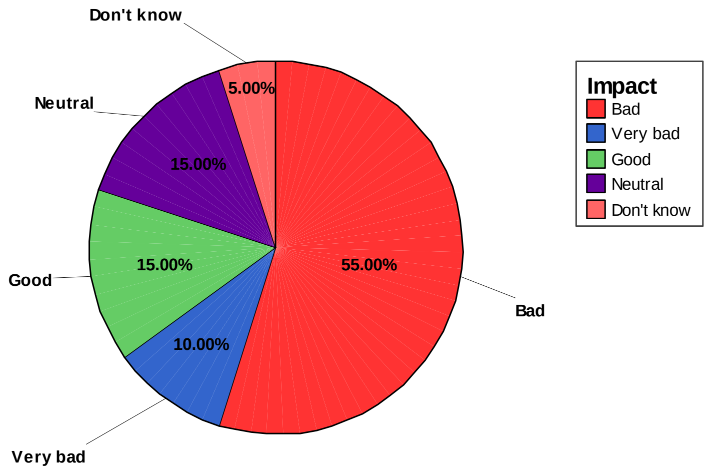

Figure 6.2: Percentage of respondents who identified climate change having impacts on operations and who ranked the impact as bad, very bad, good, neutral, and don't know.

3.) Companies are taking action to manage the impacts of climate change using a number of strategies

45% of surveyed practitioners identified that their companies were taking action to manage the impacts of climate change, with 28% reporting not knowing if action was being taken by their company (Table 6.2). Among those reporting their companies taking action, the most commonly identified responses were engineering, administrative and technological in nature. Only 13% identified taking advantage of perceived benefits being presented by climate change (Table 6.2).

Interestingly, those practitioners who perceive climate change to be occurring and being bad for business were not more likely to take action to manage the impact of climate change. Indeed, there are no significant differences between respondent characteristics and taking action on climate change. However, those respondents who identified climate hazards to have an impact on their company operations were significantly more likely to report action being taken to plan for climate change ($p = 0.041$) (
Table 6.4). This appears to indicate that experience with climatic risks is important in determining whether companies plan for climate change.

Table 6.4: Significant differences in response to selected questions by region

Region	Climate hazards affect operations	Mine lifespan as a barrier to adaptation	Less snow as a threat with climate change	More storms as a threat with climate change	Less snow will be beneficial
Western Canada	17 (85)	7 (44)	3 (18)	5 (29)	6 (50)
Central Canada	16 (89)	7 (47)*	2 (13)	5 (19)	7 (70)
Eastern Canada	23 (79)	7 (30)	3 (12)	5 (19)	8 (50)
Maritime	15 (100)*	7 (54)*	2 (14)	5 (36)	8 (89)*
North	18 (90)	6 (38)	4 (24)*	7 (41)*	6 (55)

* p =<0.05, Fischer

4.) Cost and uncertainty are the most commonly identified barriers to adaptation

83% of respondents identified there were barriers that constrain the ability to adapt to changing climatic conditions (Table 6.2). Of those identifying adaptation barriers, 43% identified cost and 45% uncertainty over climate change projections as limits to adaptation. An uncertain regulatory regime and a lack of skilled personnel were also important barriers. Fewer than 25% identified market uncertainty and short mine life span as barriers to adaptation in their business. It is noteworthy in this respect that market uncertainty was high during the survey period with the sub-prime market crisis in the U.S. dominating the media headlines.

Difference by region in identification of barriers were noted, with practitioners with operation in the Maritimes ($p=0.047$, Fischer) and Central Canada ($p = 0.016$, Fischer) more likely to identify short mine life span as a barrier to adapting to climate change (Table 6.4). There were no significant differences by region with regards to other adaptation barriers and no significant differences by other characteristics.

5.) Future climate change is expected to have impacts for future company operations

The majority (50%) of respondents expect future climate change to affect the operations of their company, with 43% expecting no impact (Table 6.2). Surprisingly, only 25% of senior executives and those in management view future climate change as impacting their company operations, and were less likely ($p=0.016$) than those in other positions to view climate as having a potential impact. In contrast, the data suggest that respondents with direct operational responsibilities (including those working as engineers and in health & safety) expect future climate change to affect company operations. All respondents from this category responded affirmatively to this question, although low cell counts in these categories preclude testing for significance. Those who indicated that climate hazards currently affect mine operations were significantly more likely to expect climate change to affect future operations, with 67% expecting impacts on operations ($p=0.006$, Fischer). Interestingly, those respondents noting current climate change to be having an impact on their operations were not more likely to view future climate change as affecting operations. There are no significant relationships between other respondent characteristics and expectation of future climate change impacts.

Of those who expect climate change to affect their company, the majority (45%) perceive the impact to be bad for business. Only 9% of practitioners surveyed believe climate change will be good for business, for example, by improving transportation access in waterways normally iced over in winter (Figure 6.3,Table 6.2). An equal number of respondents (9%) believe future climate change will be very bad for business or will be good for business. There are no significant differences between respondent characteristics and how the nature of future climate change impacts are perceived. Furthermore, those who document negative impacts of climate change on their operations today were not more likely to perceive future impacts as being negative.

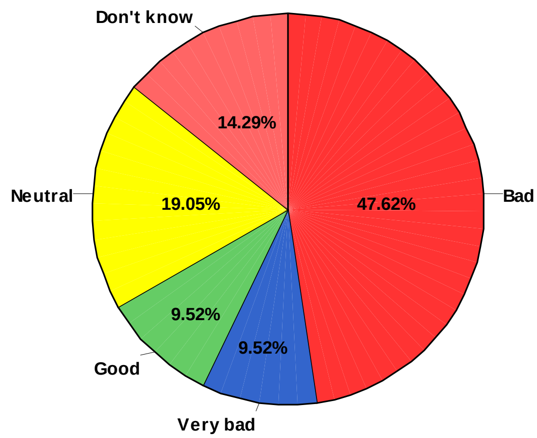

Figure 6.3: Percentage of respondents identifying climate change as potentially affecting operations and rating potential impacts as bad, good, and very bad for business.

6.) Climate change projections are viewed as threats by the majority of respondents and outweigh the potential benefits

Respondents were presented with a number of climate change scenarios which may affect the mining sector in the future and which have been identified as potential risks (Lemmen et al., 2008, IPCC, 2007b). 86% of practitioners viewed these changes as potential threats to their company operations. Increased forest fire occurrence was identified as the most serious threat followed by increased snowfall (Table 6.2). Shorter ice seasons, higher temperatures, more storms and more flooding were also frequently noted. In most instances there were no differences between regions in terms of projections identified as threats. However, practitioners with operations in the North were significantly more likely to identify less snow ($p=0.04$, Fischer) and more storms ($p=0.05$, Fischer) as potential threats (Table 6.4).

Respondents were then presented with the same projections and asked to note any benefits from those projections. Fewer (48%) respondents identified potential benefits from the scenarios. Of those that did identify benefits, more than half noted that a shorter ice season and less snowfall would be benefits (Table 6.2). Surprisingly, less flooding was not noted by any company as a potential benefit. Those with operations in the Maritimes were significantly more likely to identify less snowfall as a benefit to operations (Table 6.3). There were no other significant differences by region.

7.) Despite the perceived threat of future climate change, companies are not currently taking action to plan for future climate change

The majority of practitioners reported that their companies were not, to their knowledge, taking action to plan for climate change (Table 6.2, Figure 6.4). This contrasts with a high percentage of respondents reporting that their companies are taking action to manage current changes. A high percentage (23%) of respondents report not knowing if their companies are taking action; this may account for the low reporting of taking action. A low response rate for this question, however, limits the power of analysis. Those companies taking action to reduce the impacts of current climate change were significantly more likely to report to report taking action to plan for future climate change impacts ($p = 0.002$, Fischer), with 69% of those taking action to reduce the impacts of current climate change also planning for the future. No significant differences in taking action are noted by region, mine type or other respondent characteristics. Engineering options were the most preferred option by companies to plan for future climate change (50%) followed by administrative adaptations (38%); this behaviour closely parallels the behaviour of companies dealing with current impacts of a changing climate.

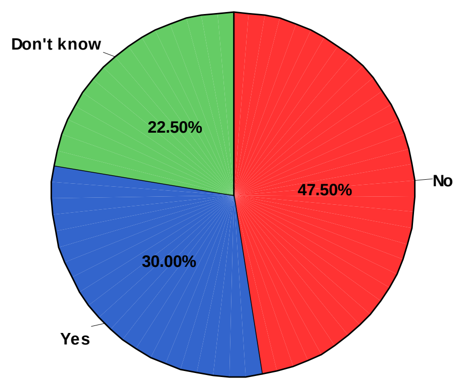

Figure 6.4: Number of respondents identifying their company is taking action to plan for the impacts of future climate change

8.) Cost and uncertainty are the most commonly identified barriers for adapting to future climate change

A number of barriers to adapting to future climate change were frequently noted. These barriers are similar to those constraining current adaptation, with the majority identifying uncertainty of climate change impacts (65%) and cost (54%) as limits to adaptation (Table 6.2). Less frequently mentioned were shortages of personnel and short mine life spans. Market uncertainty was noted by two fifths of respondents as being an adaptation constraint. There are no significant differences in identification of barriers by respondent characteristics.

9.) The mining sector is making efforts to reduce greenhouse gas emissions

The majority of practitioners noted that their companies are making efforts to reduce GHGs, with only 33% reporting making no effort (Table 6.2). 10% of respondents reported not knowing if action was being taken (Figure 6.5). Those taking action to reduce GHGs were also more likely to report taking action to reduce the impacts of current climate change on their operations (p =

<0.001, Fischer): 87% of whom reported taking action on GHGs. Furthermore, those who perceive future climate change as affecting business operations were significantly more likely (p=0.021) to report their businesses to be currently taking action on GHGs. Reducing GHGs was not, however, significantly associated with whether current or expected future impacts are believed to be bad for business, and did not significantly differ according to respondent characteristics. Of those whose companies are not reducing GHGs today, only 15% said their companies were thinking about reducing GHGs in the future. These results appear to suggest clustering in terms of those companies taking action on climate change (those who are adapting are also mitigating).

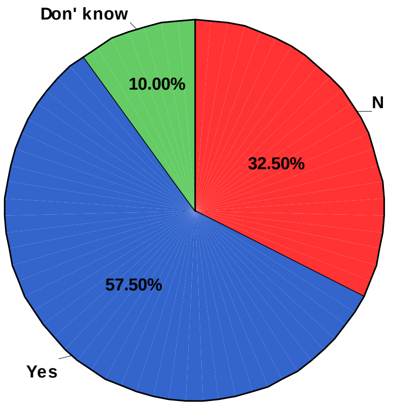

Figure 6.5: Percentage of respondents reporting their company to be reducing GHGs

6.1.6 Discussion

The survey provides some preliminary information on the perception of mining sector practitioners on the risks posed by current and future climate change, opportunities and barriers to adaptation, and role of GHG mitigation. As far as we know, it represents the first attempt to assess perceptions of climate change, impacts, and adaption in the mining sector, and is therefore an important baseline from which to conduct further research. Despite being a random sample, the survey population captures a highly influential and experienced segment of mining sector practitioners, and is indicative of the high profile nature of the PDAC conference where the sample was obtained. The survey therefore provides preliminary insights into perceptions at higher levels of decision making. Caution is also required, however, when interpreting the results given the small size of the survey population, and limited cell counts in some instances which did not allow differences to be statistically evaluated.

The results suggest that mining sector operations are sensitive to climatic hazards, particularly snowfall, ice conditions, extreme cold and forest fires. This is not surprising: many mining sector operations are located in remote locations, and are often dependent on climate sensitive transportation routes for importing supplies and exporting minerals. Moreover, weather extremes including heavy snowfall, forest fires and extreme cold can also reduce operational capacity. For example, at very low temperatures equipment may become difficult to operate, and occupational health and safety guidelines have been established for personnel working in climatic extremes. Regional differences in climate hazards are also apparent. Rainfall is more important as a hazard to mine operations in BC, where mines located in mountainous terrain are sensitive to rainfall initiated mud and debris flows, and transportation routes are at risk of wash out, particularly during heavy rainfall in the spring melt. Mine operations in Central Canada were more likely to be affected by freezing rain, flooding, extreme cold and storms, which is reflective of the extreme weather of the central provinces. Flooding was also more likely to be reported as a problem in the North, and is likely a function of the spring freshet[3] and poor ground penetration of run-off due to permafrost. Caution is required, however, when examining such regional differences given the geographic diversity in such large areas.

Climate change is having discernible impacts on biophysical systems across Canada (IPCC, 2007b, Lemmen et al., 2008). It is not surprising, therefore, that the mining sector – with operations sensitive to climatic hazards – has noted the impacts of climate change, and that the majority of surveyed practitioners believed it to be bad for business. The data suggests that climate change is perceived to be having widespread impacts on mine operations across Canada, and that engineering, technological and administrative options are currently being employed to manage climate change risks. Those who noted climate change to be bad for business, however, were not more likely to take action. Not surprisingly, respondents with mine operations which are negatively affected by climatic hazards were more likely to take action to reduce the impacts of climate change. This suggests that mining companies are not responding to climate change impacts *per se*, but adapting to change according to the magnitude and frequency of climate risks which are experienced and affect operations on a daily basis. Indeed, research highlights that, in many instances, adaptation takes place in response to alterations in everyday environmental conditions and not changing long-term conditions (Ford et al., 2006, Keskitalo, 2008).

Cost and uncertainty over climate change impacts were identified as barriers to adapting to current climate change. These barriers may help explain why some companies experiencing negative impacts of climate change are not more likely to be responding to reduce the impacts of those changes. Canadian institutions, the public in general and mining sector in particular, have been slow to recognize the threat of climate change. Indeed, some in the mining sector have disputed the science of climate change and whether climate change is occurring today (Kaufman, 2007, Popovich, 2007, 2008, The Northern Miner, 2007, 2008). Such attitudes, combined with the financial cost of adaptation in the mining sector, human resources required, time to develop and implement adaptive responses, and lack of understanding of how to adapt, may have resulted in a slow response to the negative impacts.

The mining sector practitioners surveyed here are somewhat concerned about future climate change impacts. Of those who view climate change as having implications for operations, there is a consensus that the impacts will negatively affect the mining sector. Those respondents involved in the daily operations of mines (operational management, health & safety) were more likely to view future climate change as impacting their operations than senior management. Fewer companies are taking action to plan for future climate change impacts than are currently adapting to observed climate change, which indicates that while the sector perceives climate change to be a threat a threshold has not been attained at which companies start to develop long term plans. Indeed, for some mining companies it may be that existing mine sites may no longer be in full operation when the effects of climate change begin to manifest themselves severely. Nevertheless, given the decommissioning time required for many mine sites, climate change will affect operations for even those sites with a short operational lifespan – the case studies explore in greater detail linkages

[3] Melting in spring

between mine lifespan and climate change planning. It is noteworthy that those who view climate change as currently affecting their operations were more likely to perceive climate change as affecting future operations, but were not more likely to be taking action to reduce future impacts. It is also noteworthy that those who perceive future changes to have negative impacts were also not more likely to be taking action. The disconnect between perception of impacts, adaptation action, and perception of the risks depending on role in company, appears to suggest that inertia at senior levels may be constraining mining sector adaptive planning for future climate change impacts. The survey also suggests that uncertainty over future impacts and cost appear – alongside perceptions of risk among senior management – to be constraining action.

Interestingly, when respondents were presented with future climate change scenarios deemed likely or very likely by the IPCC (2007b) and asked to comment on their impact, the majority identified potential negative impacts. Indeed, almost double the number of respondents identified potential negative impacts when presented with scenarios than when just asked if they viewed future climate change as affecting operations. In combination with the finding that many companies are not planning for future climate change despite experiencing negative impacts today, this suggests that those surveyed were not necessarily knowledgeable on potential future climate change impacts. This lack of knowledge may also be limiting action on future adaptation planning. Above all, and a major concern, it may be indicative of ineffective risk communication from the scientific to the ‘user’ community on climate change risks, or uncertainty of how to adapt. The release of Natural Resources’ Canada’s Adaptation Assessment a month after the survey was completed may increase knowledge among practitioners and is discussed in more detail in the results from the second survey.

In the mining sector, mitigation (reducing greenhouse gases) has been viewed as one way of limiting liability to climate change litigation and government regulations (see for example Ednie, 2004) and can therefore be considered part of adaptation. For the purposes of this survey, however, mitigation actions were separated from other adaptive responses. The survey indicates that the mining sector is taking action to reduce GHGs; reducing GHGs is also the most common response to climate change impacts. Interestingly, practitioners who perceive future climate change to be affecting their operations are more likely to report their businesses to be currently taking action on climate change. This association is not present with regards to other adaptive responses, and suggests the mining sector currently views mitigation as a more appropriate, cost effective, and visible means for responding to climate change. Fewer practitioners noted their companies to be thinking of reducing future emissions although the majority reported not being familiar with company planning in this area.

CHAPTER 7

7.1 PERCEPTIONS OF CLIMATE CHANGE IMPACTS, ADAPTATION AND VULNERABILITY IN THE CANADIAN MINING SECTOR: A CROSS CANADA SURVEY

7.1.1 Synthesis

A cross Canada survey was administered in summer 2008 to 62 randomly selected mining practitioners working 'on the ground' at mine sites across the country. Seven key findings from the survey are discussed in this chapter (* indicates the finding was generally *not* consistent with the PDAC survey, ** indicates the finding *was* consistent, [n/a] indicates this was a *new* finding):

- The mining sector is sensitive to climatic hazards**
- The majority of interviewees noted concern about current climate change**, but the majority have not yet noticed climate change to be affecting operations*
- The data are unclear concerning whether action is being taken to reduce the negative impacts of climate change*
- Future climate change is expected to have negative impacts for company operations**
- The data are unclear as to whether companies are taking action to plan for future climate change*
- The mining sector is making efforts to reduce greenhouse gas emissions**
- Knowledge of key scientific reports on climate change is very low [n/a]

7.1.2 Aims & Objectives of the Survey

This survey builds on the PDAC survey with the aim of developing more in-depth understanding and characterization of climate change impacts, adaptation and vulnerability in the Canadian mining sector. This survey targets the mining sector in general in Canada, aiming to proportionately sample mines in all regions of Canada. The survey consisted of 5 main sections with 30 close-ended questions (Appendix 3):

a). Respondent information: information about the experience of practitioners, the company they represented, their job description, and the geographic location in which they are based.

b). Current climate vulnerability: this section of the survey explored perspectives on current climate sensitivities and adaptive strategies being employed. Specific questions sought to: 1). *Identify* climate-related hazards affecting mining and *characterize* their importance; 2). *Evaluate* if the mining sector perceives climate change to be affecting operations; 3). *Document* impacts of current climate change and *characterize* severity of impacts; and 4). *Identify* adaptations being used by the mining sector to cope with climate change and *document* barriers to adapting. Moreover, the survey provided opportunity for respondents to rank the importance of climate risks and climate change impacts as a problem, not a problem, or a benefit to company operations.

c). Future climate vulnerability: this section sought to document perspectives on the potential implications of future climate change for mining and opportunities for adaptation. Specific questions sought to: 1). *Explore* if the mining sector perceives future climate change as a problem and *identify* potential negative impacts and benefits; 2). *Identify* if the sector is already planning for future climate change and *document* the nature of those adaptations; and 3). *Specify* barriers to future adaptation. Moreover, the survey provided opportunity for respondents to rank the importance of projected climate change impacts as a problem, not a problem, or a benefit to company operations.

d). Mitigation: this section sought to document the extent to which companies are reducing or planning to reduce greenhouse gas emissions (GHGs). Specific questions sought to: 1). *Document* how many companies are currently taking mitigation action, 2). *Identify* how many companies are thinking of reducing emissions, 3). *Characterize* what actions are being taken, and 4). *Explore* why companies are reducing emissions or considering reducing greenhouse gas emissions.

e). Research needs: this section sought to document the extent to which practitioners were aware of climate change science and policy publications, using this as an indicator for knowledge on climate change. Specific questions sought to: 1). *Assess* knowledge of 4 recently released reports on the science of climate change and policy response: Natural Resources Canada's National Adaptation Assessment (2007), The Intergovernmental Panel on Climate Change Fourth Assessment Report (2007), the Mining Association of Canada Action Plan for Reducing Greenhouse Gas Emissions (2003) and the Canadian Climate Change Scenarios Network (2007); 2). *Identify* how useful these reports have been to practitioners using a simple binary response (useful, not useful); and 3). *Identify* what additional information practitioners require to improve climate change preparedness. Respondents had the choice of 5 predetermined answers: better projections of climate change, more information on available adaptation options/engineering solutions (including costs), better information from the government, more research on how the mining sector might be affected by climate change, and better personal understanding of climate change.

7.1.3 Survey Delivery

Of those eligible to be interviewed (individuals working at mines producing metals, non-metals and mineral fuels), the focus in this survey was specifically on those working at mine sites and involved in day-to-day operations (e.g. in operations management, health & safety, engineering, administration, senior site management). The survey was administered by phone to 62 mining sector practitioners in summer 2008, who were selected using a modified random sample. Firstly, a list of *all* mine operations in Canada was obtained from Natural Resources Canada. The list was checked to ensure that mines on this list were still operational and to ensure that new mines were included, and ineligible mines according to the criteria described previously were omitted. A total of 818 mines form the target population, of which 4 were located in Northern Canada, 90 in Atlantic Canada, 294 in Quebec, 259 in Ontario, 107 in Prairies, and 64 in British Columbia. We aimed to sample a total of 25% of mine operations in each region of Canada. Secondly, the list of mines was divided up by region and a number (starting at 1) was assigned to each mine. A random number generator was then used in Microsoft Excel to sample 25% of mines in each region. Each mine selected was then contacted by phone. To ensure consistency between surveys, the following introduction was used each time a mine was contacted: “Hello, my name is *** and I work for ArcticNorth Consulting. We are doing a survey looking at how climate change is affecting the Canadian mining industry. To this end can you put me in contact with people in your company who would know about the impacts climate change is having on your mine.” In cases where there was no initial response, or individuals said they would call back but didn’t, three attempts were made to conduct the survey before being classed as a non-response. Surveys took on average 20 – 30 minutes to administer and were undertaken in English except in Quebec where they were administered in French.

7.1.4 Analysis

Basic descriptive statistics were used to describe the sample population, responses to each question, and to ascertain the distribution of responses by mining sector characteristics including mine type, role in the mining sector, and geographic location. Cross tabulations were used to explore how answers to specific questions varied by practitioner-reported characteristics (e.g. years of experience, company working for, location of company operations, etc.). Chi-squared (x^2) and Fischer’s exact tests were conducted to assess statistical significance of variation in question response by respondent characteristic. When testing for significance of association a significance level of 95% was used. Unless otherwise marked, p-values refer to x^2 tests in both text and tables; where a Fischer’s test is used it is denoted by “F”. It is noteworthy that for many questions multiple answers were permitted: cumulative question responses may therefore not add up to 100%.

7.1.5 Results

7.1.5.1 Survey population distribution

Surveys were completed with only 30% of those contacted. Common problems encountered included individuals not having time to be surveyed, individuals saying they would call back but in the end not doing so, and lack of interest. The timing of the survey, conducted during summer 2008 (June to September) may have also been a constraining factor with many individuals away on holiday. A total of 62 people answered the survey, all of whom were based at operational mine sites. The majority of mines represented by the respondents can be classed as metal mines (77%), with 23% non-metal. The majority of the interviews were conducted with individual representing operations management (27%), office / administration (26%), or senior management at site operations (24%). A small number were either scientists or engineers. All regions of Canada were represented with the distribution of respondents by region generally reflective of distribution of active mines across Canada. The respondents were very experienced with an average of 18.6 years in the mining sector, ranging from 6 months to 50 years; this is more than in the PDAC survey where the average experience was 13 years. It is noteworthy that due to the proportional nature of surveying only one mine is located in the North; it was therefore not possible to test for significance of association between how the northern respondent answered questions. Table 7.1 profiles the sample population.

Table 7.1: Profile sample population

Respondent characteristic	Respondents n (%)
Type of mining	
Metal	14 (23%)
Non-metal	48 (77%)
Interviewee role in company	
Executive / senior management	15 (24%)
Operations management	17 (27%)
Health & Safety	9 (15%)
Office / administration	16 (26%)
Scientist	1 (2%)
Engineer	3 (5%)
Average years of experience in the mining sector	18.6
Geographic region	
BC	10 (16%)
Prairies	14 (23%)
Atlantic	9 (15%)
North	1 (2%)
Ontario	21 (34%)
Quebec	22 (35%)

1.) The mining sector is sensitive to climatic hazards

Approximately 77% of respondents identified that climatic hazards have an impact on mine operations. 29% identified this impact to be large, and 48% moderate in nature. These figures are almost identical to those reported in the PDAC survey. There are no significant differences detected between reporting of climate hazards and mine type or role within company. Respondents from all regions surveyed were also equally likely to report climatic hazards affecting operations.

Of those identifying climatic hazards to be affecting company operations, the most commonly identified were too much rainfall (71%), too much snowfall (56%), storm events (33%), flooding (25%), and cold temperatures (19%) (Table 7.2). While the percentage values differ with the PDAC survey, both document the importance of heavy snowfall, flooding, and storms, and highlight that high temperatures *per se* are not regarded as hazard by many. Interestingly, forest fires were identified as a hazard in the PDAC survey but were only identified by 8% of respondents in this survey as being a risk. Significant differences between regions in terms of climatic conditions affecting operations are also evident in the data. Heavy snowfall is less likely to be a hazard affecting mines in the Prairies ($p=0.02$), lack of snowfall is more likely to affect operations in Ontario ($p=0.04$), heavy rainfall is less likely to be a problem in Ontario ($p=0.043$), and cold temperatures are more likely to be problematic in Quebec ($p=0.019$). There are no significant differences with other variables.

Table 7.2: Climate hazards most commonly identified as affecting operations (n=48)

Hazard	N (%)
Too much snowfall	27 (56%)
Too little snowfall	3 (6%)
Too much rainfall	34 (71%)
Freezing rain	8 (17%)
Warm temperature	5 (10%)
Cold temperature	9 (19%)
Storms events	16 (33%)
Ice conditions	8 (17%)
Flooding	12 (25%)
Forest fires	4 (8%)
Water scarcity	4 (8%)
Water level	2 (4%)
Disturbance to hydro power	7 (15%)

2.) The majority of interviewees noted concern about current climate change, but the majority have not yet noticed climate change to be affecting operations

55% of respondents identified being concerned about climate change impacts (a question not posed in the PDAC survey). Respondents with operations in Ontario were more likely to be concerned about climate change (p=0.004), with those with operations in Quebec less likely to be concerned (p=0.023). No significant differences between concern over climate change and mine type, role within company, or experience with climatic hazards were detected. Only 34% of respondents noted that climate change is currently affecting operations, compared to 48% of respondents in the PDAC survey. Of those identifying climate change to be currently affecting operations, the majority identified not knowing the nature of impacts when presented with a series of potential impacts (e.g. more rainfall, higher temperatures etc). This is significantly greater than the PDAC survey where only 5% reported not knowing. Testing for significance of association reveals no significant differences between respondents documenting climate change impacts today and mine type, role within company or geographic region. However, those who reported their mines experience climate hazards were more likely to report that climate change is having an impact on operations (p=0.022F), and those concerned about climate change were significantly more likely to report impacts (p=0.002). These two associations are not discernible in the PDAC survey.

Of respondents identifying climate change to be currently affecting operations (n=21), the most commonly identified problems included more rainfall (81%), more storms (43%), and more snowfall (29%). A new question in this survey also sought to document which aspects of company operations were being affected by climate change. Of those identifying climate change to be currently affecting operations, the majority of respondents identified on-site and off-site transportation to be affected the most (76%) followed by processing (43%), activity timing (43%), production (33%) and site drainage (24%).

3.) The data are unclear concerning whether action is being taken to reduce the negative impacts of climate change

66% of those surveyed identified not knowing if their companies were taking action to reduce the negative impacts of climate change, the same number also reported not knowing if action was being taken to take advantage of climate change impacts. This is greater than the PDAC survey where 28% reported not knowing if their companies were taking action on climate change. 21% reported that action was being taken to reduce the negative impacts (12% said no action was being taken), and 8% reported action being taken to take advantage of the benefits with 16% saying no action was being taken. Among those taking action to reduce negative impacts of climate change (n=13), administrative options are the most preferred (85%) followed by reducing GHGs (62%), technological changes (46%), and engineering adaptations (39%). With so many reporting not knowing, however, the results provide few insights into how or if the sector is adequately responding to climate change.

4.) Future climate change is expected to have negative impacts for future company operations

The majority (58%) of respondents expect future climate change to have an impact (positive or negative) on company operations, with 22% expecting no impact. A similar percentage of respondents in the PDAC survey expect climate change to have impacts, although it is noteworthy that almost three times more respondents reporting not knowing about potential impacts in this survey compared to the PDAC survey. Like in the PDAC survey, respondents who identified their mine operations to be affected by climatic hazards (n=48) were more likely to expect climate change to affect their operations in the future (p=0.05), with 79% expecting impacts. In this survey and unlike in the PDAC survey, respondents who had noted climate change to be currently having impacts were significantly more likely to view climate change as having impacts for their operations in the future (p=0.001), with 54% expecting impacts. No significant differences were noted between region, mine type, or role within company.

Of those expecting climate change to have impacts (n=36), 44% believed those impacts will be bad for business. 26% of respondents believed the impacts will be positive, 9% thought climate change will be very good for business, and 26% of respondents believed the impacts will be neutral. These figures closely mirror those obtained in the PDAC survey. Of those expecting impacts and rating the nature of those impacts as good or bad, significantly fewer senior management / executive respondents were likely to expect negative impacts (p=0.036F), only 33% of expected negative impacts. A similar relationship was detected in the PDAC survey. There are no significant relationships discernible with other variables.

Respondents were then presented with a number of potential changes which are projected to occur in the future with climate change and asked to identify which changes would impact operations. It is noteworthy that respondents had more options to choose from than in the PDAC survey. Just over half (52%) of respondents answered this question; 77% (n=23) of those not responding to this question indicated that the projections were not applicable to their operations with 23% (n=7) not knowing. The most commonly identified projections which respondents expect to affect mine operations were: more rainfall (56%), more snowfall and higher winter temperatures (44%), more storms (34%), stronger winds (25%), and less rainfall (25%). While the order in which these risks are perceived as having impacts are similar to the PDAC survey, as a percentage fewer people responded to this question.

Table 7.3: Projected climate changes which are believed to affect mine operations (n = 32)

Projection	%	N
Winter - Higher temperature	44%	14
Summer - Higher temperature	22%	7
More snowfall	44%	14
Less snowfall	41%	13
More rainfall	56%	18
Less rainfall	25%	8
More freezing rain	13%	4
More storms	34%	11
Stronger winds	25%	8
Shorter ice season	6%	2
More flooding	19%	6
Water scarcity	16%	5
Reduced stream flow	6%	2
Winter - Higher temperature	44%	14
Decrease in water level	6%	2
Disturbance to hydro power	25%	8
More forest fires	13%	4

Respondents were also asked which aspects of company operations are most likely to be affected by climate change; a question not asked in the PDAC survey. 60% (n=37) of respondents answered this question. The most commonly identified problem concerned transportation, with 38% concerned about impacts on transportation networks for export, and 41% concerned about on-site transportation. 43% of respondents were concerned about impacts on processing, 30% on activity timing, and 24% on drainage (Table 7.4] Testing for significant association was conducted where cell counts were large enough including the responses related to processing, transportation on-site and transportation off-site. Respondents based in Ontario were significantly more likely to identify on-site transport as susceptible to future climate change (p=0.01) and were also more likely to report off-site transport as susceptible to climate change (p=0.004). Interestingly, respondents based in Quebec were less likely to be concerned about the susceptibility of off-site transport (p=0.048).

Table 7.4: Respondents indentifying aspects of mine operations susceptible to climate change (n = 37)

Aspect of mine operation	N (%)
Containment facilities for tailings	5 (14%)
Production	6 (16%)
Transportation: on site	15 (41%)
Transportation: export	14 (38%)
Buildings	2 (5%)
Mine decommissioning	1 (3%)
Mine development	7 (19%)
Processing	16 (43%)
Drilling	1 (3%)
Drainage	9 (24%)
Discharge of waste	3 (8%)
Activity/Operation timing	11 (30%)

5.) The data are unclear as to whether companies are taking action to plan for future climate change

40% of respondents identified their companies were taking action to plan for future climate change and 21% indicated their companies were not. However, approximately 40% of respondents did not know if their companies were taking action; this is higher than in the PDAC survey thereby limiting the ability to compare. In this context it is not possible to draw a conclusion about the extent to which companies are responding to future climate change impacts. The only detectable significant difference is that Quebec companies were less likely to report taking action to manage future impacts (p=0.007). Of those companies reporting on whether their company was taking action (n=38), 42% identified administrative actions as the most common adaptation, followed by emissions reduction (29%), and engineering-based actions (24%).

6.) The mining sector is making efforts to reduce greenhouse gas emissions

The majority of those interviewed (98%) were knowledgeable about their company's position on mitigation, with 77% noting their companies were taking action to reduce greenhouse gas emissions. This is slightly higher than reported in the PDAC survey. 21% reported no action being taken, a figure slightly lower than documented in the PDAC survey. Respondents based in the Prairies were more likely to report reducing GHGs, with all Prairie respondents noting their companies were taking action (p=0.028F), while respondents with operations in Quebec were less likely to report taking action on GHGs with only 63% reporting action being taken (p=0.001F). Moreover, those companies concerned about climate change were significantly more likely to report taking action on mitigation (p=0.001F) with 93% reporting this. Unlike the PDAC survey, however, there was no significant difference it terms of mitigation action being taken by those who are seeing climate change have negative impacts on their operations.

The most commonly identified explanation for reducing emissions was to save money, with 63% of respondents identifying this as their company's prime motivation. 42% of respondents noted ethical reasons for reducing emissions, 32% noted they were trying to avoid government imposed regulations, and 13% explained that public pressure was the main reason. The most commonly employed method for reducing emissions was by investing in more energy efficient technology, with 60% of respondents noting their companies taking action this way. 45% of respondents noted their companies were improving the efficiency of how they operate without making investments in new technology, with 11% reporting purchasing renewable energy. Only 2% of those taking action to reduce greenhouse gas emissions today expect this not to continue in the future.

7.) Knowledge of scientific reports on climate change is very low

Knowledge of key scientific reports ranged from as few as 8% having heard of the Climate Change Scenarios Network to 69% of people having heard of the Mining Association of Canada's action plan for reducing greenhouse gas emissions. 63% of respondents had not heard about Natural Resources Canada's National Adaptation Assessment, a major work outlining the risks posed by climate change on a regional basis in Canada and outlining how to plan for climate change. A further 56% of respondents were not aware of the IPCC's Fourth Assessment Report. The majority (98%) of respondents had opinions with regards to what information is required to better plan for climate change. 55% of respondents identified a need for better projections of climate change and the need for more information on adaptation options; 44% said these would not be useful in increasing preparedness for climate change. The need for more research was identified as being beneficial by 52% of respondents and 52% also noted they needed better personal information on climate change impacts. 52% of respondents said better information from the government would not help.

7.1.6 Conclusion

The cross Canada survey develops new insights and corroborates many of the findings made in the PDAC survey, increasing our understanding of the perception of mining sector practitioners on the risks posed by current and future climate change, opportunities and barriers to adaptation, and the role of GHG mitigation. The sample population captures a highly experienced section of individuals working on mine sites across the nation, complementing the PDAC survey's sample of mining practitioners in general. Caution is also required, however, when interpreting the results and limited cell counts in some instances did not allow differences to be statistically evaluated. Indeed, it was not possible to assess significant relationships with mines in the North given only one northern mine was sampled. Moreover, for some key questions there were a high percentage of non-responses with respondents not sure of what their companies were doing.

It is also noteworthy that while comparison with the PDAC survey is useful in strengthening key arguments and developing more in-depth insight, caution is required. For some questions the large number of people not knowing about their company's action in a specific area makes comparison with the PDAC survey problematic. It was hoped that the larger sample size would increase the power of analysis for key questions but with non-responses there was often too little power for significance testing. There are a number of possible explanations for this. Firstly, interviews were conducted over the phone and respondents may have been more comfortable in saying they don't know compared to the in-person PDAC survey. Secondly, this survey has more detailed response options for many of the questions with the aim of obtaining a more in-depth understanding of how practitioners perceive climate change compared to the short PDAC survey. However, and of interest to future mining sector surveys, there is a trade-off between depth of response and respondents not being able to answer the question; a trade-off experienced in some of the questions in this survey. There may also be differences in self reporting in the two surveys due to the different surveying methods utilized: phone surveying in the cross Canada survey and in-person surveying for the PDAC survey. Differences in survey population further complicate comparison. Notwithstanding, where possible we compare the findings from the two surveys, noting overlap and explaining differences.

Seven key findings of interest were documented in the cross Canada survey; findings which in many cases corroborate what the PDAC survey also highlighted. Firstly, **the mining sector is sensitive to climatic hazards**. Regional differences in climate hazards are also apparent, with the Prairies less susceptible to heavy snowfall, Ontario more susceptible to heavy snowfall, and extreme cold causing more of a problem in Quebec. The sensitivity of mine operations across Canada to climatic hazards will increase the susceptibility of the sector to climate change, with climate change in many instances increasing the magnitude and frequency of existing hazards. Indeed, when respondents noted changes in climate would cause future problems, the most commonly identified problems were those already facing operations.

Secondly, **the majority of interviewees noted concern about current climate change, but the majority had not yet noticed climate change to be affecting operations**. This contrasts to the PDAC survey where the majority of respondents noted seeing climate change impacts, a difference which can possibly by explained by the different survey population. Only 38% of the PDAC survey sample represented mining companies whereas all respondents in this survey were based at mine sites. Those in industry associations, consultants, and scientists may be more inclined to see climate hazards through the lens of climate change reflecting their exposure through conferences to the science of climate change etc, whereas those on the ground at mine sites may see climate hazards through the lens of a challenge to deal with on a day-to-day basis. For these individuals, change might be viewed as just a normal challenge which has always been faced. Notwithstanding, 34% of respondents in this survey and 48% in PDAC have detected a climate change signal on their operations, confirming that climate change is an emerging issue facing the mining sector.

Thirdly, **the data are unclear concerning whether action is being taken to reduce the negative impacts of climate change**. 66% of those surveyed identified not knowing if their companies were taking action to reduce the negative impacts of climate change or take advantage of benefits. Given that the respondents were involved in on-site mining operations, we hypothesize that "don't know" answers are indicative of no response being taken; if action was being taken they should know. This contrasts with the PDAC survey and can possibly be explained by the survey sample population. The fact that the PDAC survey had more people in senior positions represented along with those in industry associations might indicate that adaptations are being considered in the industry but not yet applied or communicated to mine site operations. There is also the possibility of under-reporting of action in the cross Canada survey, in that responses which could be considered adaptations to climate change are viewed by those on the ground as measures to maintain mining operations in light of day to day challenges.

Fourthly, **future climate change is expected to have negative impacts for future company operations.** This corroborates the findings from the PDAC survey. Interestingly, respondents who identified their mine operations to be affected by climatic hazards were more likely to expect climate change to affect their operations in the future. This could be a problem for mine operations currently unaffected by climatic risks as climate change might result in the emergence of risks to which they have little experience with. This survey also documented that respondents who noted climate change to be currently having impacts were significantly more likely to view climate change as having impacts for their operations in the future. Moreover, like in the PDAC survey, of those who expect climate change to have future impacts most expect the impact will be bad for business, although potential benefits were also acknowledged.

When respondents were presented with climate change projections and asked to comment, only slightly more noted potential problems than when asked if climate change was expected to have negative implications. This contrasts with the PDAC survey where more respondents had opinions on climate change impacts when presented with projections. The most commonly identified projections which individuals noted would pose problems were very similar to the most common risks facing mine sites today: more rainfall, more snowfall, more storms, and stronger winds. These potential future risks were also widely cited by interviewees in the PDAC survey. Additionally in the cross Canada survey, respondents were asked which component of their operations would be most susceptible to climate change, with transport the most commonly identified followed by processing operations and activity timing. Many mines are located in remote regions with transportation access often by one road, rail line or airport and susceptible to bad weather, flooding etc. Moreover, on-site transportation is affected by similar conditions.

Fifthly, **the data are unclear as to whether companies are taking action to plan for future climate change.** The PDAC survey revealed that the majority of companies are not preparing for future climate change. While 40% said they were preparing in this survey, 40% also indicated that they did not know if action was being taken, and, as we hypothesize above, “don’t know” answers are likely indicative of no response being taken; if action was being taken they should know. However, the 40% who said they were responding is higher than the 30% in the PDAC survey, and shows that some mine sites are developing measures in respond to climate change.

Sixthly, this survey adds detail on the PDAC survey regarding company actions on mitigation highlighting that **the mining sector is making efforts to reduce greenhouse gas emissions**. Indeed, 77% of respondents noted their companies were taking action to reduce emissions; mitigation is therefore the most common action undertaken to address climate change. The PDAC survey also highlights that a majority of mines are taking mitigation action, although the percentage figures are more emphatic in this survey. Some caution is required when interpreting this finding however, as there is the possibility that mine companies might report taking action for public relations reasons, although the anonymous nature of the survey will have hopefully limited this. Interestingly, those companies concerned about climate change were significantly more likely to report taking action on mitigation. Saving money was the most common motivation for mitigation action, with high fuel prices likely having a major impact. Ethical reasons (i.e. to address climate change) were also noted by respondents. 32% noted they were taking action to hopefully avoid government regulations, and in this sense mitigation can also be viewed as an adaptation.

Finally, **knowledge of key scientific reports on climate change is very low** among surveyed practitioners. From this we conclude that knowledge of climate change is generally low; a conclusion we also extrapolated in the PDAC survey. Respondents were least aware of scientific publications with over half of respondents having not heard of the IPCC reports or the National Adaptation Assessment, and only 7% having heard of the Climate Change Scenarios Network. The Mining Association of Canada's plan for reducing greenhouse gas emissions however was known by 69% of respondents. This report has been out longer than the other reports and this finding could also indicate that mining sector practitioners are more likely to be aware of publications from industry associations which are targeted at the mining user group. This is of importance for scientific outreach on climate change impacts, adaptation and vulnerability in the mining sector. Specific areas where mining sector practitioners identified a need for more information include: better projections of climate change, more information on adaptation options, more research on climate change impacts, and more personal awareness of climate change.

CHAPTER 8

8.1 INTRODUCTION TO MINE SITE CASE STUDIES

8.1.1 Overview

In-depth case studies were conducted to document and describe climate change risks and opportunities for the mining industry in Canada and the adaptation and mitigation strategies being undertaken to deal with climate change. The case studies include: (1) diamond mining in the Northwest Territories, (2) mining in the urban-rural interface in south western Quebec, (3) sulphate, uranium, and potash mining in Saskatchewan, (4) base metal and gold mining in north eastern Ontario, (5) the Voisey's Bay nickel-copper mine in Nunatsiavut, Labrador, and (6) mining in the Yukon Territory. A number of key generalizations are evident across the case studies:

- The majority of mines in the case studies are affected by climatic hazards, with examples of negative impacts.
- Adaptation planning is occurring to manage existing climate risks in some instances.
- Most mine infrastructure has been developed according to design criteria relevant to the current/historic climatic regime. Design standards (e.g. building on permafrost) are usually the responsibility of the mine company and are for the most part unregulated.
- Where adaptation occurs it is usually reactive and *ad hoc* in nature.
- A number of factors constrain the ability to manage current climatic risks including regulatory uncertainty (including a lack of appropriate codes and standards), location, uncertainty in future climate change projections, uncertainty in responsibility for adaptation, and financial cost of adaptation.
- The majority of practitioners acknowledge that the climate is changing and are cognizant that climate change will occur in the future. However, knowledge of the nature, magnitude, and speed of change is poorly understood.
- The majority of respondents view climate change as a minor concern, yet, climate change projections and mine sector sensitivity to climatic risks highlights the potential for future susceptibility to a changing climate.
- There are potential benefits from climate change, which in some cases could reduce operating costs and facilitate further mineral development.
- There is limited long term strategic planning being undertaken to identify future risks or opportunities from climate change, or to develop adaptations.
- Adaptation options are available to manage the risks of future climate change but costs can be prohibitive, especially for small scale mining operations.
- Greenhouse gas mitigation is being employed by many mine operations, although in many cases the primary motivation is to save costs as opposed to responding to climate change *per se*.

Table 8.1: Summary of key exposure-sensitivities, adaptations and vulnerabilities across the case studies

		Relevant Exposure-Sensitivities	Current Adaptations	Key (remaining) *Vulne*rabilities
Northeastern Ontario	**Climatic**	• Changing climatic norms (e.g. precipitation, temperature) • Extreme weather events	• Reactive responses to damage caused by extreme weather have prevailed • Numerous mining research initiatives exist in Northeastern Ontario, focusing on a variety of relevant topics (e.g. mine engineering, environmental sustainability) • Climate change is increasingly becoming a topic of discussion for the sector (e.g. at conferences, amongst mining practitioners)	• Extreme precipitation and snow melting events could lead to flooding, release of contaminants and failure of impoundment structures and transport infrastructure • Drier conditions could lead to reduced water intake capacity and exposure of tailings to sub-aerial weathering • Abandoned mine infrastructure may need to be retrofitted with climate change • Lack of long-term planning for the impacts of climate change by the mining sector • New technologies to combat the impacts of climate change needed • Limited climate modeling data • Continued reliance on permafrost in the design of retention facilities
	Non-Climatic	• Greenhouse gas emissions • Pollution/poor air quality • Public pressure • Poor public perception of mining and pollution issues in Northeastern Ontario • Regulatory requirements	• Energy management and greenhouse gas reduction initiatives by some mines • Other pollution reduction initiatives (e.g. cutting sulphur dioxide emissions; reducing site emissions on days with poor air quality) • Greenhouse gas emissions reporting • Investigation of alternative ('green') sources of energy for mine sites and use of carbon offsets • Environmental assessment process increasingly requiring consideration of climate change impacts	• Companies caught unprepared for new climate legislation/regulatory requirements could face economic and other repercussions • Large and highly visible polluters could be at risk for increased climate change-related legislation • Legislation that is designed without significant industry input could have negative implications for the mining sector

NWT	**Climatic**	• Changing climatic norms (e.g. precipitation, temperature) • Melting permafrost • Extreme weather events • Seasonally harsh climatic conditions	• Specialized engineering and designs for cold-weather environments have been employed • A number of technologies/strategies exist to combat the effects of climate change (e.g. thermosyphons, modifying tailings cover) • For the ice road: new lighter weight and amphibious machinery has been purchased, operational efficiencies made, alternative routings have been investigated • Long term climate change adaptation planning has been done by some mining sector practitioners	• Limited long-term planning for the impacts of climate change by the mining sector • Warming will make it difficult to maintain sufficient ice thicknesses to support heavy traffic flows on ice roads • Frozen core water and tailings retention structures could lose their structural integrity due to warming • Extreme weather increases susceptibility of infrastructure to damage • Buildings erected on thaw-sensitive land could see foundations settle and shift as permafrost melts • Infrastructure built on or near steep slopes will need to consider more active slope processes • Drainage and hydrologic regimes could be affected. Flooding and erosion could result • New technologies will need to be adopted to combat the impacts of climate change • Accurate climate modeling data does not yet exist • New mines and mine closure and reclamation planning will need to consider climate change. Structures could become increasingly vulnerable if changing climate parameters are not accounted for
	Non-Climatic	• Remote location of mine sites (e.g. transport of goods is a logistical challenge, emergency response is slowed) • Regulatory requirements • Greenhouse gas emissions	• Energy management and GHG reduction initiatives • Investigation of alternative energy sources • Mine closure plans in the Northwest Territories require government approval before decommissioning can occur, company sponsored closure bonds have also been legislated. An opportunity thus exists for climate change planning to be enforced in closure planning • Environmental assessment process increasingly requiring consideration of climate change impacts	• Companies unprepared for climate legislation/ regulatory requirements could face repercussions • Legislation that is designed without significant industry input could have negative implications for mining sector • Opportunities that climate change presents (e.g. opening of Arctic seaways, longer exploration seasons) could help balance the burden of other vulnerabilities
Voisey's Bay	**Climatic**	• Severe snow storms lead to mine closures • Poor weather conditions (e.g. snow storm, fog,) can reduce visibility and limit plane access to the mine • High intensity rainfall could stress surface water management system	• Water containment system designed for the 1 in a 100 year storm or the 1 in a 25 year storm • Culverts and roads at the mine site have been designed to manage current? rainfall patterns • Mine infrastructure has been designed to withstand extreme cold temperatures	• Projected increases in the frequency and magnitude of extreme weather events could affect mine operations by further restricting air transportation to the mine. • Water containment systems may be compromised if 1 in 25 year and 1 in a 100 year storm events become more frequent

	Non-Climatic	• Limited airport infrastructure – no instrument landing system, reduces flight access to the mine. • Ship traffic through landfast sea ice affects Innu and Inuit hunting and traveling	• The mine is exploring opportunities to invest in instrumentation that would allow night and low visibility plane landings • Agreements have been reached with the local Inuit and Innu groups to help mitigate the problems associated with using an ice breaking vessel to transport ore from the mine (e.g. not shipping during the initial freeze-up period or during the seal-hunting period in the early spring)	• Climate change is expected to have future affects on sea ice and the people and wildlife that depend on it Additional consideration should be given to monitoring how sea ice changes might impact the 'coastal activity' and 'social activities of local Aboriginal people'. This could have implications for ice-breaking/shipping activities and agreements with local Inuit and Innu peoples
Quebec	**Climatic**	• Precipitation, extreme cold and heat, snowfall	• Investment in dust control in new aggregate mine development, and widespread use of dust control measures • Pumps installed at mine site for water removal • Mines open early if winters are short, close early if winters are long • Closure until conditions improve – e.g. heavy snow on conveyors, lightning • If wet summers occur, more power is used for drying	• Limited long term planning – many mine sites have a limited life-span, others would not have resources (human, financial) to adapt • Limited planning for decommissioning or how climate change would affect decommissioning plans • Less rainfall in summer would have negative impacts on dust control but would improve drying • Shorter winters would extend operating season for mines and reduce need to carry inventory • Fewer extreme cold days would reduce days when cold shuts down operations, more hot days would increase days when it is too hot to work • More heavy winter snowfall like in 2007-2008 would result in more non-operational days • More unpredictability would make planning more difficult
	Non-Climatic	• Conflict with competing land uses • Proximity to urban areas and strict regulations for dust control • Conflicting jurisdictions between province and the federal government	• Outreach to local people • Dust and pollution control. Incentive to take action on reducing emissions	• Ability to meet dust control – regulation could force mines to adapt or close • Ability to invest in new equipment in light of regulatory constraints
Saskatchewan	**Climatic**	• Annual variation in seasonal precipitation, temperature and runoff	• Increases in water use efficiency • Water storage and diversion	• Future drought conditions may present problems for certain sectors of the mining industry dependent on water availability despite efforts to increase water use efficiency

	Non-Climatic	• Market fluctuations • Distance from world markets and cost of commodity transportation • GHG emissions • Negative public perceptions on nuclear energy • Shortages of personnel • High production costs	• Adopting energy efficient practices to reduce production costs and GHG emissions	• Certain aspects of mining remain dependent on the burning of fossil fuels possibly making compliance with future regulations difficult
Yukon	**Climatic**	• Increased snowfall • Earlier/increased run-off • Increased variability and unpredictable conditions • Increased annual temperatures; change in “shoulder seasons” when rivers freeze and thaw • Permafrost degradation • Increased forest fire risk	• Construction on gravel pads; use of thermosyphons • Removal of permafrost under infrastructure/heap locations to fore-stall impact of future melt. • Flood protection measures (e.g. dike around Dawson City) • More vigilant climate monitoring • “Adaptive management”—anticipating events and responding when they occur. • Increased pre-project bonding for de-commissioning costs • New mines considering future climate in planning	• Extreme precipitation leads to potential overflow of holding ponds • Access road erosion • Highway system vulnerable to permafrost degradation; slope instability; wash-outs • Relict closed mines and associated waste and spoil-heaps potentially affected by increased precipitation and permafrost degradation • Still relatively little known about climate future in region
	Non-Climatic	• Global market conditions • Distance to markets • Land use conflicts (harvesting vs. mining) • GHG emissions (not major) • High costs of operating distant from markets and often in challenging terrain	• Hydro-power replacing diesel generation • Management boards, Yukon Land-Use Planning Process and Environmental and Social EA Process to facilitate orderly and sustainable land-use • Much mine infrastructure (e.g. accommodations) tend to be of a temporary nature given short-term fluctuations in economic well-being of mining sector	• Global market conditions • Costs of dealing with climate change vs. revenues generated in mining industry. Speculate that this is largely unknown but may become problematic given relatively short life-cycle of mines and possibility of long post-operation environmental impacts

8.2 MINE SITE CASE STUDIES

The case studies are reflective of the diverse Canadian mining sector, including: newly developed and well established mining regions, remote mine sites located in wilderness areas and mines located in the urban-rural interface, mines dependent on climate sensitive transportation networks (including ice roads) and mines well serviced by transportation infrastructure, mines located in areas subject to land claims agreements, and operations ranging from mining gemstones to aggregates to base metals. Northeastern Ontario, for example, is a long established and well recognized base metal mining region well served by transportation networks; the Northwest Territories is an emerging global producer of diamonds with mine sites highly dependent on climate sensitive transportation networks; southwestern Quebec has a long established aggregate mining sector with many small scale family-run businesses operating in densely populated areas; Saskatchewan is home to resources that are currently in high demand including uranium and potash and is similarly a well established mining region; Yukon has a long history of small scale precious metal mining and more recently copper mining in an area sensitive to climatic extremes; and Voisey's Bay is one of Canada's newest large mines in which climate change impacts were specifically considered in mine construction.

Each case study was guided by a *consistent research approach*. Firstly, in each case study, interviewees were selected using a purposive sampling technique that included mine managers, engineers, operation coordinators and other knowledgeable people with respect to mine operations. A snowball sampling method was also used, whereby interviewees identified other knowledgeable people to interview. A total of 46 semi-structured interviews were conducted across the case studies in summer and fall 2008. The interviews had five key objectives: i) document those climatic risks that mines have had to deal with and are currently dealing with; ii) identify how these risks are experienced and managed; iii) document factors that influence exposure-sensitivity to climatic risk and constrain / enhance adaptive capacity; iv) identify efforts being undertaken to reduce greenhouse gas emissions; and v) consider what climate change might mean for future operations. Interviews took place in-person at mine sites and by phone. A fixed list of questions was avoided in favour of an interview guide that identified the key themes to cover (Table 8.2). This allowed for flexibility in the interview as participants were guided by the interviewer's questions, but the direction and scope of the discussion often explored other areas of interest. The interviews were complemented with analysis of secondary sources of information including academic journal articles, government reports, newspaper articles, books, company reports, and environmental impact assessments (EIAs). These sources were analyzed using the vulnerability framework (see Chapter 5) to identify current and future exposure-sensitivity and adaptive capacity of various mining operations.

Table 8.2: Key themes in the interview guide and examples of some topics covered under each theme

Key Theme	Example of Topics Covered
Personal and company information	• Length of time in current job • Job description • Nature of mine operation working for
Operational challenges (current exposure-sensitivity and adaptive capacity)	• What are the main challenges facing the company? • What climatic risks affect operations? • What management strategies exist for handling climatic and non-climatic risks?
Current climate change (current exposure-sensitivity and adaptive capacity)	• Has climate change been observed? • Is it affecting operations? • How is the mine managing climate change risks? • Is the company taking action on mitigation?
Future climate change (future exposure-sensitivity and adaptive capacity)	• Do you think future climate change will affect operations? • Is the company planning for adapting to future climate change? • What adaptations are possible? • Is action being planned to reduce GHGs? • What other problems will affect operations?

It is noteworthy that the characterization of climate change vulnerability differs significantly in terms of breadth and depth for each case study. This occurred for a number of reasons. Firstly, willingness to be interviewed varied across the case studies, reflecting time availability of potential interviewees and their interest in the project. Secondly, for established mining regions (e.g. northeastern Ontario) and those regions which are more climate-sensitive (Northwest Territories, Yukon), the literature is much more comprehensive as it pertains to climate vulnerability; for some regions this literature is very limited (e.g. southwestern Quebec). Thirdly, case studies range from focusing on an individual mine site (e.g. Voisey's Bay) to geographically constrained areas (e.g. south-western Quebec), to large regions with a diversity of mine operations (e.g. Saskatchewan, Yukon). Moreover, for the newer mining regions (especially those where mines have developed in the last decade) some information on climate vulnerability is contained in EIAs. When sampling a cross section of an industry as diverse as the Canadian mining sector it is inevitable that there will be differences in the breadth and depth of analysis between the case studies. It is also noteworthy that in some case studies the researchers operated on the principle of anonymity to interviewees (e.g. Voisey's Bay) and mine sites (e.g. Quebec) reflecting personal preference and a recruiting technique, in the other case studies this was not necessary.

The following sections report on the key findings from the case studies, which are organized according to the vulnerability framework. The chapter finishes with a conclusion that synthesizes key findings.

8.3 DIAMOND MINING IN THE NORTHWEST TERRITORIES

8.3.1 Case Study Description

Mining represents a significant component of the Northwest Territories economy; in 2007, mineral production was predicted to be worth over $1.41 billion (NRCan, 2008b). Diamonds have been a relatively recent addition to the Northwest Territories mineral portfolio with the first mine, BHP Billiton's *Ekati*, beginning production in 1998. A second mine, Diavik Diamond Mines Incorporated's *Diavik*, began production in 2003 and De Beers Canada's *Snap Lake* began production in 2008. These three mines are clustered in an area approximately 200-300 km northeast of Yellowknife (Figure 8.1).

Although all employees are brought to the mines by airplane, the seasonal 'ice road' is the only ground transportation link between the diamond mines and cities in the south (Figure 8.1). The road is 568 kilometres long, begins just outside of Yellowknife, Northwest Territories and stretches northeast into southern parts of Nunavut Territory. Transport trucks bring the majority of supplies into the mines over the road, although only during the winter when temperatures are coldest. Some goods are also transported by year round air traffic, although ice road transportation remains the preferred (and less costly) option.

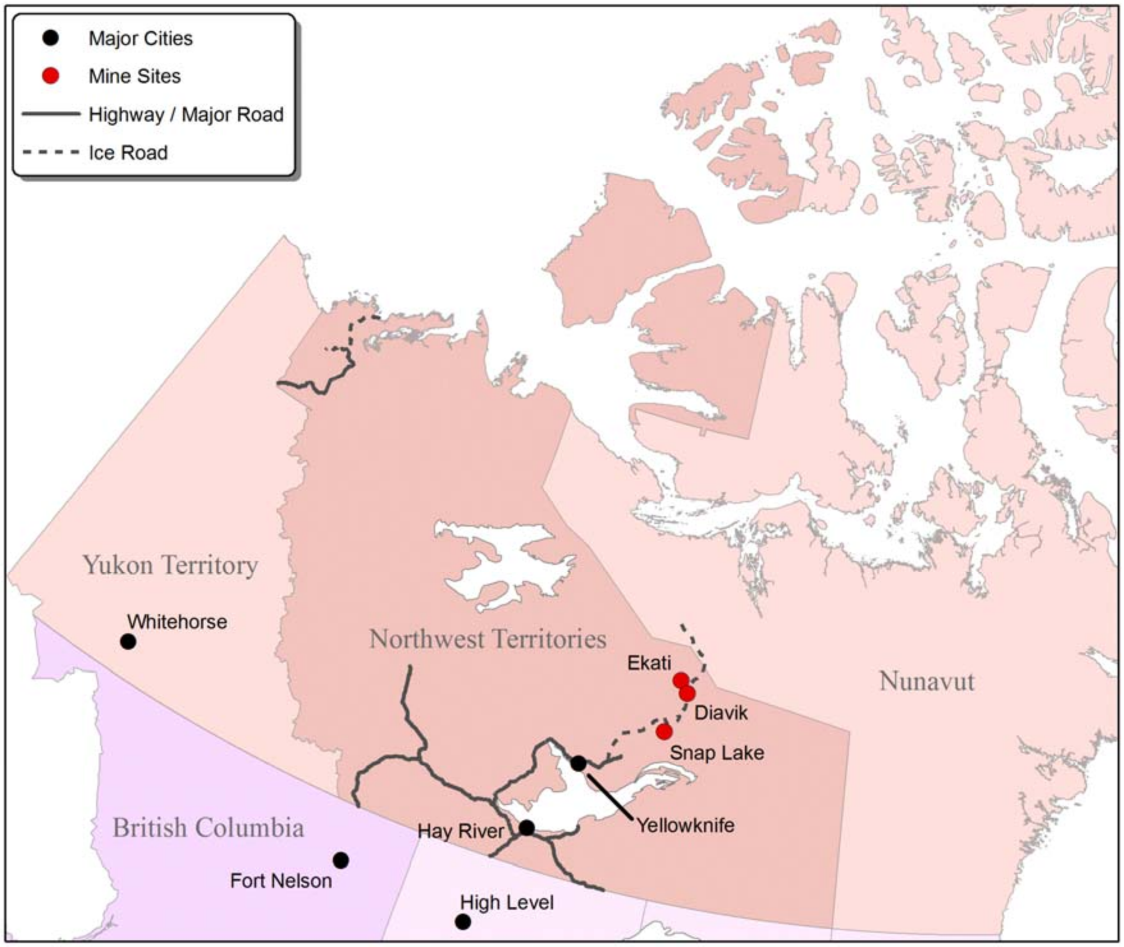

Figure 8.1: Diamond mines of the Northwest Territories and highway and ice road transportation networks

The diamond industry is now the largest contributor to the Northwest Territories' Gross Domestic Product, representing more than 50%. Northwest Territories diamonds have also been instrumental in making Canada the world's third-largest diamond producer by value; Canada now produces 11.5% of the world's diamonds on a value basis (NRCan, 2007b). Diamond exploration continues to thrive in the Northwest Territories; in 2005, $50.9 million was spent on exploration, while in 2007 there were sixteen separate exploration projects operating (NRCan, 2006). Yellowknife, the capital, now rightly describes itself as the 'Diamond Capital of North America'.

The region also benefits from the employment opportunities provided by the diamond mines. Aboriginal communities have benefited significantly from these ventures, with some mines posting Aboriginal employment rates of 30-40%. In what would otherwise be economically depressed regions, this employment is important. Residents of Yellowknife and other cities also benefit from employment at the mines, as does the mining supply and support sector.

Data for this case study was collected from scientific publications, public newspapers, industry publications and individual interviews. Interviews were conducted both in-person and over the phone, with company executives, mine managers, engineers and other knowledgeable persons. A total of 16 people were interviewed: 10 over the phone and 6 in person. The standard interview guide structured the interviews and data was analyzed using the vulnerability framework (current exposure-sensitivity, current adaptive and mitigative capacity, future exposure sensitivity, and future mitigative capacity).

8.3.2 Current exposure-sensitivities

Mining companies operating in the Northwest Territories already face unique climatic challenges. The climate can be harsh, especially in the winter months. Extended periods of -30°C to -40°C temperatures are not uncommon, short daylight hours are the norm, and winter storms present their own operational difficulties. The ground these sites are built on is also underlain by year-round permafrost, creating additional engineering challenges. Furthermore, these mines are remote. Accessible year-round only by air, or seasonally by an ice road network, needed supplies can take days to reach a site (assuming they are available). Materials necessary for the mine are often stockpiled for the year throughout the short winter trucking season, to avoid costly air transport later on.

With regards to climate change, warming temperatures are already creating some noticeable risks for diamond mining operations in the Northwest Territories. The seasonal ice road network has been especially susceptible, and a number of regulatory risks have also been noted. Acting as a virtual highway on ice, the ‘ice road’ is the only ground transportation link between the diamond mines and cities in the south. The road itself is 568 kilometres long, with 64 portages and 3 support camps. It begins just outside of Yellowknife, Northwest Territories and stretches northeast into southern parts of Nunavut Territory. Transport trucks carrying large loads traverse the road during only the coldest winter months. Transporting freight this way is essential; air transport is comparatively much more expensive.

As a large portion of the road is built on lake ice, it is obviously susceptible to warm temperatures and other climatic changes. 2006, for example, was an exceptionally bad year for the ice road. Only open for 42 days because of unseasonably warm conditions, the traditional ice road season was cut short by nearly a month (the 2005 season was approximately 70 days). Challenges of this nature are likely to become the norm in a rapidly changing climate (Lemmen et al., 2008).

As truck loads on the ice road are expected to grow in coming years with increased regional mining activity, melting conditions are an obvious concern. The financial costs of a reduced ice road season are significant. Needed freight that is not transported overland must be flown in to mine sites, with the expected increase in price that air travel brings. One of the most commonly transported items on the road is fuel – 60% of trucks on the road are carrying fuel loads – and flying in fuel is notoriously expensive. In the shortened 2006 season, Diavik alone had to fly in 15 million litres. Another mining company operating in Nunavut at the time estimated it would cost an additional $0.75 per kilogram or litre, to fly materials in rather than transport them by truck (Canadian Mining Journal, 2006). Using these figures as a base, Diavik would have spent an *extra* $11.25m in flying in fuel.

Climate change has also posed a number of regulatory risks for mining companies in the north. For example, mining projects moving from advanced exploration into production must submit themselves to a sometimes lengthy environmental impact assessment process. In recent years, this process has increasingly demanded consideration of climate change impacts by mining companies. In a Northern context, Rio Tinto's Diavik mine, BHP Billiton's Ekati, Zinifex's High Lake project, Agnico-Eagle's Meadowbank gold project, Newmont's Doris North project and Sherwood Copper Corp.'s Minto copper mine all considered climate change, at least to some degree, in their assessments. These assessments often examined future climate scenarios to identify impacts likely to occur to project infrastructure and the surrounding environment. Monitoring and mitigation strategies were also often identified. However, ways for taking climate change into consideration have not yet been characterized in a way that can lead to meaningful and consistent application of solutions.

Mining companies could face other regulatory risks. Of interest here is the possible implementation of 'cap and trade' systems and/or of carbon taxes. Those companies caught unprepared for new legislation, for example, could stand to face significant economic repercussions. Especially concerning for some mining sector representatives is climate change legislation that is designed without significant industry input, and that leads to unfair economic repercussions for the sector.

8.3.3 Current adaptive and mitigative strategies

Diamond mining companies in the Northwest Territories have out of necessity had to adapt to the harsh climate they operate in. Specialized engineering and designs for cold-weather environments have been employed, as have some adaptations to risks posed by current changes to the climate.

In light of future threats to the ice road and the 2006 extremes, some solutions have currently been generated. New, lighter-weight and amphibious machinery has been purchased to facilitate road construction earlier in the season, alternative road routings have been developed, and operational efficiencies have been achieved. Longer-term, alternatives to the ice road are also being explored. Construction of a seasonal overland route and utilizing the proposed Bathurst Port and Road Project are just two of the ideas currently being investigated.

Diamond mining companies have also been undertaking a number of GHG reduction initiatives across the north. Use of state-of-the-art technology that reduces emissions (e.g. improved ventilation and HVAC systems), and of energy auditing programs are just some examples. Other changes have also been made. For example, Diavik outfitted its large 218-tonne and smaller 90-tonne haul trucks with engine heaters to allow operators to shut down their trucks instead of idling them when the temperature is between 0 and minus 20 degrees Celsius. The new heaters could potentially save Diavik over one million litres of fuel annually (MAC, 2007). Alternative energy sources have also been investigated by the diamond mining companies. Assessments of the potential for wind, solar, geothermal and hydroelectric power have been undertaken, although no commitments have been made.

It is difficult to determine exactly how many of these initiatives are linked to climate change *directly*. In many cases, 'energy management' initiatives are undertaken primarily with cost savings in mind. Energy for the diamond mines is produced 100% from diesel fuel and this fuel must be trucked in over the ice road or flown in by plane. Both these transportation options have significant costs attached and it is thus in the interest of mine operators to reduce fuel use wherever they can.

While not directly employed by the mining companies, some consultants, contractors and engineers who are working on mining projects have made strides in climate change adaptation planning. They have been seen reporting on adaptation issues and even incorporating climate change adaptation into their work (e.g. Holubec, 2007, Hayley & Proskin, 2008a, Hayley & Horne, 2008b). The nature of mine development is often that these individuals will be hired to conduct the specialized tasks related to building a mine; they thus play an important role in the process of adaptation. For example, there are no standardized regulations for building on permafrost and it is up to the individual contractor to make their own design assertions.

8.3.4 Future exposure-sensitivities

For the Northwest Territories, climate scenarios generally indicate increases in annual amounts of precipitation and temperature (see Chapter 3). Temperature increases will be significantly higher in winter than in summer, although the winter increases in Northern Canada are typically predicted to be the largest of any region in the country, and indeed globally. The increase in precipitation levels is also a trend that is expected to increase over time. These changes are expected to present a number of risks for mining operations in the Canadian North. Left un-prepared for, climate change will create risks associated with building foundations, transportation routes, slope stability, tailings retention structures and site drainage, among others.

For example, mine infrastructure and transportation routes have been noted to be vulnerable (e.g. Instanes, 2005; Holubec, 2007; Furgal and Prowse, 2008). Buildings erected on thaw-sensitive land could see their foundations settle and shift as permafrost melts, increasing maintenance expenditures and causing potential operational delays. Extreme weather events could also increase susceptibility of buildings to damage; extreme flooding, ice storm and wind events already cause significant weather related damage to infrastructure (Auld and MacIver, 2006) and in some regions these events are expected to increase. Infrastructure built on or near steep slopes will also need to consider the increased susceptibility of those slopes to slumping and sliding as underlying frozen material looses cohesion due to melt. Examples of these considerations are already being documented in northern communities and it seems only a matter of time before mining operations could become similarly affected.

Land-based transportation routes could also face risks from melting permafrost (Instanes, 2005; Holubec, 2007; Furgal and Prowse, 2008). Road embankment instability and erosion susceptibility are some relevant examples here. Ice road networks will undoubtedly also face risks, as a warming climate makes it more and more difficult to maintain sufficient ice thicknesses to support heavy traffic flows. Remote mines without year-round ground transportation links will be particularly vulnerable. There could also be risks associated with waste rock piles and tailings retention structures (e.g. Instanes, 2005; Holubec, 2007; Furgal and

Prowse, 2008). Some tailings retention structures in the north, for example, depend on frozen conditions for the lifetime of the structure. The implications of a warming climate are that these dams could lose their structural integrity over time, possibly leading to failure. At the very least, increased air temperatures could result in increased maintenance and operational costs to keep the embankment frozen. In the worst case, tailings dam failures could spill mine wastes (including acid generating wastes) and contaminants into the environment; this would be a major concern in the Arctic where remoteness will constrain clean-up operations and the cold climate results in slow natural decomposition of pollutants. Undoubtedly, there would also be repercussions for corporate image. Companies might also have to give up the bonds they provide for surety against environmental spills. For example, in some regions and cases (Nunavut) reticence to return bonds has already been demonstrated due to fears relating to how the design of existing structures will perform under future climate conditions.

Mine site drainage and hydrologic regimes could also be affected by climate change. More frequent ‘extreme’ weather events could unleash large amounts of precipitation in relatively short periods of time, evaporation trends may be altered, and the timing of expected seasonal events could change. Large amounts of precipitation arriving during the spring freshet in the Arctic, for example, could create a significant operational issue as flooding could ensue.

Mine closure and reclamation planning will especially need to consider climate change. Buildings, roads, bridges, dams and other structures important to mining operations are often designed to last for several decades or longer based on engineering principles and design criteria (e.g. building codes) that were developed assuming that the future climate will exhibit similar characteristics in average conditions, extremes and variability as the past climate (Auld and MacIver, 2007). As the climate changes, these structures could become increasingly vulnerable if changing climate parameters are not accounted for.

8.3.5 Future adaptive capacity

Insight into the future adaptive capacity of the diamond mining sector can be obtained from comments made during interviews with mining sector representatives. On the whole, climate change is recognized as a concern, albeit a somewhat minor one, that could impart a number of risks. “It’s on our radar screen” noted one respondent, “It becomes a risk management issue”, noted another. Unfortunately, widespread, long-term and strategic planning for climate change does not seem to be occurring in the sector. One interviewee even noted “incredible stubbornness” within the sector to the adoption of adaptation measures. While adaptation planning is occurring in some limited circumstances (e.g. evaluating long-term options for the ice road), it cannot be thought of as widespread in the sector.

So what does this mean for the future? Considering the potential for risk that mining operations in the north will face with climate change, these are somewhat sobering disclosures. Numerous reasons for a lack of long-term planning may exist. For one, most mines have short operational life-spans. Mine employees are often focused on shorter-term objectives and don’t see a need to plan 50-100 years into the future. After all, most current mines won’t be operating in 2050, let alone 2100. Large investments of time and resources into climate change adaptation thus seem inappropriate to some mine companies. While it’s true that short operational lives likely preclude large investments into future adaptive measures, climate change should not be ignored. New mines will inevitably come on-line and operate well into the future, and mine closure planning will need to consider the changing climate well into the future. Moreover the latest science indicates that climate change is occurring faster than previously thought.

In most cases to date, adaptations have also been largely voluntary. That is to say, few legislative repercussions exist for those who don't develop adaptation strategies. There are (yet) no widespread legal obligations to reduce greenhouse gas emissions, for example, or to ensure closure plans take into consideration a changing climate. Fortunately, mine closure plans in the Northwest Territories now require government approval before decommissioning can occur. This approval process could present an opportunity for the government to mandate the incorporation of climate change considerations into mine closure planning. Furthermore, company sponsored closure bonds have also been legislated in recent years. This is added incentive for mining companies to meet their closure requirements, should they wish to recoup their bonds.

Finally, a lack of knowledge about the implications of climate change amongst some mining sector practitioners may be contributing to a lack of long-term planning. Awareness of climate model predictions, of predicted risks to mine infrastructure, and of potential climate change legislation were not apparent in some interviews. It goes to say that mining companies that are more acutely aware of these issues will arguably be better suited to making successful adaptations.

Luckily, engineering solutions exist for a number of the problems posed by climate change. Noted one interviewee, "We have the technology available to manage climate change impacts. Unfortunately, we often only design structures for limited life spans. Planning for climate change can be less costly if it is dealt with early." While many of these technologies are expensive, they can be effective. For example, in instances where maintaining frozen conditions are necessary, thermosyphon technology may be appropriate. Already employed in many parts of the north to stabilize thaw-sensitive areas, thermosyphons are self-powered refrigeration devices that are used to keep permafrost cool. They have their applications in mining as well: The Ekati and Diavik diamond mines already use them to help maintain thermal integrity of various structures. Similarly, tailings cover can be modified in other ways to ensure the materials below ground stay frozen, and ground-based transportation networks can be built in ways to minimize disturbance to the frozen soil layers below. Insulation of the surface (e.g. using thicker gravel pads) and clearance of snow (to promote colder ground temperatures) are some examples (Couture et al., 2003). These modifications will be especially important where frozen conditions are essential to the integrity of structures and designs.

To be most effective however, engineering designs will need to incorporate parameters from climate change models into their calculations. 'Climate forecasting' is an important and evolving area of climate change science but has yet to produce the detailed regional data needed for pinpoint engineering design. Climate models now provide us with useful, albeit generalized, pictures of predicted changes, but a need exists for their further refinement. In the absence of detailed modeling, adaptive management and active monitoring of mine site conditions will become even more important into the future.

In some cases, changing climatic conditions could even be favourable for mining companies. Something often left out of the climate change discourse are the opportunities that will occur. For example, there has been much discussion about the potential for Arctic seaways, such as the Northwest Passage. The opening of these seaways would have obvious benefits for the shipping trade, could reduce freight costs for mines and increase the accessibility of remote sites. Similarly, warmer temperatures could result in lower fuel costs for heating and lengthened exploration seasons. The degree to which any company successfully adapts to climate change will depend not only how well they handle the impacts, but also on the degree to which they embrace opportunities that arise.

8.4 MINING IN THE URBAN-RURAL INTERFACE IN SOUTHWESTERN QUEBEC

8.4.1 Case Study Description

Quebec has one of the highest concentrations of mines in Canada. While many are located in the interior and north of the province, the region around Montreal also has a high density of mine operations. To compliment the other case studies which have focused largely on remote sites, this case study focuses on mining operations in a more populated setting: the Montreal area (Figure 8.2). All operations reported on in this case study are within a 90 minute drive of the city. This provides insights into the nature of current and future climate change vulnerability in mine operations in areas that are well served by transportation and logistics infrastructure, and operating in locations with high population density and competing land uses.

All mine operations within a 90 minute drive of Montreal were identified and five were selected: 2 sand mines, 2 limestone mines, and 1 dolomite mine. These companies were contacted in advance and asked to select the most relevant person to be interviewed regarding climate change; all five companies contacted agreed to be interviewed. In this case study we agreed that all interviewees and their mines would be anonymous. Interviews were conducted in French and lasted between 20 and 45 minutes in length. The standard interview guide used in the other case studies was employed (in translated form) to identify key topics to be covered in the interview, with the vulnerability framework guiding analysis. The companies selected for the interviews reflect a cross section of mines operating in the province, including small family-run companies operating a limited number of mine sites in Quebec to large multinational firms with many operations across Canada.

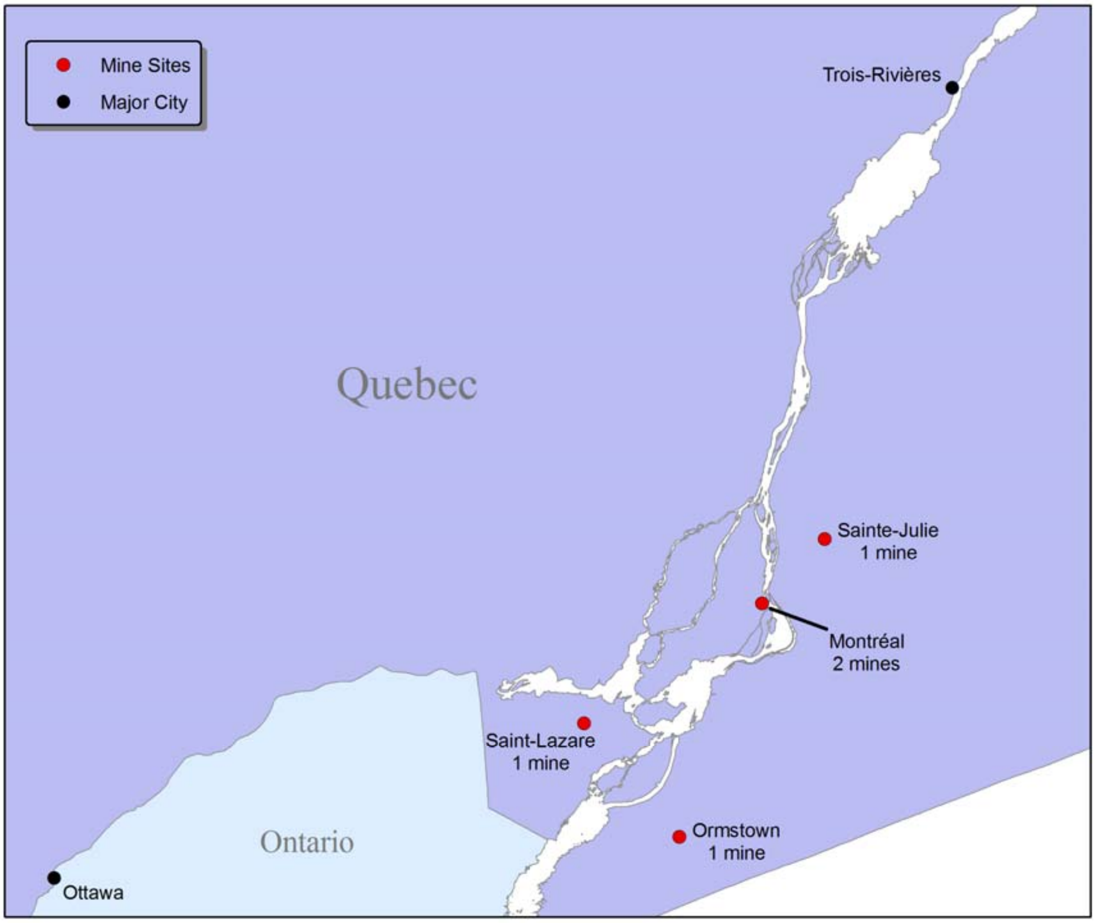

Figure 8.2: Locations of surveyed mine sites in SW Quebec

8.4.2 Current exposure-sensitivities

All interviewees identified that mine operations were sensitive to *climatic conditions*, although the degree to which they were sensitive differed by operation. The most commonly identified concern was dust emissions and the role of *warm dry conditions* in exacerbating this problem. Most mining companies use dust control procedures, which mostly involve spraying water at mine sites, although some of the larger operators have shelters to cover storage and processing areas. One of the larger operators has even invested in extensive dust control at its Bedford facility at considerable expense. In this respect the wet summer in 2008 was beneficial and reduced the costs of dust control. Dust control was particularly an issue for those mines close to urban areas, as municipal regulations closely control the amount of atmospheric dust loading that occurs.

Variations in *rainfall* were also frequently noted as affecting operations. On the one hand rainfall is beneficial in that it controls dust and for some mines is important in recharging local lakes used for water supply and hydro power generation. Too much rainfall, however, was identified as a problem by all mines as it could increase the costs of drying mined materials and sieving the rock, which subsequently increase GHG emissions because of greater power usage. For example, dolomite that is used for asphalt paving has to be dried and if it is wet this considerably increases drying costs. During the wet summer of 2008, this company reported spending considerably more on drying than normal. For mines with deep quarries, too much rainfall also increases the costs of water removal from the mine site. Intense rainfall events and storms are the most problematic, as operations have to suspend work when lightning is detected. One company also noted that one major storm during the previous summer backed up their sewage system and blocked mine access, resulting in employees being stuck on the mine site. Storms can also be problematic if they knock out the mine's power supply.

Temperatures were not identified as a major problem by the interviewees, although some operations are obviously sensitive. Extreme cold, for instance, makes it more expensive to run machinery by lengthening warm-up time for efficient usage and increasing de-icing costs, although only the larger companies reported operating during the winter. During the coldest days of the year one interviewee reported that operations were not possible for three days as the machinery was too cold to start. Extreme heat was also identified as a cause for concern, as during very hot days operations sometimes have to halt to prevent workers from getting ill. One of the sand quarry operators noted that cold winters were even beneficial, as ice forms over the sand and prevents infiltration of moisture and therefore reduces drying costs.

Snowfall and *winter conditions* were frequently identified as affecting mine operations. Heavy snow, such as that experienced during 2007-2008, is a problem and reduces operational capacity. It necessitates costly snow removal and increases costs of drying the mined material. The interviewee from the dolomite producing company noted that winter temperatures had become more variable in the last 5 to 6 years, resulting in events such as the melting of ice in January. Furthermore, the mine doesn't operate in winter and the water removal pumps are shut down, which can result in flooding and the potential to damage the $300 000 worth of electric motors used in the rock crushers. The timing at which winter arrives is also important, especially for the smaller mines which close when snowfall and cold temperatures begin to limit operational capacity. Shorter winters – such as those noted in recent years (except 2007-08) – are beneficial because they decrease the need to build-up inventory for those companies that cannot operate in the winter. For one mine site, up to $400 000 is spent on maintaining inventory during winter so that they can continue to operate; shorter winters can therefore have economic advantages. The increasing unpredictability of the start and end of winter, however, causes difficulties for operational planning and the stockpiling of mined materials. Winter *ice storms* that damage power infrastructure can be particularly problematic for operations. Two of the small rural operators noted having to close for between 3 and 4 weeks during a 1998 ice storm due to loss of power. While both had generators they were not enough to provide full operational power. This highlights the risks faced by companies located in rural locations.

It was non-climatic conditions, however, that dominated company concerns in the interviews. Non-climatic conditions will be especially important in determining how climate change is experienced and will shape a company's ability to respond. A major concern noted by all interviewees was *conflicts over land use* and the fact that operations take place in close proximity to populated communities. One sand quarry operator whose family mine had been operational for over 100 years noted how the expansion of a local town had resulted in loss of land for quarry expansion and calls from new home owners to reduce quarry traffic flow and noise. Another interviewee, whose company has quarry operations in urban Montreal, also highlighted local residents' concerns about noise and dust, even though company guidelines are noted as being stricter than those imposed by the province. In this case, local concerns were also noted as having advantages, including motivating the company to think about reducing pollution and greenhouse gas emissions. Conflicts over land use were noted as being particularly problematic when mines are considering expanding. Two mine sites noted their ability to continue operations will be limited if they are not able to expand. Given the proximity of these mines to the market (i.e. Montreal and Port of Montreal), closure could have negative climate change implications if material has to be transported over larger distances from other mines.

Regulation was also frequently noted as a constraint to mine operations. The majority of concerns related to expansion, although one of the larger mine operators noted that they were having difficulty getting approval to build a biomass oven to replace charcoal used in lime processing. In this case, the new energy source would be ready in early 2009 if they started construction now but the company does not expect to get authorization from the provincial government for at least 2 years. Larger companies also noted the conflicting regulations affecting mine operations in Quebec, with provincial and federal jurisdictions sometimes overlapping. Overlapping jurisdiction was noted by respondents as being a feature common in Quebec. One representative from a larger company even illustrated how waste management regulations were having somewhat perverse environmental implications. The company of mention produces 40 000t of lime kiln dust per year, which has historically been buried at the quarry site. As of January 2009, however, this will not be possible due to new regulations, and the company is now considering shipping the dust off-site. Not only is this an extra expense to the company but it will also increase transport-related GHG emissions. Other problems noted by interviewees include *lack of water for processing*, and concerns over *mine longevity*. The high *cost of oil* was also cited as a problem, with operational costs linked to the changing price of fuel.

8.4.3 Current adaptive and mitigative strategies

The mining companies operating in the Montreal region are sensitive to climatic conditions and some interviewees said that climate change was already affecting their operations. A number of strategies have been developed to manage some of these risks and some companies are considering developing responses to changes they have already experienced. No interviewees, however, reported actually developing strategies specifically for climate change.

Dust control is employed by all companies and, as discussed above, is especially important when dry hot conditions prevail. Municipal and provincial regulations mandate a certain degree of dust control, which have to be abided by to avoid fines. In many cases, adaptations to climatic risks involve making *ad hoc* changes as risks manifest themselves. Especially for the small companies interviewed, beneficial conditions such as short winters are taken advantage of by increasing production and extending the operational season. Likewise, if winters are longer than usual, there is heavy snowfall, or temperatures are very cold or very high, then production is decreased. For example, one of the larger mine sites has over 1km of conveyors. If there is heavy snow they have to shut down until these conveyors are cleared, and the extended length of the conveyors precludes covering them all. Indeed, for many climatic risks the adaptive response is to reduce production until climatic conditions improve. While this entails sometimes significant economic costs, when there is extreme heat or cold, loss of power, heavy rainfall, or lightning, there appear to be few options available. Some technical and engineering responses have been developed though. The mine site whose employees were stranded due to flooding raised the existing access road by 30cm to prevent this from happening again, and one company is considering building shelters at its site to reduce dust from storage areas during the summer months.

The majority of those interviewed reported their companies were addressing climate change by reducing greenhouse gas emissions. One of the smaller companies even recently developed a small hydro power generating station with a subsidy from Hydro Quebec. The larger operations have company-wide programs to reduce greenhouse gas emissions as well as site specific initiatives. These programs advocate a number of ways of reducing emissions, including:

- Each truck having an automatic stop function which is activated after 8 minutes of idling
- Recycling of used oil to a company called Ecocycle who filter it for reuse at the mine site. However, they are currently exceeding the capacity to recycle.
- Conversion of some machines to maximise their fuel efficiency
- Purchasing of small cars when trucks are not needed

The smaller companies, however, indicated that they did not have the staff or financial capacity to think about future risks, especially climate change.

For some companies, climate change and environmental protection has been the motivation for trying to reduce greenhouse gas emissions. Especially for the larger companies and the mine operating directly in Montreal, public pressure is a major concern. The high cost of energy was also noted as a motivating factor along with the desire to increase efficiency and profitability.

8.4.4 Future exposure-sensitivities and adaptation options

The interviewees had all heard about climate change and had an appreciation for some of the changes which might occur. Concern about climate change and its impacts on mine operations, however, varied. An interviewee at a sand mine noted the short lifespan of the mine meant they were not concerned by climate change as they will not be in operation when many of the changes manifest themselves. Indeed, sand mines have limited decommissioning responsibility which limits their future liability. However, the other mine operators all had long term mining interests in their location and noted some of the potential benefits and drawbacks of climate change. Importantly, most did not view climate change as a major concern, with other non-climatic stresses viewed as having greater importance. Conflict with competing land uses was one example. Two of the mines, in particular, have experienced growing populations near their mine sites and are concerned that people will continue to demand less mine-related noise and traffic.

For this region of Quebec, climate scenarios (chapter 3) generally indicate higher temperatures in winter and especially in summer, and increasing precipitation year round. Increased summer rainfall will bring benefits in terms of reduced dust control. However, if the increased rainfall occurs through more intense storms as opposed to longer periods of rain, as predicted, this may have limited impact on dust control and may create new problems such as flooding and erosion of stored material (especially sand and gravel). Moreover, more rainfall may increase the costs of drying mined material although if temperatures increase and there are more intense rain events (rather than just more rainfall over the entire year), the impact on drying might be neutral. For the purposes of both dust control and drying, companies are considering building shelters and one company's new mine site now includes a significant investment in dust control measures. Local land use concerns as opposed to climate change concerns, however, were the main motivating factors for this decision. Increases in winter precipitation could cause problems for the mine sites, especially for deep quarries which do not operate in winter. The company that experienced flooding in recent years due to winter melt is considering investing in new pumps to deal with winter thaw.

Temperature increases are predicted for winter and especially summer months. Rising summer temperatures do not threaten operations *per se*, but the associated increase in occurrence of heat-waves could result in a slow-down of operations when it is too hot for employees to work safely. Potential adaptations could involve use of air conditioning and establishment of cool zones, or shortening the amount of time workers spend outside in the sun. Inadvertently, some of these adaptations would also increase energy use and GHG emissions. Increasing winter temperatures would bring benefits to mine operations if winter is consequently shorter in duration. For the smaller companies it would mean an extension of their season of operation, while larger companies would have to carry less inventory. Warmer temperatures would also mean less need to invest in de-icing equipment. However, if temperatures warm while snowfall levels increase (e.g. 2007-2008 was a warm winter but had lots of snow) this would necessitate increased expenditure on snow removal, would increase snow loading risks on infrastructure, and could bring increased flood risk during spring melt.

8.4.5 Future adaptive capacity

A number of options are available for companies to reduce the negative impacts of climate change and take advantage of potential new opportunities. The ability to utilize these options, however, will depend upon institutional, economic, regulatory, and location factors. Firstly, all interviewees noted the short term view many of their companies take when planning for climatic risks and environmental issues. As one respondent noted regarding future climate change impacts, "We take it as it comes". This *ad hoc* approach is largely reflective of how the other interviewees viewed climate change and future risks to their operations. For the interviewees from the smaller companies, this perspective was explained in terms of the limited human and financial resources available to them; they are simply too busy mining and supplying customers to think about climatic risks and climate change. At the larger companies, interviewees noted that it was important to think about these issues but explained that planning was handled at a higher level. Unfortunately, it was also noted that the senior managers were more preoccupied with short term problems than things like climate change planning. Research has demonstrated that in many instances, planning today for future climate change will be more cost effective than waiting until the effects of climate change manifest themselves (IPCC, 2007). The repercussions of ignoring climate change are thus significant. Notwithstanding this, the larger companies did report taking action on climate change fronts, such as reducing GHGs.

Secondly, economic factors have a major influence on adaptive capacity. Many of the adaptations to climatic risks - those employed to date and those available for the future - are costly. Only if these investments can bring immediate benefits will they be more likely to be considered by company management. Thirdly, location constraints will affect the ability of mines to adapt to climate change. While the mines in this case study do not suffer from the problems associated with transportation logistics at remote mine locations, their presence near urban areas with competing land uses affects what adaptation options are available. For example, government regulations may require certain investments to be made by companies regardless of cost (to maintain environmental quality and other legal obligations, for example). An example here would be the need for dust control at mines near urban areas. Other adaptations such as accessing new water sources, expanding mine sites, etc. may also be constrained in such contexts. Fourthly, regulation may inadvertently constrain the ability to adapt in other ways. For example, some large capital investments require provincial approvals which are often time consuming and may act as a disincentive to investment.

8.5 SULPHATE, URANIUM, AND POTASH MINING IN SASKATCHEWAN

8.5.1 Case Study Description

Mining is a major contributor to the Saskatchewan economy. The mining sector ranks third amongst Saskatchewan's leading industries in terms of value of sales, being surpassed only by oil and gas production, and agriculture. Mineral sales were valued $3.2 billion in 2006; $2.4 billion of this was from potash sales and $640 million from uranium sales. These two minerals underpin the Saskatchewan mining economy and are important contributors to Canadian mining production numbers. Canada supplies 33% of the world's potash and 28% of the world's uranium and Saskatchewan is Canada's leading producer of both minerals. Canada, it should be noted, is also the world leader in production of both these minerals. Saskatchewan is Canada's only producer of uranium and has all but one of the country's potash mines; the other one being located in New Brunswick. Although a smaller part of the Saskatchewan mining economy, sodium sulphate production also makes a significant contribution. Much of these mineral reserves are untapped, but successful mines have operated throughout much of the province's history.

Sodium sulphate mining is extremely sensitive to climate, as the processes used in extraction of the mineral are climate dependent. The implications of climate variability for extraction efficiency are discussed later in this chapter. Potash and uranium mining, although not significantly sensitive to climate, could play major roles in adapting to or mitigating the impacts of climate change. Potash is a key component of fertilizer and therefore an important mineral for agricultural production and the production of biofuels. Uranium is used to generate nuclear energy, which can be used to produce electricity with significantly lower GHG emissions compared to fossil fuel-based power generation. For potash and uranium mining, vulnerability to climate change is largely related to regulatory actions and policies of future governments regarding GHG emissions and climate change adaptation.

The potential impacts of climate change on the Prairies are largely related to the availability of water to meet consumptive demands. Although precipitation is expected to increase in both quantity and frequency of events (Kharin & Zwiers, 2000), moisture deficits (Gameda et al., 2005, Nyirfa & Harron, 2001) and aridity (Sauchyn, 2008) are also expected to increase due to climate warming. Annual stream flows down many of the rivers supplying water to the Prairies are expected to decrease; for example, a reduction of flow by 8.5% is expected for the South Saskatchewan River at Lake Diefenbaker (Pietroniro, 2006). Many of these rivers are fed by glacial melt water and reductions in stream flow have already been observed due to glacial retreat (Demuth & Pietroniro, 2003). Implications of these changes for the mining industry and its ability to cope are discussed in this chapter.

A literature review of government and scientific publications was completed to provide background for the case study. Semi-structured telephone interviews were conducted with individuals involved in the mining industry in Saskatchewan using the standard interview guide and analyzed using the vulnerability framework. A second literature review was then conducted to document climate sensitivities, both present and future, and to triangulate and clarify the responses of interviewees.

8.5.2 Current Exposures-Sensitivities

The Saskatchewan mining industry faces a number of challenges in terms of remaining economically and environmentally viable. Globalization has locked the industry into highly variable and competitive global markets and, as with many other industries in the province, geography often does not favour Saskatchewan mines. Saskatchewan is landlocked and thousands of miles away from the closest ports, placing mines at significant distance from key markets. Climate, in addition to distance, also impacts the profitability and competitiveness of Saskatchewan mining operations, with interviewees at sodium sulphate mines reporting sensitivities to climate. For example, access to large lakes define the energy-use efficiency of sodium sulphate mining operations and energy use increases if sodium sulphate mines do not have access to these lakes and if temperature, precipitation and runoff conditions do not favour the brining processes used to extract minerals from the lake. Favourable climate conditions – such as ample spring runoff, warm summers and cold winters - allow mines to take advantage of natural sources of energy, such as heat from the sun, instead of relying on fossil fuels for energy. Reduced reliance on fossil fuels can result in higher profit margins, as natural energy sources can be significantly less expensive than fossil fuels. Some mines have even been forced to close due to the high cost of fossil fuels, inefficient use of these fuels, distance from markets and unfavourable market pricing.

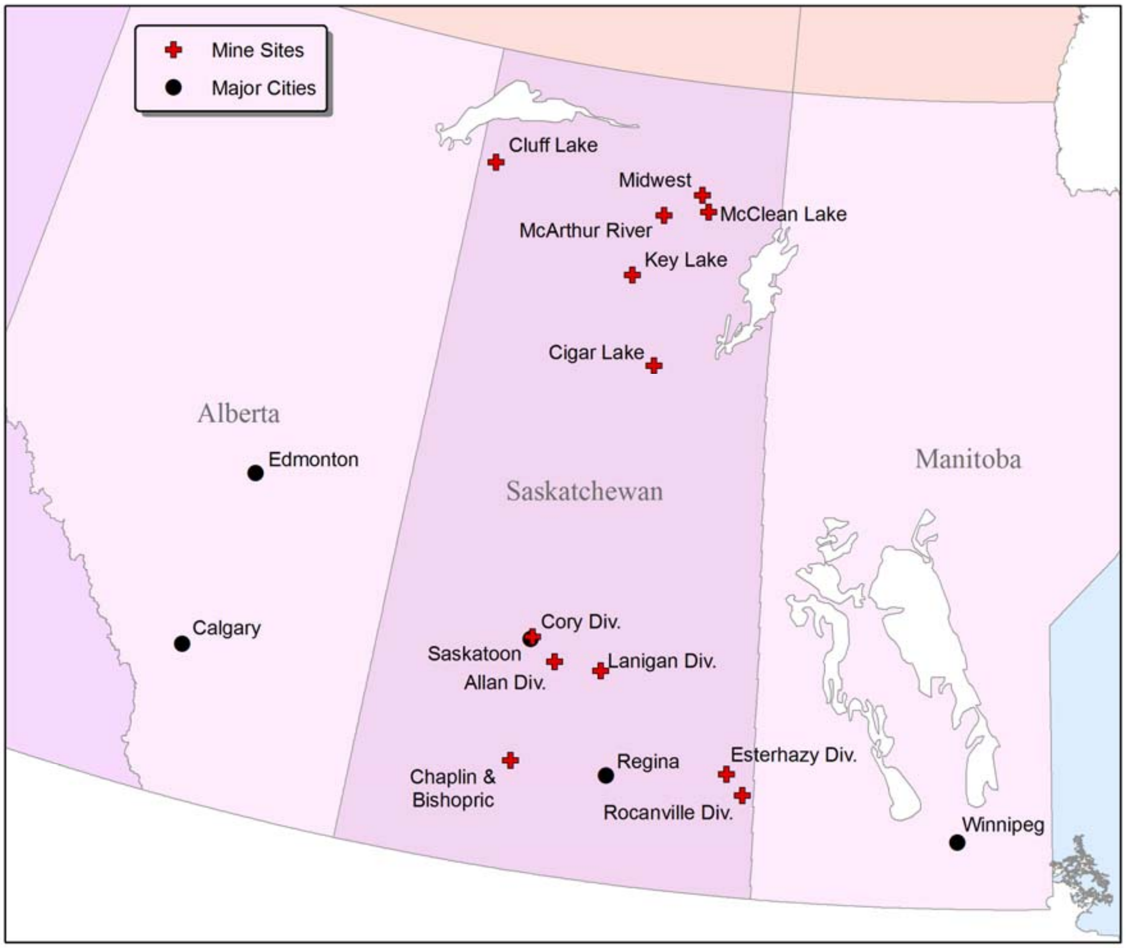

Figure 8.3: Sodium sulphate, potash, and uranium mines in Saskatchewan

1. Sodium sulphate mining

The Saskatchewan Minerals Inc. sodium sulphate mine located at Chaplin has been successful because of its ability to exploit an 18 square kilometre alkali lake for minerals and the favourable temperature, precipitation and runoff conditions of South Central Saskatchewan. In ideal climatic conditions, sodium sulphate mines can take advantage of the sun's energy to extract minerals. Heat from the sun is used to evaporate water from a solution of sodium compounds until they precipitate out and are then gathered from the bottom of reservoirs. This process requires optimum climatic and environmental conditions, including: (1) sufficient water supply; (2) hot dry summers to optimize brine strength; and (3) cold winters to facilitate the collection of sodium sulphate from reservoir floors. If conditions are ideal, sodium sulphate can be extracted from reserves with minimal energy input, thus reducing the cost per ton of production and increasing the ability of mines to compete in global markets. The size of Chaplin Lake coupled with the typically dry summers and cold winters in the region have provided suitable conditions conducive to sodium sulphate extraction at the mine site.

In some instances, sub-optimal climatic conditions have manifested themselves in the Chaplin Lake region. Water supplies, seasonal precipitation and temperature have been affected and have created significant operational problems. For example, brining at the Chaplin mine has on occasion been impeded by low amounts of spring runoff as adequate water supplies must be present in the spring to dissolve the sodium sulphate from the reserve underneath Chaplin Lake. While this water is mostly supplied by from a melting snowpack, in 2008 there was virtually no runoff. Luckily, the mine received five inches of rain in June and was able to complete its brining process as expected; had the rain not occurred, productivity would have been significantly reduced.

Dry years can also affect productivity. While the mine has water storage to withstand 1 to 2 years of drought (depending on the severity), extended and severe periods of drought can be problematic. The 1988 drought was particularly difficult for the mine due to a number of dry years which had preceded it and water levels were reduced to the point where production was almost at a standstill. Droughts preceded by wet years are not as problematic and the mine can sustain operations during these periods. Too much precipitation throughout the summer though, can stress operations as hot and dry conditions are necessary to optimize the concentration of minerals within the brine. Too much precipitation delays the brining operation, decreases recovery and increases the amount of energy required to bring brine to adequate concentrations; pumps must be used to remove excess water instead of solar energy. Once the brine reaches desired concentration levels, the solution is then moved to reservoirs and stored at 9 to 10 foot depths to be further evaporated until the sodium sulphate falls out of solution and gathers at the bottom. Removal of sodium sulphate from the bottom of the reservoir requires cold climatic conditions sufficient to freeze the ground and allow heavy equipment to retrieve the sodium sulphate. Warm winters can thus create further operational delays and increase the cost of recovery. The winter of 2005-2006 was particularly difficult for the mine due to high temperatures and profits were significantly reduced due to increased expenditures on sodium sulphate recovery from the reservoirs.

2. Potash and uranium mining

Interview respondents from potash and uranium mines in Saskatchewan reported little sensitivity to climate variables. Both potash and uranium mining involve the subsurface extraction of minerals and are not considerably affected by climatic conditions. Extreme weather events may damage surface infrastructure or delay surface operations, but these stresses were reported as being fairly irregular and insignificant. The main risks and opportunities faced by uranium and potash mining are socio-economic in nature. Uranium production, for example, is sensitive to low market prices. Public opinion on the safety of uranium mining and uses of the mineral has also historically impeded growth in this industry. Currently, prices are increasing due to increased demand from nuclear power plants, which are increasingly being promoted as a green source of energy. As such, climate change mitigation initiatives can actually be credited for some of the growth in the uranium industry. Mining operations in the province are beginning to see benefits from the ‘nuclear renaissance’ and surely hope this trend continues into the future. High costs of production and shortages of personnel are among some of the most pressing concerns for uranium mines in the province at the moment. Production costs are often highly variable and can increase drastically over short periods of time, making them difficult to manage. Meeting labour force requirements has also been a challenge as the ‘baby boomers’ retire and mining companies are forced to compete for employees with their neighbours in the Alberta oil sands and elsewhere.

For potash mining, distance from world markets and costs of transportation affect the growth and profitability of mining operations in the province. Saskatchewan is an expensive place to operate for potash mines since the vast majority of production is exported internationally. Certain aspects of potash production are also dependent on adequate supplies of water, although this was not reported as being problematic by interviewees. To date, water use has always remained within the thresholds of available quantities.

8.5.3 Current Adaptive Strategies

1. Sodium sulphate mining

The process of sodium sulphate extraction employed at the Chaplin mine has evolved as a result of local climate conditions. The process is not suitable for many other locations, but has allowed the mine to remain viable in a highly variable market environment while other more mechanized mines, have failed. To remain competitive, the Chaplin mine has adopted a number of practices and built specialized infrastructure to ensure its survival. Access to greater amounts of water has been developed to aid in times of water shortages; water can now be diverted from the Wood River to the Chaplin Creek and then used in the Chaplin Lake through a system designed in partnership with Ducks Unlimited. These sources have been used in the past to ensure adequate water levels in the spring and the mine has also built storage areas that can be used to control the flow of water into the lake. Water use efficiencies have also increased over the last twenty years, aided by the development of dikes to divide the eighteen square kilometre lake into smaller sections; this increases the amount of control mine operators have over lake levels. Water can be added to the sections where it is needed and does not need to be spread over the entire lake. Similarly, pumps are used to remove surplus water in the brining process. Brine optimization and sodium sulphate recovery are thus improved and water needs decreased by using this set-up. This technique is more costly and energy inefficient than using solar energy, but is necessary in the brine recovery process.

2. Potash and uranium

Potash and uranium mines do not appear to be altering their operations in any significant fashion to deal with climate risks. These risks are not a pressing concern for those who were interviewed; rather, they were more concerned about staying competitive in world markets. Energy and water efficiency practices were reported on by interview respondents though, but other adaptations were not mentioned.

8.5.4 Future Exposure-Sensitivities

Droughts are expected to increase in both severity and frequency across Saskatchewan with climate change (Lemmen et al., 2008). The sodium sulphate mine at Chaplin - already taking measures to deal with limited water availability - could be further stressed by this. Mine operations are currently at peak efficiencies in terms of water use and securing water supply. They are resilient to short periods of drought, but longer periods or more frequent droughts projected by climate models could be problematic. Projected increases in winter temperatures could also increase the cost of recovering sodium sulphate from reservoirs as they may prevent the use of heavy equipment during recovery. While other techniques are available, they are much more costly and time consuming. Warming winters will also reduce snowpack (Brown et al., 2006) and therefore runoff on the Prairies (chapter 3). While this may be problematic for operations at the Chaplin mine, precipitation amounts are also projected to increase in the winter and spring (Sauchyn & Kulshreshtha, 2008), which could compensate for a lack of runoff.

Mine practitioners interviewed from potash and uranium mining companies did not report being concerned about future climate change. They felt their operations were not climate dependent and that sensitivities were not likely to develop in the future. Even though potash production is partially dependent on water availability, company representatives have explored future water level predictions and do not appear concerned. It is believed that potash extraction will continue to be 'business as usual' without any significant modifications or adaptations needed.

Regulatory changes were, however, identified by all interviews as a major concern. It is feared that future government policy could force the mines to reduce production in response to environmental, safety and GHG emission concerns. Although there are already considerations for these within the current legal framework, respondents believe that regulations will become stricter in the future and further stress their operations. Federal regulations were of particular concern to interviewees, especially if regional and provincial priorities are ignored when regulations are developed. Some respondents were pessimistic these priorities would not be considered by federal regulators.

8.5.5 Future Adaptive and Mitigative Capacity

The sodium sulphate mine at Chaplin will likely face a number of risks associated with the future projected climate. It has already demonstrated sensitivities to climate conditions, many of which are expected to be exacerbated with climate change. Technological and infrastructure adaptations have already been developed in some instances to manage current climate exposures, but future shifts in climate may exceed the coping capacity of the mine. However, as with many mining operations, the mine may have outlived its operational lifespan by the time climate change impacts manifest themselves; the mine has been in operation for sixty years and there is likely only twenty to thirty more years of production left.

Regulatory changes are a pressing issue for interview respondents from the Chaplin mine. Although some aspects of the operation use renewable energy, some fossil fuels are still used. Natural gas is the main source of energy, but there are plans to change to coal as it is a cheaper, but more polluting option. Reducing greenhouse gas emissions has been noted as a concern for management, but energy use is a necessary part of production. The move to coal will likely involve adopting the most 'clean coal' technologies but, depending on future regulations, these may not keep the mine under required emission levels. Development of other sodium sulphate mines in Saskatchewan may also become less feasible as regulations tighten. Sodium sulphate production in other areas is likely to be highly dependent on mechanization and use of fossil fuels, and their GHG emissions will likely be much higher than those of the Chaplin mine. These types of mines were not always viable during the past century and it is uncertain they will be viable in the future.

Interview respondents noted that potash and uranium mines will continue operating under changing climatic conditions without making significant climate-related changes or adaptations. Mining officials were also skeptical about their ability to adapt to changing regulations regarding GHG emissions. Aside from the development of significant technological advancements in emissions reduction, interviewees believe there are few options for decreasing GHG emissions that do not also reduce production. Interviewees also stated that their mine sites already employ state of-the-art technologies in terms of fossil fuel use efficiency. As regulations continue to decrease allowable GHG emissions, the uranium industry is hoping to capitalize on its marketing as a ‘cleaner’ source of energy. Uranium mines are now trying to expand their operations and develop new sites, although this requires a significant time commitment due to regulatory hurdles.

8.6 BASE METAL AND GOLD MINING IN NORTHEASTERN ONTARIO

8.6.1 Case Study Description

Northeastern Ontario has long been one of the principal mining regions in Canada. Centered on the cities of Sudbury, Timmins and North Bay, the region is known for its base metal (e.g. nickel, copper) and gold mining, and provision of specialized mining services (Figure 8.4). Some of the largest mining companies operating in Canada are located here, including Vale Inco Limited, Xstrata Plc, Goldcorp Inc. and Kinross Gold Corporation.

Sudbury, with a population of approximately 160,000 people, is the heart of the region’s mining industry. Known primarily for base metals, the Sudbury basin has four companies operating thirteen mines. Timmins, with an approximate population of 42,500 people, is better known for its gold production, although base metals are also mined here. Seven gold and base metal mines are currently operating in the area. While there are no operating mines in or around North Bay, the city is nevertheless known for it provision of specialized mining services. Numerous contractors, suppliers and consultants are located in North Bay, providing ample employment for the city’s approximately 54,000 people.

Mining in this region makes a significant contribution to the local and Ontario economies. In 2006 it was reported that mining operations in the Sudbury Basin *alone*, directly employed 6,254 people (OMA, 2006). Compared to other Ontario industrial employees, miners also earn relatively large weekly salaries; in 2005 they earned on average $1,008.00/week (greater than average weekly earnings in the manufacturing, construction and logging and forestry industries, for example) (OMA, 2006). Northeastern Ontario mines also make pivotal contributions to Ontario’s exceptional mineral production numbers. In 2007 the province produced $4606 million worth of nickel, $1403 million worth of copper and $1259 million worth of gold. This represents 47% of Canada’s nickel production, 53% of Canada’s gold production, and 31% of Canada’s copper production, respectively (OMNDM, 2008a).

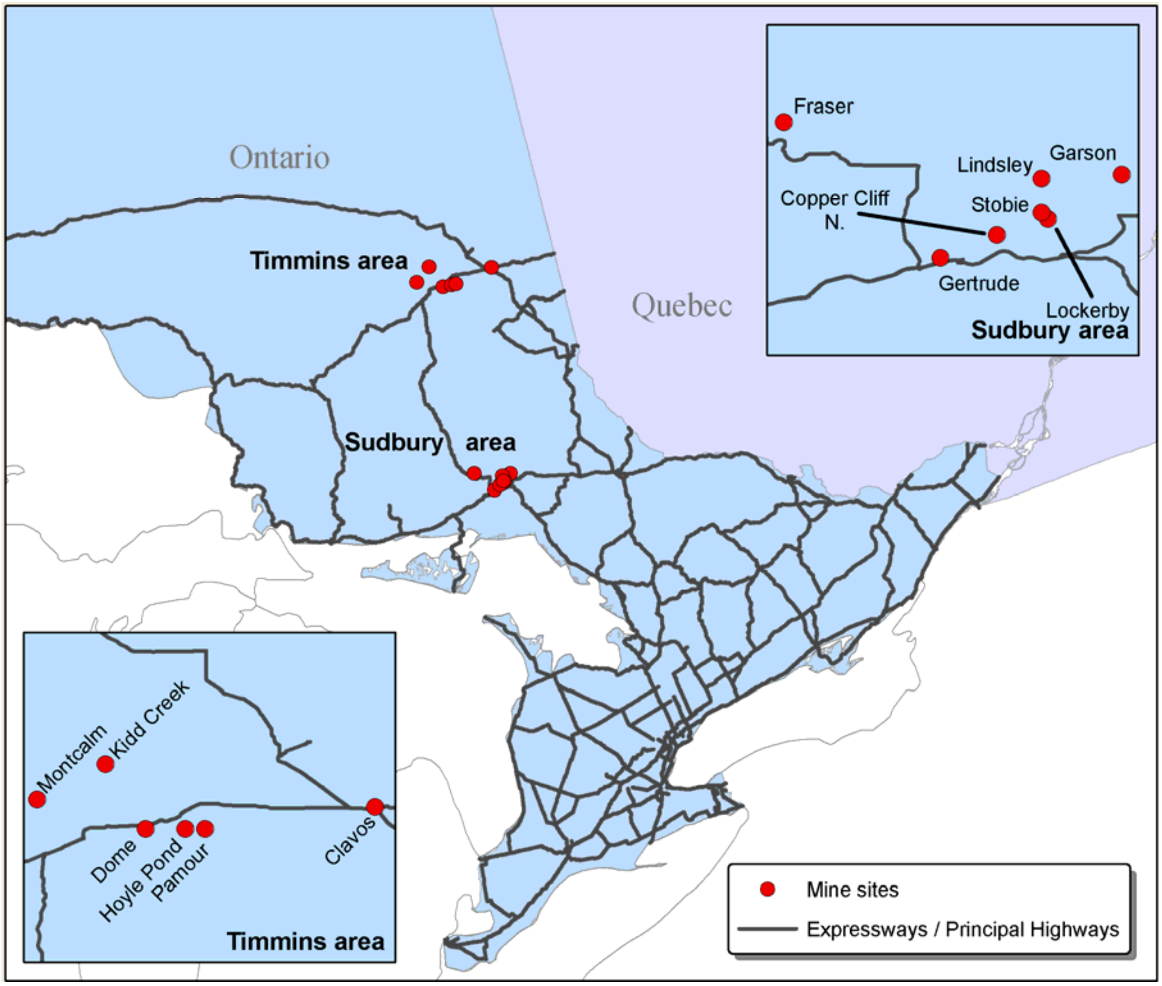

Figure 8.4: Mining in the Sudbury/Timmins area

Table 8.3: Operating gold and base metal mines in the Sudbury and Timmins areas

Sudbury Area		
Name of Mine	**Owner**	**Commodity**
Levack Mine	FNX Mining Company Ltd.	Nickel, Copper
McCreedy West Mine	FNX Mining Company Ltd.	Nickel, Copper
Lockerby Mine	First Nickel Inc.	Nickel, Copper
Copper Cliff North	Vale Inco Limited	Nickel, Copper
Copper Cliff South	Vale Inco Limited	Nickel, Copper
Creighton	Vale Inco Limited	Nickel, Copper
Garson	Vale Inco Limited	Nickel, Copper
Gertrude	Vale Inco Limited	Nickel, Copper
McCreedy East/ Coleman	Vale Inco Limited	Nickel, Copper
Stobie	Vale Inco Limited	Nickel, Copper
Fraser	Xstrata Plc	Nickel, Copper
Onaping/Craig	Xstrata Plc	Nickel, Copper
Lindsley	Xstrata Plc	Nickel, Copper
Timmins Area		
Name of Mine	**Owner**	**Commodity**
Clavos Mine	St. Andrew Goldfields Ltd	Gold
Dome Mine	Porcupine Joint Venture – Goldcorp Inc., Kinross Gold Corporation	Gold
Hoyle Pond Mine	Porcupine Joint Venture – Goldcorp Inc., Kinross Gold Corporation	Gold
Pamour Mine	Porcupine Joint Venture – Goldcorp Inc., Kinross Gold Corporation	Gold
Kidd Creek Mines	Xstrata Plc	Copper, Zinc
Montcalm Mine	Xstrata Plc	Nickel, Copper
Redstone Mine	Liberty Mines Inc.	Nickel, Copper

Source: Ontario Ministry of Northern Development and Mines

Data for this case study was collected from scientific and industry publications, public newspapers, and individual interviews with mining sector practitioners. Interviews were conducted both in-person and over the phone, with company executives, mine managers, engineers and other knowledgeable persons. A total of 14 people were interviewed: 10 over the phone and 4 in person. Interviews followed the standard interview guide and were analyzed using the vulnerability framework.

8.6.2 Current exposure-sensitivities

Mining operations in Northeastern Ontario are already subject to a number of climatic risks. Winters can bring very cold temperatures and elevated levels of snowfall. In the Sudbury Basin, for example, average snowfall levels in January are approximately 64cm, while average winter temperatures in that month are approximately -14°C; extreme temperatures of nearly -40°C have also been documented. Spring and summer, on the other hand, can bring heat and rain. In the Sudbury Basin again, average July temperatures are approximately 19°C, yet extremes of nearly 38°C have been documented. Precipitation averages for that same month are approximately 77mm, although September (the month with the greatest amount of precipitation) receives on average over 100mm of precipitation.

Engineering structures are often built to withstand current climatic norms and conditions, and function relatively well within these parameters. While most activities in Ontario - mining included - are well adapted to current climate risks, extreme events can nevertheless bring about considerable damage (Chiotti & Lavender, 2008). These extreme climatic events can stress engineering structures to their limits and beyond. In some cases from outside of Ontario, structural failure has even been documented. For example, the WISE Uranium Project (2006) and the International Commission on Large Dams (2001) have documented a number of tailings dam failures around the world which have been triggered by heavy rain and flooding events.

Interview respondents from the region recognize that their mining operations are sensitive to climatic risks. In some cases, respondents observe that climate change is already occurring. Most of these observed changes have been temperature-related: “Winters are warmer and not as harsh anymore”, was a common description of changes that have been experienced. In some cases these warmer temperatures have brought benefits, in the form of lower costs for operational heating in the winter.

Atmospheric conditions and air quality also affect mine operations. Due to voluntary commitments with local stakeholders, on days with poor air quality (e.g. ‘smog’ days), some operations are obliged to reduce site emissions. As poor air quality days increase, so too do the number of days that mining operations have to further regulate these emissions. Some mining operations are especially sensitive to pollution and emissions related problems. Sudbury, for example, has a long history of mine-related pollution. Acid rain was a major concern in the area, particularly in the 1980s, as local smelting of ore released sulphur into the atmosphere, which combined with water vapour to form sulphuric acid and acid rain. Furthermore, tall chimneys were built to disperse sulphur gases away from the city of Sudbury itself. One of these, the 380m Inco ‘superstack’, is perhaps the most recognizable, being a very visible feature of the Sudbury skyline. For many Ontarians, the ‘superstack’ is representative of larger pollution issues associated with mining in the area.

8.6.3 Current adaptive strategies

Mining companies in Northeastern Ontario currently manage climate-related risks in a number of ways. For example, buildings, roads, bridges, dams and other structures important to mining establishments are designed to last for several decades or longer based on engineering principles and design criteria (e.g. building codes) that were developed assuming that the future climate will exhibit similar characteristics in average conditions, extremes and variability as the past climate (Auld and MacIver, 2006). As long as climatic thresholds don't change, (which has been generally true in Northeastern Ontario to date), limited risk exists for mine infrastructure. In other parts of Ontario, reactive responses to climatic events have prevailed. In 2005, for example, a number of mining operations located near Marathon were forced to significantly reduce operational intakes of water and find alternative sources, because of reduced water levels caused by unseasonably warm, dry conditions in their watershed (Brown et al., 2006).

Mining companies have also made efforts to reduce pollutants including sulphur dioxide (a major contributor to acid rain) and greenhouse gasses. A number of mines have embraced energy management and greenhouse gas reduction initiatives (e.g. Xstrata, 2008, CVRD Inco, 2007), greenhouse gas emissions reporting (MAC, 2007b), and have investigated the potential for renewable sources of energy production and the use of carbon offsets. As one interview respondent noted, "It is important for us to be seen doing something. We have a very visible role in the community and the public demands action." Indeed, public pressure was documented in a number of interviews to be a motivating factor in corporate reduction of greenhouse gases and other pollutants. "The public drives us …" noted one respondent, "…we need to continually work to maintain our social licence to operate." Pressure from shareholders, upper management and other employees in the company to reduce emissions were also mentioned as motivations for change. In other instances, existing legislation (e.g. Ontario Regulation 419[4]), corporate requirements (e.g. internal environmental management systems, industry reporting initiatives) and the threat of future legislation (e.g. carbon taxes, cap and trade systems) were noted as driving the reduction of emissions.

8.6.4 Future exposure-sensitivities

For Northeastern Ontario, climate scenarios generally indicate increasing annual precipitation and temperature (see for example Chapter 3, also Chiotti and Lavender, 2008). Temperature increases will be significantly higher in winter than in summer, although Ontario as a whole is generally projected to see some of the highest summertime increases of all regions in Canada. Furthermore, extreme precipitation events are expected to become more intense and more frequent (Hengeveld & Whitewood, 2005).

These changes to regional temperature and precipitation regimes may have the potential to affect mine site hydrology and water balance. At some operations, runoff is collected in a basin or drawn from rivers to be used in mine operations (e.g. for mineral processing). Increased incidences of hot, dry summers, for example, could alter water intake capacity. Increased temperatures will also lead to increased evaporation from tailings ponds, potentially exposing

[4] Ontario Regulation 419/05 (Air Pollution – Local Air Quality) came into effect on November 30, 2005, and replaced Ontario Regulation 346 (General – Air Pollution). This new regulation incorporates stricter air quality standards with variable averaging periods to better reflect the potential health and nuisance impacts from pollutant emissions. The regulation also specifies how the dispersion calculations outlined in Ontario Regulation 346 will be phased out and replaced by more scientifically advanced models from the United States Environmental Protection Agency.

raw tailings to sub-aerial weathering. Similarly, passive contaminant reduction systems (e.g. wetland filtration) could be at risk if ground cover dries up and re-exposes metals and contaminants in the ground below.

Extreme rainfall, rain-on-snow events and rapid melting of the snowpack within a watershed can also overwhelm site drainage and diversion structures, causing excess runoff to tailings impoundments. This can lead to saturation, erosion or rapid rise in water levels and overtopping (ICOLD, 2001). In the context of such projections, release of acid rock drainage and other contaminants to the environment is a concern. Slope stability and the integrity of engineered berms are also vulnerable to extreme precipitation (Chiotti and Lavender, 2008). Erosion of the dam slope or gullying at the base of the impoundment structure can occur, causing weaknesses in the dam and increasing its risk of failure. Saturation of the impoundment structure causing piping, slumping or failure is also a risk (ICOLD, 2001).

Transportation infrastructure is also at risk from climate change. Chiotti and Lavender (2008: 255) note that the vulnerability of critical transportation infrastructure (especially road and rail) to extreme weather events is an issue of “greatest concern” for this part of Ontario. Similarly, a report prepared on the vulnerability of road networks to climate change in the City of Greater Sudbury revealed “potentially major vulnerabilities” to roads-related drainage infrastructure (Dennis Consultants, 2008). Climate-related disruptions to road networks are most likely to result from extreme precipitation (rainfall or snow).

A number of these risks are particularly important in relation to mine closure planning. Structures left on-site after closure will need to withstand changing climatic conditions long into the future. Similarly, already abandoned tailings ponds or stacks may not have been designed for the full range of these changing climatic conditions and will need to be retrofitted accordingly. There are currently more than 5,700 known abandoned mine sites located within Ontario, containing more than 16,400 documented mine features. Approximately 30 - 40 per cent of these abandoned mine sites are estimated to be located on Crown land, while the remainder are located on privately owned or municipal lands (Ontario Ministry of Northern Development and Mines (OMNDM), 2008b). Left abandoned and un-remediated, some of these sites could pose significant risks to the environment and surrounding communities, especially in light of changing climatic conditions.

In at least one Ontario case, an environmental assessment board forced climate change to be considered in a company’s closure plan. For the decommissioning of the Quirke and Panel Uranium Mines in Elliot Lake, the environmental assessment panel recommended ongoing monitoring of climate variables to detect emerging climate trends and monitoring of water cover depths so remedial action could be taken to prevent loss of tailings saturation (Lee, 2001, EAP, 1996). The obvious possibility here is that other mines preparing closure plans could face similar requirements by regulators.

Mining companies could face other regulatory risks. Of interest here is the possible implementation of ‘cap and trade’ systems and/or of carbon taxes. Those companies caught unprepared for new legislation, for example, could stand to face significant economic repercussions. Especially concerning for some mining sector representatives is climate change legislation that is designed without significant industry input, and that leads to unfair economic repercussions for the sector. Smelter operations in Northeastern Ontario could be particularly at risk because of their large emissions and highly visible public profiles.

8.6.5 Future adaptive capacity

It has been noted that Ontario as a whole has a strong capacity to adapt to climate change. This is based on a variety of indicators, such as economic wealth, technology, information and skills, infrastructure, institutions, social capital and equity (Chiotti & Lavender, 2008). More broadly, the general climate change literature often classifies wealthy developed regions as those most resilient to climate change. Mining operations in Northeastern Ontario can similarly be thought to have a high capacity to adapt to changing climatic circumstances. With numerous mines and mine services operating in close proximity to each other, many resources are available to tackle common threats.

Furthermore, academic institutions with mining programs and large, collaborative mining research initiatives such as the *Centre for Excellence in Mining Innovation*, *MIRARCO* and the *Canadian Mining Industry Research Organization* already exist in the region. Their foci are diverse (e.g. environmental sustainability, mine engineering, automation) and often spotlight regional mining operations. From a research standpoint, the potential for future knowledge and technology transfer related to climate change is obviously significant.

Isolated cases aside, few of the mining practitioners interviewed in this study indicated that they were engaging in long-term planning for climate change in Northeastern Ontario. Interview respondents noted their companies to be primarily focused “on day-to-day operations” and “short-term objectives”. Indeed, some respondents even questioned whether any action was required with regards to climate change. One respondent noted: “I just can’t see how it will have an effect on our operations”. Notwithstanding this, some discussion regarding adaptation appears to be occurring amongst mining company representatives. Largely ‘off the record’, informal, or preliminary in nature, these discussions nevertheless highlight that climate change is an issue that is becoming increasingly important in the sector. Furthermore, engineers and consultants involved in mining projects are now beginning to assess adaptation options. Recent research projects, presentations and publications devoted to the topic are a testament to this. While not employed directly by mining companies, these people nevertheless play important roles in the mineral development process and in identifying issues of importance to the mining sector. Consultants and contractors, for example, are often involved in the planning, design, management, and monitoring of mining operations.

Interviewees were asked what needs to be done to ensure the sector’s long-term adaptability to climate change, and were quick to identify a number of options. Certainty in legislation and regulation, for example, were major concerns. Unless companies know what will be expected of them (e.g. in terms of greenhouse gas reductions) less incentive exists to embrace change. The development of new technologies and designs were also mentioned as ways climate change adaptation could be more fully embraced. Indeed, as the climate changes, mine infrastructure will have to be designed to withstand climatic risks of a magnitude and frequency not previously experienced in this region of Ontario. New technologies will need to be employed, or at least transplanted from other parts of the world. To be most effective however, engineering designs will need to incorporate predictions from climate change models. Unfortunately, these models have often been criticized in mining circles for not providing the detailed, local-level predictions needed for long-term planning and engineering designs. Climate models provide us with useful, albeit generalized, pictures of predicted changes, but a need exists for their further refinement. In the absence of detailed modeling, adaptive management (i.e. iterative decision making that takes into account changing climatic variables) and active monitoring of mine site conditions will become even more important into the future.

It appears that a significant amount of work remains if successful adaptation to climate change is to be ensured at Northeastern Ontario mining operations. While modest adaptations are being made by mining companies in some instances (e.g. through greenhouse gas emissions reduction programs), reactive responses to climatic events have prevailed in others. It is obvious that long-term strategies for managing climate change impacts at mining sites are thus needed; investing in adaptation today in many cases will save money in terms of a reduction in negative impacts of future climate change (Stern and Taylor, 2007). Again, mining companies operating in Northeastern Ontario have a number of opportunities available to them in this regard. Northeastern Ontario has a number of mining companies operating at multiple locations, a strong mining service sector, and institutions (e.g. universities, government offices) similarly working to advance the sector. The potential for cooperatively developing effective adaptation strategies is thus substantial, and an area for further research.

8.7 THE VOISEY’S BAY NICKEL-COPPER-COBALT MINE IN LABRADOR

8.7.1 Case study description

The Voisey’s Bay project was selected as a case study to provide further insight into the vulnerability of mines operating in remote locations and on land subject to Aboriginal land claims. Moreover, this is a relatively new mining region and contrasts with more established mining regions elsewhere in Canada. Many of Canada’s new mine developments are now located in remote regions and the case study provides insights into the vulnerability of remote mines. It also provides insights into how climate change is integrated into planning decisions for mines developed at a time when climate change is widely regarded as having implications for future developments.

The Voisey’s Bay Nickel Mine is owned and operated by Vale Inco and is located on the northern coast of Labrador, roughly 35km southwest of the community of Nain (
Figure 8.5) (Vale Inco, 2009). The area in which the project is located is subject to land claims by the Innu and Inuit of Labrador, and Vale Inco has negotiated Impact and Benefit Agreements (IBAs) with the representative bodies of both these groups. These IBAs were both signed in the summer of 2002 (Vale Inco, 2003) but, consistent with other IBA processes, the details of these agreements remain confidential (Prno, 2008b). The main ore-body of the project contains an estimated, proven, and probable resource of 28.9 million tonnes, with an additional 38.5 million tonnes of indicated resources, and 6.3 million tonnes of inferred resources (Vale Inco, 2009); this makes Voisey’s Bay one of the largest nickel deposits in the world. The site is known for its production of nickel sulphide concentrates and copper sulphide concentrates (Infomine.com,

2007). The mine ships approximately 1,250,000 tonnes of nickel-copper-cobalt concentrate and some 150,000 tonnes of copper concentrate annually. Most of the nickel-copper-cobalt concentrate and all of the copper concentrate is shipped in the ice free open water period. Additionally, some cargoes are shipped through ice between January and March. The mine allows the initial ice to become 20 cm thick before beginning icebreaking and similarly ceases shipping operations during April and May. This is done to avoid disturbing travel routes on the sea ice used by local people and wildlife, to access hunting grounds and other locations only accessible by the ice.

The mine began its open pit operations in August 2005. 450 people are currently employed by the mine and concentrator operations, and Aboriginal employment is significant. In 2006, Aboriginal employees accounted for 52% of the mine's workforce (Voisey's Bay Nickel Company Ltd, 2006a). The mine itself has an estimated life of 14 years, while the total project life is estimated to be 30 years. Of course, the company's ongoing exploration projects could lengthen this timeframe (Vale Inco, 2009). The estimated capital investment for the mining project for the 30 year period is $2.9 billion CAD (Infomine.com, 2007).

This case study reviewed the Environmental Impact Assessment (EIA) reports produced during mine development and EIA update reports, and is complemented with a phone interview with an anonymous company employee involved in the mine's development and operation.

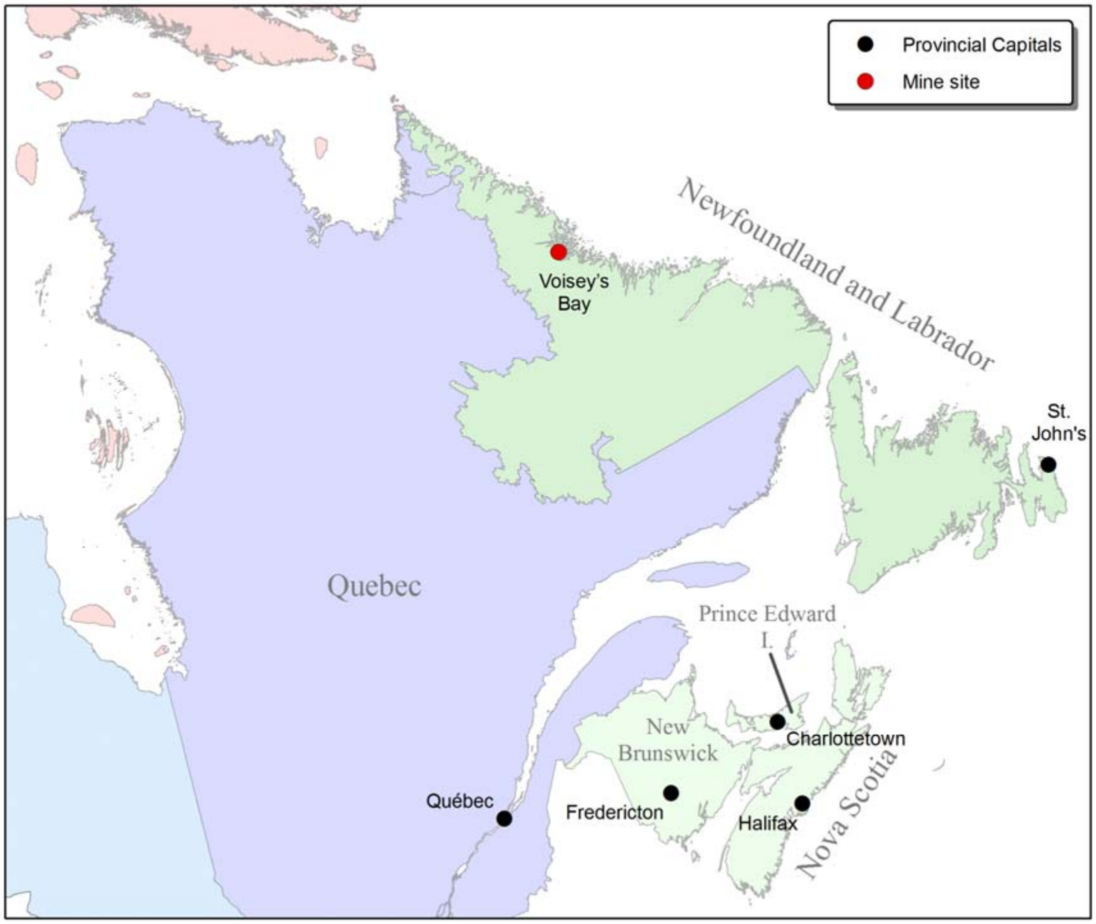

Figure 8.5: The Voisey's Bay mine

8.7.2 Current Exposure-Sensitivities

This region of Labrador is considered to be a transition zone between the Arctic and sub-Arctic, with extreme temperature ranges of -40˚C to +30˚C occurring over the year. January and February are the coldest months (mean daily temperatures of -20°C to -23°C), while July and August are the warmest (mean daily temperatures of 8°C to 14°C) (CEAA, 2002). Extreme temperatures and seasonal fluctuations are basic characteristics of the northern climate and dealing with these conditions is part of daily operations at the mine. Some climatic conditions that are particularly relevant to mine operations include fog, high intensity rainfall, and sea-ice conditions, which affect transportation access and operational capacity.

Plane access is vital to the operation of the mine with flights on every work day transporting supplies (including food) and workers. Poor weather conditions including snow or fog pose a major challenge to flight operations. The airport servicing the mine-site does not have an Instrument Landing System (ILS) and pilots must have visual contact with the land from a certain altitude. When extended periods of fog and heavy snow storms occur, airplanes cannot land or take off. In addition, night flights are currently not permitted to the site, which further reduces transportation options for the mine.

Managing the natural water flows on site is also a challenge, and the Voisey's Bay environmental progress reports for 2004, 2005 and 2006 make reference to problems associated with the management of surface water, particularly during the spring runoff. The 2005 report in particular notes that "[d]espite a relatively normal period of runoff, the volume of surface water that impacted active construction and work areas was immense"(Voisey's Bay Nickel Company Ltd, 2004, 2005, 2006b). The current water containment systems at the mine site are either designed for the 1 in a 100 year storm or the 1 in a 25 year storm and, luckily, flooding has not yet been a problem. High intensity rainfall events could, however, stress these systems more often and to a larger extent.

During the environmental review for the mine, concerns were raised by the Labrador Inuit Association and the Innu Nation concerning mine shipping traffic through landfast ice, and the potential for disruption to people travelling over the ice to other communities or to reach hunting grounds. Agreements have since been reached with these groups to help mitigate some of these problems by not shipping during the initial freeze-up period or during the seal-hunting period in the early spring (CEAA, 2002); transportation access is therefore sensitive to ice thickness and ice dynamics. It is noteworthy that the mine representative interviewed stressed that the mine currently has very good relationships with the local Aboriginal groups, who additionally have their own environmental monitors to check on Vale Inco operations.

8.7.3 Current adaptive and mitigative capacity

Specific engineering designs have been factored into mine design to reduce the mine's sensitivity to climatic risks. For example, the mine's water containment system manages current precipitation levels and regulates mine flooding. Additionally, culverts and roads on the mine site have been designed to manage current rainfall patterns. These provisions, however, are designed to cope with historic climatic trends and new codes and design standards will likely be needed to withstand expected future trends in precipitation. Ice conditions, at present, have not posed a significant problem to the mine operation as it is serviced year-round by an ice-breaking vessel, but could affect the access of local hunters to hunting areas in the future with repercussions for transportation potential as per the agreement with local communities. Mine site equipment is also designed to withstand the extreme cold temperatures characteristic of Labrador winters.

In terms of reducing greenhouse gas emissions, Vale Inco is developing company-wide plans for their operations, which will then be submitted to their individual mine sites for consideration. The Voisey's Bay mine relies primarily on diesel fuel for power generation, although some hydropower potential exists in proximity to the mine. Heat recovery equipment has been installed to increase the efficiency of electricity usage and the mine has energy conservation programs which encourage employees to turn off lights when not in use. Vale Inco is encouraged by economic savings to reduce energy consumption at its mine sites and is making company-wide efforts to enhance the overall sustainability of their operations.

8.7.4 Future Exposure-Sensitivity

In the 1997 Environmental Impact Statement (EIS) for the Voisey's Bay project, expected changes to the local climate were predicted to be minimal over the projected lifespan of the mine (approximately 30 years). Some key climatic changes noted in the report include a decrease in mean temperature of 1˚C, more extreme weather events, and a rise in sea level of 12cm. The EIS also acknowledged that changes to ice and sea conditions could occur over the mine's lifespan, but that these changes were difficult to predict (Voisey's Bay Environmental Impact Statement - 8.1.3.1 'Climate Change'). Changing ice regimes, however, could have a large impact for the mine with regards to its agreement with local communities to uphold sea ice access routes to traditional hunting grounds. Recent climate change models suggest that the EIS projections are on the low end of what can be expected from climate change in the Labrador region in the future. In the next 50 years, the Canadian Climate Impacts Scenario predicts a decline in annual average temperature of -1.8˚C, an increase in annual precipitation by 11%, a 30% decline in annual snowfall, 10% decline in annual wind speed, and a sea level rise of 9cm to 88cm (CEAA, 2002). Increased frequency and magnitude of extreme weather events would also affect mine operations by further restricting air transportation to the mine. Given the operation's current exposure-sensitivities, it is reasonable to expect that extreme variations within these changes would pose additional operational challenges. For example, water containment systems could be stressed as 1 in 25 year and 1 in a 100 year storm events become more frequent. Given the company's stated goal of increasing the lifespan of the mine, climate change projections should be examined over a longer time period than the 1997 EIS used in order to strengthen future development planning.

8.7.5 Future Adaptive Capacity

Although Vale Inco has a policy that recognises the issue of climate change and the need for improved energy efficiency and reduced emissions, the Voisey's Bay mine at present has no formal plan for dealing with or adapting to potential future climatic changes (CVRD Inco, 2007). The mine representative that was interviewed noted that such planning will only occur when significant climatic changes are documented and start to have a discernible impact on company operations. There is also limited mention of climate change mitigation or adaptation in any of the five Voisey's Bay environmental progress reports (spanning 2002 to 2006). A recent study for the Canadian Environmental Assessment Agency, however, noted that the Voisey's Bay EIS would have benefited from the inclusion of information that is available regarding regional climate change projections. Also noted is the need for further guidance and research on the potential effects of these climatic changes on ecological systems around the mine site. Specifically, the report stressed that ongoing monitoring, observation and risk assessment should take place for local wildlife (notably caribou, birds and arctic char) and for how sea ice changes might impact the 'coastal activity' and 'social activities of local Aboriginal people'. It states that the issue of sea ice is the most likely to "involve interactions of both the project and the effects of climate change, and warrants consideration given the concerns and related agreements over shipping" (CEAA, 2002).

Figure 8.6: Image of icebreaker trail heading into Voisey's Bay.
Source: flickr.com account http://www.flickr.com/photos/baine/269630705/ and available under Creative Commons license, rules of which are available here: http://creativecommons.org/licenses/by-nc-nd/2.0/deed.en

8.8 YUKON CASE STUDY

8.8.1 Case study description

The Yukon is one of the oldest mining regions in Canada. A century ago the Klondike gold-rush in the central Yukon established the popular image of mining in the north as a rugged endeavour set in an unforgiving climate. Placer mining was the earliest activity, but hard-rock mining became increasingly important, and over recent years has become the most dominant. Subsequently the fortunes of the Yukon have been very closely associated with the mining industry, and long part of regional psyche and identity (Government of Yukon, 2008a). The industry in the Yukon has a long history of adapting to a complex interplay of market conditions and climate and its experiences are germane to understanding the relative vulnerability of mining to climate change.

In looking at the question of vulnerability and mining in the region, two closely related themes become evident. One is the vulnerability of the mining industry to economic and environmental factors; the other is the vulnerability of the well being of Yukoners to the behaviour and fortunes of the mining industry. Much of the contemporary settlement system of the Yukon evolved to support the mining industry, and the manner in which it changed over time and fluctuations in population can be very closely related to shifts in the location of mines and changes in associated transportation technology (Duerden, 1982). In essence, factors impacting the viability of mining in the Yukon typify mining environments throughout the north. It is high cost - a result of high labour costs due to isolation, high transport costs because of distance to markets, and high technical costs associated with working in inhospitable terrain characterized by climate extremes, and climatically enforced seasonality of some operations. Together these cost factors mean that mining is highly sensitive to price fluctuations in distant markets.

Through much of the twentieth century severe winter conditions, the absence of an all weather transport system, the difficulty of mining in a permafrost environment, and seasonal water deficits, variously, prompted a range of responses. The Yukon and Stewart Rivers were major arteries of communication, but were impassable at time of freeze and break up and essentially the mining industry ran to the rhythm of the land with ores stockpiled in winter for transport in the summer. Technology was applied to melt permafrost for placer mining, and in the Klondike water was diverted from neighbouring watersheds to satisfy the demands of the placer industry in the Klondike's tributary creeks in the summer. Essentially mining adapted to constraints of climate, terrain and distance, but in some areas this was at considerable cost to the environment.

Placer mining remained the mainstay of the Yukon economy until the early 1920's, and it has been intermittently important since then as world gold prices fluctuated. In the first part of the century increased demand for industrial minerals (copper) and high silver prices gave rise to hard rock mining in widely dispersed areas of the Yukon including the Mayo region (silver/lead) Whitehorse (copper), the Kluane region (gold) and in the vicinity of Carcross (gold and silver). The Mayo deposits were discovered in the Keno Hill area in 1906. The first mill was constructed in 1925 and mining operated more or less continuously until production was suspended in January 1989 due to low silver prices. The region is spotted with abandoned underground mines and open pits all of which are exposed to the vagaries of climate, and changing conditions resulting in increasing erosion or permafrost melt could have an adverse impact on local natural environments.

Construction of an all weather road system and demands for a wide range of minerals in the second half of the twentieth century led to diversification of the mining industry. This was typified by the asbestos mine at Clinton Creek (c1968) and the Anvil Dynasty lead\zinc mine at Faro in the central Yukon (1978). There is abundant evidence that historically the well-being of the mining industry was regarded as being essential to the well-being of the Yukon - the Yukon Placer Act giving precedence to mining over any other form of land-use, and heavy government investment both in essential infrastructure for the mining industry and in some cases in mines themselves.

Over the past 20 years critical evaluation of the role of the mining industry and increasing environmental awareness has led to greater environmental regulation of the mining industry, reflected in the provisions of the Yukon land Claim Agreement, the introduction of the Yukon Land-Use Planning Act, and the Yukon Environmental and Social Impact assessment process. However, it should be noted that recognition of the link between the mining industry and the economic well-being of the Yukon is a persistent theme. It was seen in government investment keeping the Faro mine alive in the 1980's and in the decision to allow the Minto mine to make unregulated discharges into the Yukon River in the summer of 2008.

Although average annual temperatures in the Yukon have risen over the past fifty years (C-CIARN North, 2006) and the IPCC is predicting an increase in the average global temperature of 1.4°C to 6.4°C over the next century there is considerable uncertainty about the manner in which climate change will be manifest in the Yukon. It is generally expected that permafrost will be degraded, and that precipitation will increase, with increased snowfall but accelerated and earlier snow-melt; greater variability of conditions characterised by more extreme events is also anticipated.

Contemporary and emerging issues in the mining industry that are climatically related include threats to the transport system as highways are potentially compromised by permafrost melt, changes in precipitation accompanied by permafrost melt potentially affecting the ability to decommission and remediate mine-sites, and increased variability of the weather. Notwithstanding this negative prognosis, warmer conditions could make placer mining in the Klondike easier as permafrost degrades, while the proponent of a major copper deposit in the Finlayson District of the NE Yukon commented; "The cold Yukon climate and permafrost conditions presents major engineering challenges for the mining industry, difficult transportation conditions, restricted access seasons, and high freight and labour costs. In these regards, a warming climate may create new opportunities for the industry" (Yukon Zinc Corporation, 2008).

It is clear from the preceding narrative that while mining has had a sustained presence in the Yukon for more than a century the life cycle of many ventures was relatively short, and the landscape of the central Yukon is littered with much of the deleterious impacts of past activities. These reflect the response of many operations to the high costs of operating in the north and their exposure to the vagaries of global markets. Currently (2008), active mining is confined to the Klondike, and to the Minto Mine in the central Yukon (copper), while a new mine some eighty kilometres to the south at Carmacks (also copper) has gone through the approval stage and is scheduled to open in 2010 (Figure 8.7).

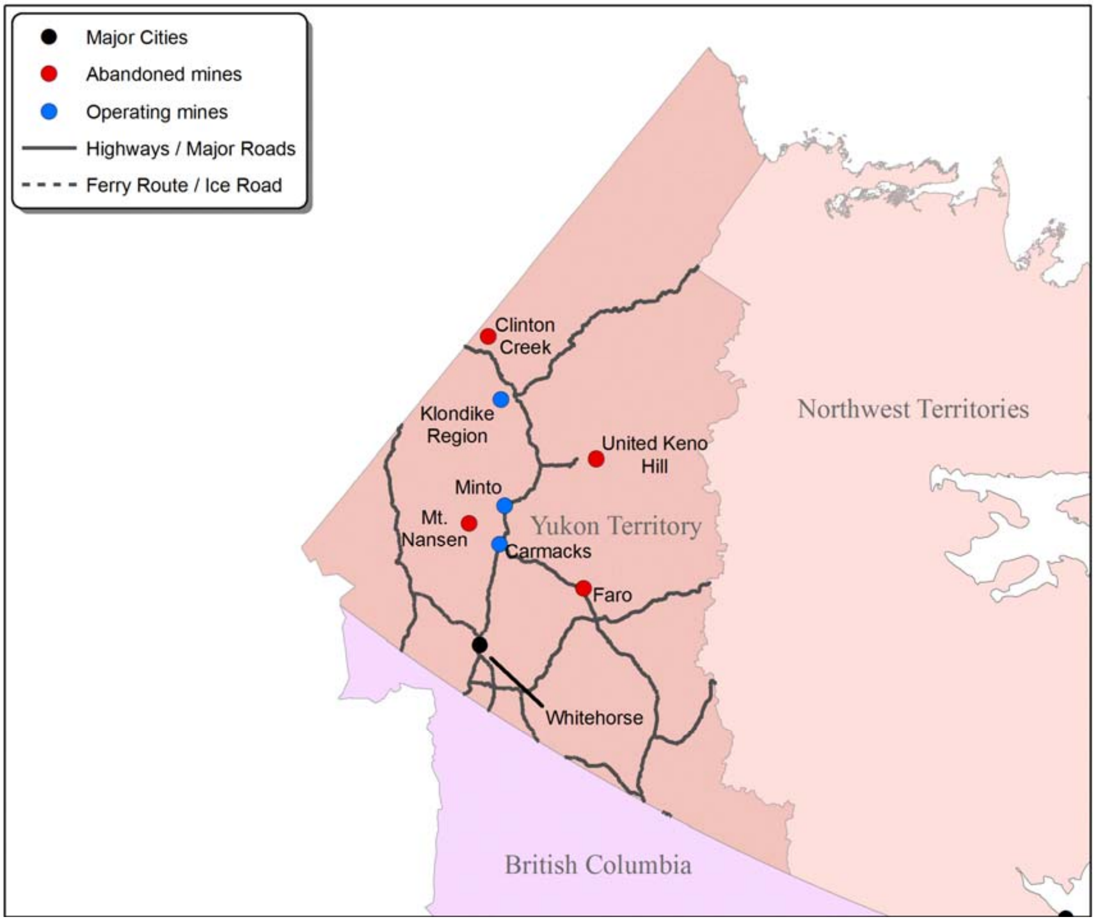

Figure 8.7: Mining in the Yukon

8.8.2 Current Vulnerabilities and Adaptive Responses

8.8.2.1 The Mining Industry

Historically, distance to markets and the high costs of working in adverse climatic conditions and in difficult terrain meant that mining in the Yukon was highly vulnerable to fluctuations in global mineral prices. Commercially, a response to high transport and operating costs was "high-grading" of ores,--transporting those ores with the highest mineral content to market, and dumping the rest in spoil heaps. This meant that spoil heaps might still have a high incidence of mineralization. Consequent interaction with weathering agents (e.g. ice and water) meant there was an enhanced potential to produce ecologically damaging toxins.

Development of mining camps were also an adaptive response to the fact that most ventures were viewed as relatively short term and their survival very much dependent on global market conditions. Because of short project life-span very little capital was invested in social infrastructure until the late 1960's when the new towns of Clinton Creek and Faro were developed. These communities also had very short life-spans; Clinton Creek was abandoned in 1978 and Faro went into decline when the mine closed.

In a land of climate extremes, weather can have serious environmental implications for abandoned mine sites. Although governments recognised that abandoned mines could have potentially deleterious impacts on the environment, long term costs of mining were not required to be appropriately factored into costing by mining companies. The operating life of a mine is only a very small portion of its life cycle; for example, the Faro mine operated for less than thirty years but subsequent site monitoring will be at least two centuries (Lois Craig pers. com.). Historically, relatively little serious attention was given to the lifecycle of a mine and in many instances mines were abandoned without clean up. A common trend has been for companies to declare bankruptcy and then pass the costs of clean up and site remediation on to government. In 2000 there were approximately 120 abandoned mines in the Yukon Territory; of these, 45 sites were found to have physical or chemical stability problems (Mackasey, 2000).

8.8.2.1.1 Infrastructure

There are three broad components to the mine support infrastructure in the Yukon: transport, power, and communities.

a) Transportation - Yukon communities (with the exception of Old Crow) are served by a network of all weather roads linking to Alaska, the Northwest Territories, southern Canada and the United States. Minerals are exported through the ice free port at Skagway. Given that the highway system is some 4800 km in length and is served by some 129 bridges and countless culverts there is potential for it to be compromised by changing climatic conditions, especially given that much of it traverses discontinuous permafrost (Government of Yukon, 2008b).

Most mines are connected to the main highway system by un-surfaced access roads that are built to less exacting standards than the highways. Generally, this makes them more susceptible to erosion and wash-outs, and may prove to be an increasing problem if (as is anticipated), climate change is manifest in more precipitation. In the summer of 2008, four kilometres of the Minto mine access road were washed out or flooded. While lower engineering standards may possibly make the local-access road system more vulnerable to the impacts of a changing climate, such as permafrost slumping or washouts, the manner in which they are constructed makes them relatively easy to repair using a backhoe (for example) and locally available materials. In the case of the Minto mine there was no disruption in delivery because there were already 12,000 tonnes of copper concentrates in the port of Skagway awaiting shipment.

b) Power - Electricity for most small mining operations (such as those in the Klondike) is almost exclusively produced by diesel generators; however, the Yukon has a maturing hydro-electric power (HEP) grid, with dams on the Aishihik River west of Whitehorse, on the Yukon at Whitehorse, and on the Mayo River in the north east Yukon. Two new mining projects (i.e. Carmacks Copper and the Minto Mine) are anticipating using this power rather than diesel generators, thus mitigating GHG production.

c) Communities - Much of the Yukon's settlement system evolved to serve the mining industry, with communities functioning as service centers, supporting transport links, or as mining settlements. The advent of the all weather highway led to the collapse of many communities, but Dawson, the communities of the Mayo Region, and the Klondike Highway communities still have a strong link to the mining industry. These communities are thus vulnerable to conflicting implications of mining. Mining is important for local economies providing local employment, either directly in the mining industry or indirectly through the provision of services. However, local environmental quality may be compromised through discharges into water-courses or as a result of land-use conflicts. A substantial portion of the Aboriginal population depends on local fish and wildlife harvests, and First Nations whose traditional territories contain active or proposed mines (notably Selkirk and Carmacks) have taken a strong pro-active approach to protecting their environmental interests through involvement in the environmental assessment process, monitoring and lobbying. They are very much aware that climate change may have implications for the way in which landscapes will be affected by mining and see climate change as a factor to be considered in screening applications for mine licenses.

8.8.3 Future Exposures/Adaptive Responses

8.8.3.1 Climate Change Implications

In northwestern Canada the average annual temperature has risen 3°C over the past fifty years (C-CIARN North, 2006). Over the next 100 years the Intergovernmental Panel on Climate Change (IPCC) is predicting an increase in the average global temperature of 1.1°C to 6.4°C. The average annual near ground temperature in most of the Southern Yukon is between 0 and -2°C and thus warming is expected to have a significant impact on the stability of permafrost (Government of Yukon, 2007, Smith & Burgess, 2004). Mine sites mainly lie in the central Yukon, underlain by discontinuous permafrost (and close to the climatic threshold for permafrost), which will be especially sensitive to warming.

Drawing from workshops held by the Canadian Climate Impacts and Adaptation Research Network (C-CIARN) and stakeholder meetings, major impacts of climate change observed in the Yukon include:

a. Degradation of surface level permafrost: The Yukon has regions of both continuous permafrost and discontinuous (or sporadic) permafrost. As temperatures increase, some of the permafrost will melt and its southern boundaries will shift northward. This will have implications for transportation and for stability of mining infrastructure. For some operations (e.g. placer mining in the Klondike) it may even make access to minerals easier. In many other cases, climate change will present a number of risks to mining operations. For example, early detection of permafrost disruption will be critical in avoiding catastrophic unplanned events such as dam failure or structural deformation in buildings. EBA Engineering in Whitehorse is concerned with the permafrost problem, but argue that permafrost trends can usually be determined by careful analyses of long-term historical records from the nearest meteorological station (EBA, 2004). The reality is that meteorological stations in the north are few and far between, records are sporadic, and that permafrost warming and thaw may require remedial action or further engineering modifications to existing infrastructure. Waste retention ponds and lakes that rely on the impervious nature of permafrost to retain environmentally hazardous materials are a particular concern.

b. Glacial Melt: The St. Elias mountain range in the southwestern Yukon contains the 3rd largest terrestrial ice field in the world after Antarctica and Greenland and contains approximately 1% of the world's frozen fresh water. All of the glaciers in the region are melting and the rate of recession is increasing. The amount of melt in the last five years already exceeds the melt of the ten previous years. While there has been sporadic mining activity in the Kluane region for the past century there are currently no functioning mines in the watershed draining the St.Elias Mountains.

c. Increased Variability in Precipitation and Storms: It is anticipated that weather events will become both more unpredictable and extreme, with increased precipitation in some areas but water deficits in others. There is already some evidence of this trend. In June 2005 the Yukon set a record for highest precipitation in a single storm and through 2008 heavy rainstorms were experienced in the central Yukon, impacting both the Minto mine (where polluted run-off has been allowed to flow into the Yukon River system) and the Faro mine-site. The Yukon Government's Department of the Environment observed that changes to precipitation in the Yukon region could require costly upgrades and redesign of tailing dams and water diversion structures (Government of Yukon, 2007).

d. Hydrological Shifts in Lakes and Rivers: It is anticipated that shoulder seasons will lengthen as freeze-up arrives later and break-up comes sooner. For transport this is perhaps not as great a problem as it was before the advent of the all-weather road system, but may be of some significance for the Minto Mine which relies on ferry and winter roads to access the Klondike Highway. It could be problematic for any new mine west of the Yukon River, as the only bridge on the 500k stretch of river between Whitehorse and the Alaska border is at Carmacks. Accelerated spring run-off may also present erosion problems.

8.8.4 Case Examples

An examination of mining operations at different life-cycle stages serves to exemplify both the possible implications of a changing climate and the manner in which operators and government regulators plan for projected future climate change effects. Climate change has important implications for all stages of mine life-cycle. In the Yukon:

8.8.4.1 Mine Abandonment

a. United Keno Hill

This silver property with over nine different mines came under the management of the Yukon government when United Keno Hill Mines went bankrupt. The mine had operated from 1921-1982. When the price of silver plummeted worldwide the mine then operated sporadically with many different owners, and different stock plays. It is currently for sale by the court-appointed receiver and the federal government has severed the environmental liability from the site, although any new owners would be required to manage it. Site remediation will be taking place in an environment characterised by a changing climate.

b. Clinton Creek Mine

The Clinton Creek asbestos mine was operated by the Cassiar Asbestos Corporation Ltd. from October 1967 until August of 1978. The mine had three open pits, located on the south side of Clinton Creek, and there are now 60 million tonnes of waste rock which have blocked the creek and formed Hudgeon Lake. During its short life, the mill discharged 10 million tonnes of tailings to the Wolverine Creek valley. When the mine was planned neither seasonal frost nor permafrost thaw potential were considered to be significant. The possibility of climate change was not considered and it was thought that permafrost would remain frozen forever. The tailings dumps have since failed and formed two lobes, blocking the flow of Wolverine Creek. The creeks have eroded both the tailings piles and waste rock, and the fish habitat of upper Clinton Creek and Wolverine Creek have been destroyed. The federal Government has paid for gabion (mesh cage) beds to stabilize the waste rock piles and allow water flows to resume in the creek. Cost estimates to stabilise the property range from $17 million to $35 million.

c. Mt. Nansen/BYG Mine

This gold mine closed in 1997 because it was unable to meet the terms of its water licence. A territorial court judge later found that the actions of the company “demonstrate an attitude consistent with the raping and pillaging of resources in the Yukon”. Arsenic, cyanide, lead and other toxins had contaminated Dome Creek. It now costs the federal government almost $2 million a year to maintain the site, and full reclamation costs are estimated to be some $7 million. The mine is on the land of the Little Salmon Carmacks First Nation. The significance of climate change is, given that it is long term the context environment will change over time with consequences for a derelict site on the broader physical environment (Mining Watch, 2007).

d. Faro

The Faro Mine Complex, located in south-central Yukon some 200 km northeast of Whitehorse in the traditional territory of the Kaska Nation and upstream from the traditional territory of the Selkirk First Nation, was one of the world’s largest zinc mines.

The mine opened in 1969, the Anvil Range Mining Company purchased it in 1994, operated it until 1997 and declared bankruptcy in April of 1998. The cost of closing and cleaning up the mine had been estimated in 1993 at $124 million, against which Anvil held a Reclamation Securities Trust. In November 1994 Anvil Range had agreed to fund the Trust from operating revenues with contributions linked to the changing net price of zinc. They also recognized a liability of $43.5 million for environmental remediation on the property, assuming that reprocessing of tailings would bring the costs well below those estimated in 1993. However, zinc prices subsequently fell and the re-processing of tailings became less economical. The company never revealed the increasing cost of its environmental liability and by 1998, when the company declared bankruptcy, inflation and the increased volume of waste materials had raised cost of clean up to some $50 million.

At the mine site currently there is a large quantity of waste, comprising crushed rock/ore and tailings made up of naturally occurring minerals and metals which are potentially harmful to the environment. These include metals such as lead, zinc, and copper in various forms and other minerals such as metal sulphides. As the waste rock and tailings are exposed to air, wind and rain, the metals and minerals may be released and the natural level of these metals in the surrounding air, water and ground may be increased to levels that can be harmful. The toxic waste pond contains some 55 million tonnes of acid generating waste and there are some 320 million tonnes of rock in waste heaps.

In the summer of 2008 the region experienced intense rainfall that caused erosion problems and, given the prognosis for increased precipitation in the central Yukon, this problem could potentially worsen. Accelerated permafrost melt, for example, could increase the potential for leaching. The aim of the mine closure plan is to identify whether this process may happen over the long term and to close the site in such a way to prevent any unacceptable risks. A conservative estimate of remediation costs is $500 million and it will likely take ten years to stabilise the site, while long term monitoring will extend into the next century (Lois Craig, pers com).

Climate change also threatens the integrity of the Faro town-site, which was purposefully located above the Pelly River Valley where temperatures were somewhat milder. Most notable were the occurrence of pockets of permafrost that over time were responsible for considerable infrastructure damage. The community hotel suffered from subsidence as did the school, and many homes in Faro have experienced damage due to melting of underlying ice (Town of Faro, 2003, Northern Climate Exchange, 2007). Given the prognosis for marked permafrost melt accompanying climate change it is anticipated that infrastructure degradation will continue to worsen.

8.8.4.2 Active and Proposed Developments:

a. Klondike

Mining in the tributary creeks of the lower Klondike River has been an almost permanent feature since the Gold Rush of 1898. Activity has fluctuated widely, a reflection of both the exhaustion of the most accessible ore and fluctuations in the price of gold. Today gold mining in the Klondike is only a shadow of what it used to be with the industry only consisting of a number of relatively small scale operations. It is a seasonal (spring-summer) operation that makes a considerable contribution to the economic base of Dawson City.

Climate has always been a paramount consideration in the operation of mines in the Klondike. Snow, ice, and extreme winter cold mean that extraction is largely confined to the warmest eight months of the year. Gold bearing gravels were often found in frozen muck and permafrost, and permafrost thawing was and remains an important component of the production process. In the years following the Gold Rush demand for water for processing gold-bearing gravels was such that water had to be diverted from a neighbouring river valley to supplement the waters of the lower Klondike.

Seasonality of operations was the adaptive response of mining in the Klondike to climate extremes, and superimposed upon this annual rhythm were longer term fluctuations in population as the mining industry responded to swings in the price of gold.

Recent work conducted by the Pacific Climate Consortium (unpublished report for Northern Climate Exchange, 2008) suggests that with climate change there may be more precipitation in the longer term, greater variability in the weather and more extreme events. However, base data are so limited and the meteorological record so sparse it is difficult to make predictions with great confidence. There is some evidence that the region's permafrost may be becoming degraded, and periodically forest fires are now a problem. A major fire west of the gold fields in 2004 disrupted transport to Dawson and forced the closure of mines. Permafrost degradation could actually be a positive spin-off from climate change, as it would make access to gold bearing gravels easier (Lori Carter. Pers. Comm.).

The current mining industry is relatively small scale, seasonal, and largely housed in temporary structures. This relative lack of infrastructure investment combined with the seasonal and migratory nature of mining probably means that the mining industry in the Klondike may be well-placed to deal with events arising from a changing climate, as they will be able to adjust as the new climate regimes unfolds. Historically gold mining has been most sensitive to fluctuations in gold prices, and it will probably retain this sensitivity to world market conditions into the future (Workshop, Dawson City, November 14, 2008).

b. Sherwood Copper; Minto Project

Sherwood Copper Corp. operates a high grade copper-gold mine located 240km north of Whitehorse, west of the Yukon River. Entering production in 2007 it was the first new mine to be developed in the Yukon since 1997. Approximately 371 million pounds of copper and 154,000 ounces of gold are expected to be produced in concentrates over the mine's initial anticipated eight year life span, although the discovery of a second copper-gold deposit immediately south of the main deposit is expected to extend the mine's life and/or increase production capacity by over 40% (Sherwood Copper Corp, 2008). Extracted materials follow a process of crushing, grinding and flotation on site to produce copper concentrates and significant gold and silver outputs. Concentrates are then exported to smelters in Asia through Skagway, Alaska. Access to the highway is via an all weather road from the mine site to the Yukon River at the now abandoned community of Minto. In summer transport across the Yukon is by barge; in winter it is by ice bridge. Currently the mine relies on diesel power generators on site, though the corporation has entered into a power purchase agreement with Yukon Energy to supply electricity directly to the mine. A new 138 kV transmission line will be built from Carmacks to Stewart Crossing in the Central Yukon (approximately 172km long), with a spur line connecting to the mine. The power line will significantly reduce Minto's reliance on fossil fuels and its GHG emissions.

The project has already experienced climatic stresses. For example, heavy rains in August 2008 forced the company to release untreated water into the Yukon River system. Some 350,000 cubic meters of water had to be siphoned out of the mine's water treatment plant and discharged. Ironically the water storage pond was designed to assure water availability throughout the year, given an expectation of occasional seasonal summer drought. The discharge (.05 mg per litre) was higher than Yukon licence standards (.01 mg per litre). The same rainfall also washed out a four kilometre section of the mine haul road leading to Minto Landing.

c. Carmacks Copper Mine

The Carmacks Copper project, owned by Western Copper Corporation, is located 175 km north of Whitehorse. The project will employ some 100 people and produce some 14,000 tonnes of copper per annum, received approval from the Yukon Environmental and Socio-Economic Assessment Board in August 2008. The company is proposing extracting copper, placing it in a spoil heap, spraying it with sulphuric acid to release the copper, and then detoxifying the heap by spraying it with a neutralizing solution and water. The theory is that if the leaching solution is able to reach all parts of the heap evenly, the neutralizing solution will also be able to do so.

A synthesis of the statements made by the project proponent and documentation provided through the environmental assessment process demonstrates that climate and climate change considerations played a significant role in establishing the terms and conditions for the project's execution. The proponent identified structures, facilities, and processes upon which extreme fluctuations of the environment could have an effect, including the spoil heap (including berms and liners), the open pit, and the waste rock storage area. While the potential adverse effects of the environment largely involve extreme precipitation or temperatures, changes in climate were deemed not likely to impact project operations given its relatively limited time horizon, but become very relevant for the long-term stability of the site post-closure.

Extreme weather events may cause disruption to routine mining operations. It is likely that such events could result in the malfunctions or failures of structures (e.g., embankments), equipment (e.g., accidents, breakdowns) and processes (e.g., water collection/transport). In addition, extreme weather events may cause effects on structures that remain during and after reclamation and closure. Climate change effects could cause disruption of geochemical and physical stability in the mining structures and disruption of mining processes:

- Current infrastructure design criteria (i.e., to withstand one in 100 or 200 year events) are thought to be able to handle the minor changes in mean weather conditions resulting from climate change over the life of the project. Of greater concern are the potential effects of climate variability and increased frequency and magnitude of extreme events, especially in the post-closure period. More, or more extreme, weather events including heavy precipitation events, severe hot or cold temperatures and storms with high winds are also possible scenarios.

  In the project review process a number of specific potential climate related problems were cited, and subsequently the proponent identified a number of adaptive responses.

- Temperature increases. Periods of high temperature increase the evaporation rates which are an important part of the project's water balance. During operations this may result in increased make-up water being required for the spoil heap. Post-closure, increased evaporation is a potential benefit as it will decrease the amount of water that would potentially percolate through the heap or waste rock storage area (WRSA). Extended higher temperatures could also result in permafrost melt and, in response, the proponent intends to either melt or excavate and replace any known areas of permafrost or thaw unstable soils under the heap or WRSA. Furthermore, extended periods of higher temperatures could result in more extended melting of local discontinuous permafrost, but it is not expected that this would adversely affect the project.

- Though the evaporation to precipitation ratio in the project area is slightly negative and the project is anticipated to run a water deficit (i.e. it will require makeup water from wells), it is conceivable that a series of extremely high precipitation events could result in high volumes of water that would need to be actively managed on site. The events pond and sediment ponds can both be used to control precipitation and have been designed to capture and control excess precipitation (i.e., 1 in 200 year event, plus snowmelt, with a minimum freeboard of 1 m). Should precipitation exceed the volumes being planned for, the HDS treatment plant will be in operation in the event that runoff will need to be treated and released.

- Storms and high winds. Storms and high winds, especially with blowing snow, can reduce visibility and restrict access to or from the mine site so that workers may not be able to adequately carry out their required tasks. Tree blow down could hamper access to the mine site or affect power lines causing power failures and disruption of operations. High winds could cause wave action and potential erosion of the embankments of the events and sediment ponds. Armouring and lining of these ponds is expected to control any potential for wind-induced erosion.

- During the project, local and regional weather will be monitored. Any impacts of climate change on local weather conditions, and in particular the water management regime, will also be monitored. The company argues that "adaptive management of project operations and processes will allow appropriate response to changing weather patterns". This monitoring will provide additional information to better predict weather through post-closure. The project will operate for approximately 15 years, inclusive of decommissioning, although some installations like the heap, WRSA, open pit, and spillways will remain, in some state, in perpetuity. Both the heap and the WRSA will be reclaimed through contouring, soil covers and re-seeding. Over the course of time, it is anticipated that the open pit will fill to the height of the surrounding water table level.

- The company will have to post a $22 million security deposit with the Yukon Government to cover the costs of site remediation should the project be abandoned. Critics (notably the Yukon Conservation Society) argue that this does not reflect a realistic assessment of the costs of remediation (especially when compared to the Faro mine).

Although the environmental assessment process did not explicitly address the question of climate change, the potential for climate change impacts were alluded to. Better quality data was seen as the key to adaptive management and the ability to respond to changing circumstances. This was described in the environmental assessment report by: "Monitoring will provide additional information to better predict weather through post-closure. Additionally, climate change predictions will continue to improve as climate change research grows and builds on existing knowledge, data and technology."

8.8.5 Conclusions

Historically mining has survived in the region's extreme environments because it produced exotic or high demand minerals that periodically commanded very high prices, allowing it to absorb high transport and operating costs. It has also been very vulnerable to fluctuations in global mineral prices, and the various abandoned and ecologically compromised sites across the Yukon's landscape are testament to boom-bust cycles. The industry may already be experiencing some of the initial symptoms of a changing climate as seen in examples of permafrost degradation, and manifest in the problems at the Clinton Creek mine-site. Extreme precipitation events in the central Yukon also affected the Faro mine site and the Minto mine in the summer of 2008.

There is considerable uncertainty about the types of conditions mining in the Yukon will need to adapt to, and more detailed local scientific information on climate and climate trends would assist managers and decision makers in developing adaptation plans. There are general expectations that accelerated permafrost degradation, changes in the precipitation regime, and increased incidence of extreme events will occur, but there is a paucity of quality long-term data at the local or regional level to provide a well-informed basis for anticipating and planning for climate trends.

The relatively short life span of many mine operations suggests that adapting to a changing environment may not be overly problematic because climate change is a long term phenomenon, with the most severe impacts perhaps not manifesting themselves for decades after mine closure. Review of the Carmacks and Minto adaptation initiatives indicate that climate considerations, climate monitoring, proactive engineering initiatives, and the notion of "adaptive management" play an important role in the planning and operation of new mines. Given these proactive approaches and a mining culture that has had a long history of adapting to the vagaries of local environments and global markets, adapting within the short life span of individual mines may not be problematic. In some instances in fact, a changing climate is seen to be potentially beneficial in facilitating mineral extraction.

The real vulnerabilities are temporal and spatial. The long-term impact of mining on landscapes is potentially significant; without climate change mine site remediation in the Yukon would already be substantive issue. With climate change, it becomes even more significant. Mining companies are now obliged to factor remediation costs into their operations. Whether estimated costs are realistic is debatable, and the extent to which such costs will affect the viability of individual mines is not clearly known.

8.9 DISCUSSION

1. The majority of mines in the case studies are affected to some degree by climatic hazards, with examples of negative impacts. The majority of mine sites have been designed to operate effectively within particular climatic parameters and to manage events of a certain recurrence interval (e.g. 1 in 50 year storm events). Yet climatic events that exceed mine design sometimes occur and have had dramatic consequences. The last decade, for example, provides a number of instances where mine operational capacity has been compromised by climatic events; events which are expected to become more intense and frequent with climate change.

Those regions depending on climate sensitive transportation networks (e.g. ice roads, air transport) are particularly susceptible to climatic risks. Such mines often depend on limited and climate sensitive transportation networks. For those mines located in more populated regions, transportation is less problematic, although some risks exist. Notwithstanding these effects, the self reliance developed by mines operating in remote regions buffers them to certain climatic risks. Power at remote locations is often generated locally (e.g. by diesel generation) reducing vulnerability to power outages similar to what was experienced during the Quebec ice storm when long distance transmission lines were destroyed. Mines located near more densely populated areas are susceptible to climatic conditions in other unique ways too. Stringent air pollution and dust regulations, for example, commonly affect mines operating in the urban-rural interface (e.g. Sudbury, south-western Quebec) and can force mines to decrease production and processing on hot, smog, or dry days.

2. Most mines and associated infrastructure have been designed assuming current climatic conditions will prevail. As noted above, mines are often designed to cope with events of a certain recurrence interval (often no longer than a 1 in 50 year, or 1 in 100 year event) and within specified climatic parameters. In some instances, extreme weather events have pushed mine infrastructure beyond its limits, with sometimes tragic consequences. These extreme weather events are predicted to become more common with climate change. In instances where new risks have emerged during mine operation, **adaptation is usually reactive and *ad hoc* in nature**; re-affirming the findings of the two surveys. There are very few examples in the case studies where new risks have been identified *a priori* and coping mechanisms developed; it usually first involves infrastructure damage or constrained operational capacity before investments in adaptation occur. **A number of factors are limiting the ability of mines to manage current climatic risks** including financial cost of adaptation and the difficulty in justifying such expenditures. For some smaller operations, adaptation to climatic risks often involves closing operations until weather conditions improve. In a changing climate, such conditions may become the norm forcing the extended closure of operations that are unable to adapt. Analysis of current responses to climate risks provides insights into how companies might respond to future climate change; like the survey results it indicates that companies are likely to ‘react’ to changes as they begin to affect operations, rather than take more proactive approaches.

3. The majority of practitioners interviewed are aware that the climate is changing and are cognizant that more prevalent climate change will occur in the future. In the case of some recently developed mines climate change has been viewed as both a potential risk and opportunity for their operations. For some mine sites located in areas especially sensitive to climatic conditions (e.g. in the Northwest Territories and Yukon), climate change has been noted to negatively affect various aspects of mine operations (e.g. ice road networks) and elsewhere has been noted to have benefits (e.g. decreased heating costs, longer operating seasons). However, **the majority of respondents viewed climate change as only a minor concern**, particularly when compared to more pressing issues such as meeting regulatory and human resource requirements, and managing fluctuating market conditions. These results again correspond with the survey findings. A number of factors may explain the ranking of climate change by mining practitioners as a relatively minor issue. First, and as the second survey documented, knowledge of the nature, magnitude, and speed of climatic change is poorly understood. Very few respondents were aware of scientific / industry publications on climate change or what changes were projected to occur in their region. Even for mines where climate change was assessed in the environmental assessment process, knowledge of climate change by mine site employees was often limited. Second, many mine operations have a limited life span, dictated largely by the size of the deposits being mined. Several practitioners view climate change as a risk decades in the future and therefore of limited *immediate* importance. Third, for small mines in particular, the focus is on meeting customer requirements and there are limited resources and incentives available to contemplate future challenges such as climate change.

4. Given the ranking of climate change as a minor risk by interviewees it is no surprise therefore that there is little long term strategic planning being undertaken to identify future risks and opportunities and develop adaptations. This absence of planning is further reinforced by the apparent high cost of many adaptations and lack of regulation requiring mines to develop adaptation plans. **In many instances, adaptation options are available to manage future climate change risks but cost of these options is sometimes prohibitive, especially for small profit margin mining operations**. Limited planning for climate change is a cause for concern given the climate sensitivity of current mine operations, as climate change could compromise mine operational capacity, result in periods of reduced production, and force companies to make reactive and possibly costly adaptations to continue operating in the future. Buildings and built structures for example, are sensitive to potential storm damage and collapse due to permafrost melt in a changing climate; transportation networks are sensitive to flooding, temperature increases, and heavy snow; slope stability could be affected due to flooding and permafrost thaw; tailings ponds could be affected by flooding and gullying of slopes; and site drainage/hydrology more generally is likely to be affected by changing precipitation regimes. Indeed, recent modeling for Canada has indicated that by mid-century currently ‘low probability’ events will become more common: by 2050 a 1 in 20 year return event will occur every 11.3 years and once every 8 years with a moderate emissions scenario (Kharin & Zwiers, 2005). Failure to invest in adaptation could also have wider and much more tragic implications: failure of mine tailings containment infrastructure or other waste structures could have ramifications for surrounding communities, local wildlife and water quality, for example.

Moreover, while many interviewees view climate change as something that will occur many decades into the future and thus not a current business risk, evidence indicates that climate change might be occurring faster than scientists had originally predicted. The rapid decline of summer sea ice extent in the Arctic Ocean in 2006 and 2007, for example, is of a magnitude that scientists did not expect to witness until mid-century (Comiso et al., 2008). In this context, climate change may present itself as a major business risk to mining operations sooner than expected. A positive trend, which may affect future mine planning for climate change, is that mining sector consultants that were interviewed were more often aware of climate change and the need to adapt. This trend has also been evident at industry meetings, conferences, and in trade journal reporting. Consultants play an important role in the conception, development and closure of mines and will play an important role in long term adaptation of the mining sector.

5. Mitigation is being considered by many mine operations, although in many cases the motivation is to save costs as opposed to responding to climate change *per se*. Some small mines, however, noted not having the resources (i.e. financial, human) to invest in reducing emissions despite seeing the advantages of such activities. For the large multinational companies mitigation is viewed as a business risk and opportunity, important for corporate reporting and public image, and is viewed by some as an adaptation to help offset potentially costly government intervention in the sector to reduce GHGs in the future. Indeed, practitioners at some of the large companies noted that shareholders are demanding carbon disclosure (a business/investment risk) and action on mitigation, and that the public at large is demanding sustainable mining practice more generally. A number of barriers to mitigation besides cost, however, were also noted, including regulatory environment. There were examples in the case studies of mines partnering with government / utilities to reduce emissions although such cases were limited in number. It is also noteworthy that in many instances, mitigation and adaptation do not appear to be separate activities but are more closely linked. In the Northwest Territories, for example, diamond mines are striving to increase energy efficiency to reduce the use of costly diesel fuel. Given that diesel has to be brought in by ice road (or, in worst case scenarios, flown in), reduced fuel consumption has also increased the adaptability of the mines by reducing the need to use the increasingly unpredictable ice road for fuel shipments.

6. A number of priorities for future research and action to reduce vulnerability in the mining sector are suggested by analysis of the case study data:

- More effective knowledge and dissemination of information about the potential risks posed by climate change is needed in the mining sector.
- Research is needed to identify the most cost effective measures and technologies that will allow mines to adapt to climate change. Specifically, win-win adaptations that bring benefits regardless of the severity of climate change impacts need to be identified.
- Adaptation and mitigation in many instances can reinforce each other. Research is needed to assess how this can be achieved for different mining operations and regions.
- Regulations are needed to mandate that mines plan for climate change both during their operational lifespan and through decommissioning. Indeed, while some EIAs have stipulated that climate change must be included in mine planning, the research reported here indicates that this does not appear to have a major impact on long term company planning for climate change. Regulations need to extend not only to mines being developed but also to operational and abandoned mines as climate change could affect these sites at some stage of their lifecycle.
- Regulatory certainty in regards to GHG mitigation needs to be established before mitigation efforts truly take hold in the mining sector. Developing this certainty should be a priority for regulators.
- There is a need for improved climate modeling to better understand the risks that might affect mine sites and the main mining regions. Weather and climate data are crucial to the development and calibration of climate models and more weather stations located in strategic locations are needed.
- In light of uncertainty, adaptive management and monitoring of climatic conditions will be necessary for mining operations.

- Collaboration between mining companies and other industrial sectors on issues pertaining to climate change adaptation and mitigation will greatly enhance chances of success.
- Embracing opportunities of climate change will help offset some of the costs of climate change.

CHAPTER 9

9.1 CONCLUDING REMARKS

In the course of this study a number of methods have been used to identify climate change impacts, adaptations and vulnerabilities in the Canadian mining industry. The study focused on the extent to which the industry is exposed and sensitive to the impacts of a changing climate, the industry's attitudes towards climate change, and the extent to which the mining sector is responding to climate change through adaptation and mitigation. Literature reviews documented the scientific community's perspective on climate change and climate change predictions, and the extent to which the question of climate change in the mining industry has also been addressed. Surveys, first with the broader mining community (e.g. with consultants, engineers, mining company representatives, government representatives) and then with company representatives only, served to identify industry attitudes, awareness of climate trends, and ways in which the industry is affected by and is responding to the challenges presented by climate change. Finally, case studies from around Canada provided practical and detailed perspectives on the experiences of individual mines. While detailed conclusions are provided in some chapters of this report, a number of general conclusions can be drawn from the results of this project:

1a. Climate exposures and sensitivities are prominent in the mining sector: The mining sector was frequently documented to be sensitive to climatic stresses. Stresses related to changes in temperature, precipitation, extreme weather and storms have affected mining infrastructure and operations in the past, and continue to do so today.

1b. Climate change poses a number of risks to mining operations: Mining operations will likely face a number of infrastructure, regulatory and other business risks with climate change.

Infrastructure risks

Most mines and associated infrastructure have been designed assuming current climatic conditions will prevail. Mines are often designed to cope with climatic events of a certain recurrence interval (e.g. a 1 in 100 year storm event) and within specified climatic parameters. Climate change thus has the potential to seriously affect buildings and built structures, transportation networks, slope stability, tailings and water retention structures, and site hydrology in some regions of Canada. For example, buildings erected on thaw-sensitive permafrost could see shifting – and in the worst case, collapse – as permafrost melts. Buildings may also suffer damage from extreme weather events and increased storm intensity and occurrence. Land-based transportation routes could be affected by increased flooding, permafrost melt and decreasing ice thickness due to warming temperatures (in the case of ice roads), while air transportation schedules could be affected by storms and extreme weather.

In northern regions, slopes could increasingly slump and slide as underlying permafrost material loses cohesion due to melt, while frozen waste rock piles and tailings retention structures could lose their integrity over time if warming temperatures are not managed properly. In all regions of Canada, mine site drainage and hydrologic regimes could also be affected by climate change. Depending on the region, more frequent 'extreme' weather events could unleash large amounts of precipitation in relatively short periods of time, evaporation trends may be altered and drought could ensue, and the timing of expected seasonal events could change. This could have implications for tailings management, dust suppression, flooding, and water use needs on site.

Regulatory and Other Business Risks

There are a number of regulatory and other business risks the mining sector will face with climate change. Talk of ‘cap and trade’ systems and carbon taxes has led many in industry to consider how new legal landscapes might look, and how business would be affected. Those companies caught off-guard by new legislation stand to face significant economic repercussions, while early actors could find benefits for the bottom line.

Some publically-traded companies have also seen their shareholders demand carbon emission disclosure; in light of impending and existing climate-related legislation, shareholders have said these emissions represent a significant business, or investment risk. Mining projects moving from advanced exploration into production need to be especially cautious with climate change, as the environmental impact assessment process increasingly demands that climate change is considered. However, how to operationalise adaptation planning for climate change remains uncertain for many mining projects.

2. Long-term adaptation planning is largely not occurring in the mining sector: Currently, long-term adaptation planning, planning that considers present and projected future climate change impacts, is not occurring throughout the mining sector. The mining industry appears to be driven mostly by ‘day-to-day’ operations and activities, and is comparatively much less interested in adapting to projected future climate change. Mining sector representatives noted adaptation such as strengthening or redesigning infrastructure as being costly and largely unnecessary considering the short operating lives of many mines. Furthermore, it was said there is still considerable uncertainty about future climate change predictions, which has also deterred investment in adaptation measures. Encouragingly, some mines were documented to be developing climate change adaptations. Regulatory processes such as environmental impact assessment have increasingly required the potential impacts of climate change to be considered in mine planning, and some mine designers have included climate change parameters into their plans. Pro-active adaptation planning, however, is currently limited to only a select few mining operations and there are as yet no clear, generally agreed upon guidelines for how to undertake critical tasks, such as interpreting a range of climate change scenarios and model outputs and factoring them into infrastructure and closure design.

3. Mitigation rather than adaptation is the current response: Currently, the major emphasis in addressing climate change in the Canadian mining sector is through mitigation (i.e. reducing GHGs). GHG abatement is viewed by larger companies as an energy and cost saving measure, a buffer against impending climate-related legislation, and as beneficial for corporate image. In some cases GHG reductions have required investments in new technology, while in others considerable gains have been made through simpler process efficiencies.

4. Engineering solutions exist for many adaptation problems: In many instances the technologies and strategies necessary for adaptation to climate change in the mining sector already exist. In some instances these technologies are expensive (e.g. thermosyphons, strengthened holding facilities, alternative transportation routes, etc.), but are nevertheless effective. Investing in adaptation today will in many cases save money as reacting to climate risks (e.g. extreme storm event, melting of ice roads) can be costly.

5. Poor understanding of anticipated trends exacerbates vulnerability: There is considerable dissonance between the message about future climate change and its implications for human activity delivered by scientists, and awareness of predicted trends by many in the mining industry. Mining sector representatives generally acknowledge that the climate is changing, but the nature of possible changes and their probable impact on the sector are not well understood by them. Especially striking were the vast majority of respondents who were not aware of major scientific reports or predictions related to climate change. It is further revealing that many respondents had no awareness of whether adaptation measures were being undertaken in their own companies. Vulnerability is not just a matter of the likelihood of physical structures to be adversely affected by climatic events – it is also reflective of the attitudes, expectations and knowledge of mining practitioners in regards to climate change. Naturally, poor understanding of the issue will exacerbate vulnerability; the mining sector is unlikely to adapt to something that it does not first understand.

6. Significant vulnerabilities may exist in the mine post-operational phase: Most current mines have a relatively short life span and are not expected to be operating when the most severe effects of climate change manifest themselves in the future. From an operational standpoint, these mines do not necessarily need to be designed to accommodate changing climatic conditions for the near term. However, climate change could present potentially serious risks for mines in the post-operational and closure stages. If mine infrastructure is developed only according to design criteria relevant to the current climatic regime, the risk of structural failure due to the forces of future climate change becomes pronounced. Particularly worrisome are the vast number of abandoned mine sites across the country which have not yet been assessed for vulnerability to climate change.

The mining sector faces numerous other vulnerabilities which could affect the degree to which climate change is made a priority: The mining industry is especially vulnerable to other non-climate related factors. Swings in commodity prices and market conditions, securing project financing, and managing land-use conflicts and public opinion (factors that are also influenced by national and international climate change policy) all affect the ability of mining projects to successfully operate in Canada. In many regards, these factors outweigh climate change concerns in the sector and could minimize its perceived importance.

7. Experience drives adaptation: Where action has been taken to adapt to climatic conditions it has largely been reactionary in nature or in response to past experiences with climatic events. These adaptations are, of course, opposite to proactive approaches based on scientific assessments of the likely climate future. Perhaps not surprisingly, there were noted differences in the attitudes of respondents who work ‘on the ground’ at mine sites, and those who work in ‘office’ setting administrative and managerial roles. The former tended to see climate change in a much more negative light, likely because of greater day-to-day interaction with climate at an operational level. As climate change continues to manifest itself in the mining sector, the need to manage its impacts will grow.

8. Future research and action is needed: Results of this study have consistently indicated areas for further research and developments necessary to reduce vulnerability:

- More effective communication of the potential risks posed by climate change is needed in the mining sector.
- Research is needed to identify the most cost effective measures and technologies that will allow mines to adapt to climate change. Specifically, win-win adaptations that bring benefits regardless of the severity of climate change impacts need to be identified.
- Adaptation and mitigation in many instances can reinforce each other. Research is needed to assess how this can be achieved for different mining operations and regions.
- Regulations are needed to mandate that mines plan for climate change both during their operational lifespan and through decommissioning. Regulatory certainty in regards to GHG mitigation needs to be established before mitigation efforts truly take hold in the mining sector. Developing this certainty should be a priority for regulators.
- There is a need for improved climate modeling and communication of climate change projections to better understand the risks that might affect mine sites and the main mining regions.
- In light of uncertainty, where pro-active adaptation has and has not occurred, adaptive management and monitoring of climatic conditions will be necessary for mining operations.
- Collaboration between mining companies, mining associations, regulators, and other industrial sectors on issues pertaining to climate change adaptation and mitigation will greatly enhance chances of success.

The manner in which the mining industry responds to the challenges brought on by climate change has important implications for the national economy and especially for widely dispersed regions across Canada. Climate concerns are a central fact of business life and adapting to the reality of climate change is in the best interests both of mining companies and communities whose well-being is intractably tied to the success of the industry. To date, the response to current and expected future climate change has been slow, but the same can be said for other sectors of the Canadian economy, and where there has been response it has largely been the result of learning through experience.

The reluctance of the mining industry to take a pro-active stance on adaptation is largely the result of uncertainty about the emerging climate, but the scientific evidence persuasively suggests that some future climate change is imminent. The Canadian landscape will be altered due to climate change and there will be challenges for mining and other industries in the country. In shifting the agenda from the focus on mitigation to encompass adaptation as well, it must be recognized that the industry is an intractable and vital component of Canadian life with considerable experience and vested interest in addressing climate related issues. In Canada, there are a number of mining companies operating at multiple locations, a strong mining service sector, and institutions (e.g. universities, research organizations, government offices) similarly working to advance the sector. The potential for cooperatively developing effective mitigation and adaptation strategies is thus substantial, and an area for further research. There now exists a real opportunity for Canadian companies to become leaders in climate change mitigation and adaptation. The lessons that are learned in Canada could soon be applied around the globe.

APPENDIX 1

Suzuki Presentations and Publications

Some of the chapters in this report form the basis of articles in trade journals and the popular press. They are as follows:

Ford, J., Pearce, T., Duerden, F., Prno, J., and Marshall, D. (2008). Climate Change Impacts on the Canadian Mining Sector. The Canadian Mining Journal, 6th April 2008.

Ford, J., Pearce, T., Prno, J., Duerden, F., Berrang-Ford, L., and Marshall, D. (2008). Stormy days ahead: weather changes pose many threats to the mining industry. Canadian Mining Journal, September 2008, 1-3.

Pearce, T., Prno, J., Ford, J., Duerden, F., and Marshall, D.. (2008). Climate change and the Canadian mining sector: Risks and responses. Mining & Quarry World, Volume 5, issue 3, September 2008.

Prno, J., Ford, J., Pearce, T., Duerden, F., and Marshall, D. (2008). Climate change and the Canadian mining sector. Presentation at the Arctic logistics conference, Calgary, June 2008.

Prno, J. 2008. We’re breaking up: What does climate change mean for the mining industry. Up Here, November p.2008, 25-26.

CBC News North. 13th November 2008. A 5 minute interview with Jason Prno on the mining sector research with a focus on mining in the NWT (Interview on ArcticNorth Website).

APPENDIX 2

2008 Survey: perspectives of mining sector practitioners on climate change impacts, vulnerability, and adaptation

Dear Canadian Mining Sector Practitioner:

ArcticNorth consulting is researching the current and potential impacts of climate change on the mining sector in Canada and adaptation and mitigation strategies that are or could be implemented to mitigate those impacts. We would like to include your perspective in our study and would appreciate your help in completing the attached survey.

How will results be used?

Results from the survey will be published in a report together with results from additional research including in-depth case studies. The final report will be available for **FREE** on our website and will be distributed within the Canadian mining sector community.

Returning the Survey:

Please return your completed survey to one of our surveyors at the 2008 PDAC convention in Toronto.

Please send an email to Tristan Pearce: tristan.pearce@arctic-north.com or Dr. James Ford: james.ford@arctic-north.com with any questions, comments or concerns. Thank you for your time and effort. We look forward to sharing the results with you.

Survey Note: if you work for a company that represents a certain mining sector or the mining industry as a whole, please rephrase the questions from asking about, "…your company" to "…of those businesses your represent."

Survey Note: multiple answers are allowed for most questions. Questions where only one answer is allowed are indicated by: **

In your professional capacity, are you primarily involved in the mining sector in Canada?

No	0
Yes	1

If <u>YES</u> continue with survey. If <u>NO</u> the person is not eligible, finish the interview.

How would you describe the company you work for:

Mining company	1
Mine supplies and services (inc. transport)	*2*
Government/regulator	3
Consulting	4
Industry association	5
Financier/investment	6
Legal	7
Research	8

If the person does not represent one of these categories, they are <u>NOT</u> eligible to continue, finish the interview.

What type of mining is your company involved in?

Metal mine	1
Non-metal mine	2
Coal mine	3
Oil and gas	4
Other	

**How would you describe your role in the company?

Senior/executive management	1
Operations management	2
Environmental Health and Safety	3
Office and administration (e.g. Human Resources, Public Relations, Marketing, Sales)	4
Tradesperson/operator/miner/labourer	5
Scientist	6
Engineer	7
Other	

What geographical area(s) of Canada does your company work in?

Western Canada (AB, BC)	1
Central Canada (SK, MB)	2
Eastern Canada (ON, QC)	3
Maritime (NB, NS, NF, PEI)	4
North (NU, NT, YT)	5

How many years experience do you have in the mining sector?

____

**Would you say that climatic hazards – events such as flooding, heavy snow fall, heavy rainfall, poor ice conditions, forest fires etc:

Have a **large** impact on the operations of your company / those you represent	1
Have a **moderate** impact	2
Are **not** a problem	3
Don't know	4

If climate hazards **ARE** a problem, ask question 8. If **NOT** then proceed to question 9

Which of the following climatic conditions affect the operations of your business?

Snowfall	1
Rainfall	2
Freezing rain	3
Ice conditions	4
Temperature – heat	5
Temperature – cold	6
Storm events	7
Flooding	8
Forest fires	9
Don't know	10

Other ____

**Is climate change currently having an impact on the operations of your company / the businesses you represent?

No	0
Yes	1
Don't know	2

Are these changes:

Bad for your business	1
Very bad for your business	2
Good for your business	3
Very good for your business	4
Neutral	5
Don't know	6

**Is your company taking action to manage the impacts of climate change / are companies you represent taking action?

No	0
Yes	1
Don't know	2

If **YES** go to question 12 A and B. If **NO** go to question 13

How would you characterize your company's actions / the actions of companies you represent?

A).

Engineering based (e.g. infrastructure strengthening)	1
Administrative / Legal (e.g. advance planning, hazard preparedness)	2
Technological (e.g. bring in new machinery)	3
Behavioural (e.g. avoid development in certain areas)	4
Reducing greenhouse gas emissions	5
Taking advantage of new benefits with climate change	6
Don't know	6

Other ____

B).

In anticipation of impacts	1
Reacting to impacts	2
(If applicable) Localized to certain mines	3
(If applicable) Widespread across your operations	4
Don't know	5

Other ____

What barriers exist to adapting to these changes?

Cost	1
Uncertainty of climate change impacts	2
Uncertainty of political/regulatory changes?	3
Markets/economic uncertainty?	4
Lack of skilled/knowledgeable personnel?	5
Short life span of mine/project?	6

Other ____

In order, how would you rank the following risks to your business? [Rank from 1 – 5, 1 being the most important]

Commodity prices
New regulations
Climate change
Trade conditions
Ability to secure capital
Other not mentioned:____

**Scientists are predicting climate change for most regions of Canada. Do you expect climate change to affect the operations of your company / operations of those you represent?

No	1
Yes	2
Don’t know	3

Do you expect the impacts of future climate change to be:

Bad for your business	1
Very bad for your business	2
Good for your business	3
Very good for your business	4
Neutral	5
Don’t know	6

Which of the following projections would be problematic for your company / those you represent?

Higher temperatures	1
Shorter ice season	2
More snowfall	3
Less snowfall	4
More forest fires	5
More storms	6

More flooding	7
Less flooding	8
No problems	9

Other:______________________________

Which of the following projections would be beneficial for your company / those you represent?

Higher temperatures	1
Shorter ice season	2
More snowfall	3
Less snowfall	4
More forest fires	5
More storms	6
More flooding	7
Less flooding	8
No benefits	9

Other:______________________________

**Is your company taking action to plan for the future impacts of climate change?

No	1
Yes	2
Don't know	3

If **YES** go to 19. If **NO** go to 20

What action is being undertaken to plan for future climate change impacts?

Engineering based (e.g. infrastructure strengthening)	1
Administrative / Legal (e.g. advance planning, hazard preparedness)	2
Technological (e.g. bring in new machinery)	3
Behavioural (e.g. avoid development in certain areas	4
Reducing greenhouse gas emissions	5
Planning to take advantage of benefits	6
Don't know	7

Other ______________________________

What barriers exist to planning for the impacts of future climate change?

Cost	1
Uncertainty of climate change impacts	2
Uncertainty of political/regulatory changes?	3
Markets/economic uncertainty?	4
Lack of skilled/knowledgeable personnel?	5
Short life span of mine/project?	6

Other

In order, how would you rank the following risks to your business in 20 years time? [Rank from 1 – 5, 1 being the most important]

Commodity prices
Regulations
Climate change
Trade conditions
Ability to secure capital
Other not mentioned:

Is your company (companies you represent) currently reducing greenhouse gas emissions that are responsible for climate change?

No	1
Yes	2
Don't know	3

If NO ask question 24, if YES finish the survey.

Is your company (companies you represent) thinking about reducing greenhouse gas emissions that are responsible for climate change?

No	1
Yes	2
Don't know	3

END OF SURVEY
THANK YOU!!!

APPENDIX 3

ArcticNorth

Perspectives of mining sector practitioners on climate change impacts, vulnerability, and adaptation

Survey Administration

The following descriptions provide an overview of the project and should be explained to the survey respondent either via email prior to the phone/in-person interview and/or before the phone/in-person interview takes place.

The Project

ArcticNorth Consulting is researching the current and potential impacts of climate change on the mining sector in Canada, and adaptation and mitigation strategies that are or could be implemented to mitigate those impacts. The project is funded by the David Suzuki Foundation. We would like to include your perspective in our study and would appreciate your time in completing a survey. We will be contacting you by phone to conduct the survey and expect it to take about 15 minutes of your time.

How will results be used?

Results from the survey will be published in a report together with results from additional research including in-depth case studies and disseminated at national and international conferences and meetings. The final report will be available for **FREE** on our website (www.arctic-north.com) and will be distributed within the Canadian mining sector community. The surveys are completely anonymous.

Some definitions of interest to the project'?

Adaptation: response to climate change that aims to reduce the negative impacts of current and future climate change and take advantage of new opportunities that may arise.

Mitigation: efforts to reduce greenhouse gases responsible for climate change.

Note: multiple answers are allowed where indicated

PART A: RESPONDENT CHARACTERISTICS

What type of mining is your company involved in? [MULTIPLE ANSWERS ALLOWED]

Metal mine	1	1 Cobalt	8 Molybdenum
		2 Gold	9 Nickel
		3 Ilmenite	10 Platinum group metals
		4 Indium	11 Other precious metals
		5 Iron Ore	12 Silver
		6 Lead	13 Tantalum
		7 Magnesium and Magnesium Compounds	14 Uranium and Thorium
			15 Zinc
Non-metal mine	**2**	16 Amethyst	31 Potash
		17 Asbestos	32 Potassium compounds
		18 Baryte	33 Precious Stone
		19 Diamonds	34 Pumice
		20 Dolomite	35 Salt
		21 Granite	36 Sand and gravel
		22 Graphite	37 Sandstone
		23 Gypsum	38 Shale
		24 Lime	39 Silica and its compounds
		25 Limestone	40 Slate
		26 Magnesite	41 Sodium compounds
		27 Mica	42 Talc, soapstone and pyrophyllite
		28 Nepheline syenite	43 Tremolite
		29 Niobium	44 Zeolite
		30 Peat	

Other ____

Which of the following best describes your role in the company?

Senior/executive management	1
Operations management	2
Environmental Health and Safety	3
Office and administration (e.g. Human Resources, Public Relations, Marketing, Sales)	4
Tradesperson/operator/miner/labourer	5
Scientist	6
Engineer	7
Other	8
No answer	99

What geographical area(s) of Canada does your company have operations in? [MULTIPLE ANSWERS ALLOWED]

British Columbia (BC)	1
Alberta (AB)	2
Saskatchewan (SK)	3
Manitoba (MA)	4
Ontario (ON)	5
Quebec (QC)	6
New Brunswick (NB)	7
Prince Edward Island (PEI)	8
Nova Scotia (NS)	9
Newfoundland (NLF)	10
Yukon Territory (YT)	11
Norwest Territories (NWT)	12
Nunavut (NU)	13
No answer	99

How many years experience do you have in the mining sector?

____

PART B: SENSITIVITY OF OPERATIONS TO CLIMATIC CONDITIONS

Would you say that climatic hazards – events such as flooding, heavy snow fall, heavy rainfall, poor ice conditions, forest fires etc:

Have a **large** negative impact on the operations of your company / those you represent	1
Have a **moderate** negative impact	2
Are **not** a problem	3
Don’t know	4
No answer	99

If climate hazards **ARE** a problem, ask question 6; If **NOT** then proceed to question 7
Which of the following conditions affect the operations of your company? [MULTIPLE ANSWERS ALLOWED]

Climatic conditions	
Too much snowfall	1
Too little snowfall	2
Too much rainfall	3
Too little rainfall	4
Freezing rain	5
Warm temperature	6
Cold temperature	7

Storm events	8
High winds	9
Environmental conditions	
Ice conditions	10
Flooding	11
Forest fires	12
Water scarcity	13
Disturbances to hydro power	14
Low stream flow	15
Ground subsidence due to permafrost thaw	16
Water levels in rivers / lakes	17
Don't know	19
No answer	99

Other(s) ______________________________

PART C: CURRENT CLIMATE CHANGE

Is your company or organization concerned about climate change?

No	0
Yes	1
Don't know	2
No answer	99

Do you see any evidence that a changing climate is currently affecting operations?

No	0
Yes	1
Don't know	2
No answer	99

If answers **YES** to this question ask the **next question**,
If **NO** move on to question **16**
(Note for data entry for questions 9 - 15: if they answer no to question 8, for each column in data entry enter 50 to indicate not applicable)

Are these changes:

Bad for your business	1
Very bad for your business	2

Good for your business	3
Very good for your business	4
Neutral	5
Don't know	6
No answer	99

Which of the following CHANGES has had an impact on your operations? [Note: for this question, ask which of the listed changes have been observed, entering a 1 to say yes, and a 0 for no. Then ask if the change has been a problem. If a problem enter a 1, not a problem enter 0, change is good a 3 etc. No answer = 99] [MULTIPLE ANSWERS ALLOWED]

Observed change	Yes (1) No (0)	Significance: 1 = problem, 0 = not a problem, 2 = don't know, 3 = change is good
Climatic changes:		
Higher temperatures during the winter		
Higher temperatures during the summer		
More snowfall		
Less snowfall		
More rainfall		
Less rainfall		
More storms		
Stronger winds		
Environmental changes:		
Shorter ice season		
Permafrost thaw		
Ground subsidence due to permafrost thaw		
More flooding		
Water scarcity		
Reduced stream flow		
Increase in water levels in rivers / lakes		
Decrease in water levels in rivers/lakes		
Disturbances to hydro power		
More forest fires		
No answer		

Other(s)____

What aspects of your company operations have been affected by climate change? [MULTIPLE ANSWERS ALLOWED]

Operation	Impact (yes = 1, no = 0, 2 = don't know)	IF YES: Significance (1 = a problem, 2 = big problem, 0 = not a problem)
Containment facilities for tailings		
Transportation Infrastructure: on-site (roads, rail)		
Transportation infrastructure: for export (rail, shipping, roads)		
Buildings		
Mine decommissioning		
Mine development (e.g. location, planning)		
Processing		
Drilling		
Mine site drainage		
Discharge of wastes (i.e. due to reduced stream flow)		
Activity timing/'operations' – e.g. timing of drilling, exploration flight cancellations, road closures, equipment issues		

Other:____

Is your company taking action to reduce the NEGATIVE impacts of changes in climate?

No 0
Yes 1
Don't know 2
No answer
99

If **YES** go to question 13; If **NO** go to question 14

How would you characterize your company's actions to reduce the negative impacts of climate change? [MULTIPLE ANSWERS ALLOWED]

A)

Engineering based (e.g. infrastructure strengthening)	1
Administrative / Legal (e.g. advance planning, hazard preparedness, rescheduling)	2
Technological (e.g. bring in new machinery)	3
Behavioural (e.g. avoid development in certain areas)	4
Reducing greenhouse gas emissions	5
Reduce amount of employees	6
Increase amount of employees	7
Don't know	8
No answer	99

Other ____

B)

In anticipation of impacts	**1**
Reacting to impacts	**2**
Don't know	**5**
No answer	**99**

Other ____

Is your company taking action to <u>take advantage</u> of these changes?

No	0
Yes	1
Don't know	2
No answer	99

What barriers exist to adapting to these changes in climate that are affecting your company? [MULTIPLE ANSWERS ALLOWED]

Cost	1
Uncertainty of climate change impacts?	2
Uncertainty of political/regulatory changes?	3
Markets/economic uncertainty?	4
Lack of skilled/knowledgeable personnel?	5
Short life span of mine/project?	6
Technological limits	**7**

Don’t know	8
No answer	99

PART D: FUTURE CLIMATE CHANGE

Scientists are predicting climate change for most regions of Canada. Do you expect climate change to affect (positive or negative) the operations of your company?

No	0
Yes	1
Don’t know	2
No answer	99

If **YES** - next question
if **NO** go to question 23

Do you expect future climate change to be:

Bad for your business	1
Very bad for your business	2
Good for your business	3
Very good for your business	4
Neutral	5
Don’t know	6
No answer	99

Which of the following projected change would affect your company? [MULTIPLE ANSWERS ALLOWED]

Observed change	Yes (1) No (0)	Significance: 1 = problem, 0 = not a problem, 2 = don’t know, 3 = beneficial
Climatic conditions	-	-
Higher temperatures - winter		
Higher temperatures - summer		
More snowfall		
Less snowfall		
More rainfall		
Less rainfall		
Stronger winds		
More storms		
Environmental changes	-	-
Shorter ice season		

Permafrost thaw		
Ground subsidence due to permafrost thaw		
More flooding		
Water scarcity		
Reduced streamflow		
Increase in Water levels in rivers / lakes		
Decrease in water levels in rivers/lakes		
Disturbances to hydro power		
More forest fires		
No answer		

Other(s):____

Which aspects of your companies operations do you think climate change will affect? [MULTIPLE ANSWERS ALLOWED]

Operation	Yes (1) No (2)	Significance (0 = not a problem, 1 = problem, 2 = don't know, 3= beneficial, 99 = no answer)
Containment facilities for tailings (Storage for waste could collapse because of too much rainfall)		
Transportation Infrastructure: on-site (roads, rail)		
Transportation infrastructure: for export (rail, shipping, roads)		
Buildings		
Mine decommissioning (mine clean up their operation, revegetate, decontamination)		
Mine development (e.g. location, planning)		
Processing		
Mine site drainage		
Discharge of waste (i.e. due to reduced stream flow)		
Activity timing – e.g. timing of drilling, exploration		

Is your company taking action to address the impacts of future climate change?

No	0
Yes	1
Don't know	2

No answer 99

If **YES** answer next question; If **NO** go to 22

Which actions are being undertaken to plan for future climate change impacts? [MULTIPLE ANSWERS ALLOWED]

Engineering based (e.g. infrastructure strengthening)	1
Administrative / Legal (e.g. advance planning, hazard preparedness, rescheduling)	2
Technological (e.g. bring in new machinery)	3
Behavioural (e.g. avoid development in certain areas	4
Reducing greenhouse gas emissions	5
Planning to take advantage of benefits	6
Reduce amount of employees	7
Increase amount of employees	8
Researching impacts	9
Don't know	10
No answer	99

Other____

What barriers exist to planning for the impacts of future climate change? [MULTIPLE ANSWERS ALLOWED]

Cost	1
Uncertainty of climate change impacts	2
Uncertainty of political/regulatory changes?	3
Markets/economic uncertainty?	4
Lack of skilled/knowledgeable personnel?	5
Short life span of mine/project?	6
Technological limits	7
Don't know	8
No answer	99

PART E: REDUCING GREENHOUSE GASES

Is your company (companies you represent) currently reducing greenhouse gas emissions?

No	0
Yes	1
Don't know	2
No answer	99

If **NO** ask question 27, if **YES** ask question 24

Why is your company reducing greenhouse gases? [MULTIPLE ANSWERS ALLOWED]

Public relations/public pressure	1
Avoid government regulation	2
To make savings (e.g. with rising price of oil & gas)	3
Ethical reasons (i.e. right thing to do)	4
To avoid litigation at a future date	5
To attract employees	6
Don't know	7
No answer	99

How is your company currently reducing GHGs? [MULTIPLE ANSWERS ALLOWED]

Increasing energy efficiency (e.g. at mine sites, in HQs, in admin etc)	1
Purchasing renewable energy	2
Developing own renewable energy capacity	3
Improving efficiency of operations (e.g. traveling less, more bulk shipments)	4
Investing in more efficient technology (e.g. replacing old inefficient machinery)	5
Other technology (e.g. carbon capture, emissions abatement) chemical that take out CO_2	6
Carbon offsets/purchase of carbon credits	7
Don't know	8
No answer	99

Is your company planning to continue reducing greenhouse gas emissions in the future?

No	0
Yes	1
Don't know	2
No answer	99

DON'T ask Q. **27 & 28**
Go to **Q. 29**

Is your company planning to reduce greenhouse gas emissions in the future?

No	0
Yes	1
Don't know	2

No answer 99

Why is your company thinking of reducing GHGs in the future? [MULTIPLE ANSWERS ALLOWED]

Public relations	1
Avoid government regulation	2
To make savings (e.g. with rising price of oil & gas)	3
Ethical reasons (i.e. right thing to do)	4
To avoid litigation at a future date	5
To attract employees	6
Don't know	7
No answer	99

PART F: NEEDS ASSESSMENT

Have you heard about the following [MULTIPLE ANSWERS ALLOWED]

Source of Info	Yes (1) No (0)	Are they useful to you in planning for climate change? Yes = 1, No = 0
Canadian Climate Change Scenarios Network		
Natural Resources Canada's National Adaptation Assessment		
The Intergovernmental Panel on Climate Change		
Canadian Mining Association – An action plan for reducing greenhouse gas emissions		

What additional climate change information is needed to make you better prepared for current and future climate change? [MULTIPLE ANSWERS ALLOWED]

Information	Yes (1), No (0), Don't know (2)
Better projections of climate change	
More information on available adaptation options/engineering solutions (including costs)	
Better information from the government	
More research on how the mine sector might be affected by climate change	
Better personal understanding of climate change	

Other ____

END OF SURVEY
THANK YOU!!!

REFERENCES

ACIA (2005) Arctic Climate Impacts Assessment. Cambridge, UK, Cambridge University Press.

ALESSA, L., KLISKEY, A., BUSEY, R., HINZMAN, L. & D. WHITE (2008) Freshwater vulnerabilities and resilience on the Seward Peninsula: Integrating multiple dimensions of landscape change. *Global Environmental Change-Human and Policy Dimensions,* 18**,** 256-270.

AULD, H. & MACIVER, D. (2006) Changing Weather Patterns, Uncertainty and Infrastructure Risks: Emerging Adaptation Requirements. *IEEE Conference* Environment Canada, Adaptation and Impacts Research Division.

AULD, H., MACIVER, D. & KLAASSEN, J. (2006) Adaptation Options for Infrastructure under Changing Climate Conditions. *IEEE Conference.* Environment Canada, Adaptation and Impacts Research Division.

BERRANG FORD, L., MACLEAN, D., GYORKOS, T., FORD, J. D. & OGDEN, N. (2008) Climate change and malaria in Canada: a systems approach. *Interdisciplinary Perspectives on Infectious Diseases.,* In Press

BJELKEVIK, A. (2005) Water Cover Closure Design for Tailings Dams, State of the Art Report.

BONSAL, B. R., ZHANG, X., VINCENT, L. A. & HOGG, W. D. (2001) Characteristics of daily and extreme temperatures over Canada. *Journal of Climate,* 14**,** 1959-1976.

BORROW, E., B. MAXWELL & P. GACHON (EDS.) (Ed.) (2004) *Climate Variability and Change in Canada: Past, Present and Future,* Toronto, Environment Canada.

BROWN, A., DART, J. & QUESNEL, J. (2006) Climate Change and Watershed Management at the Hemlo Operations. *Sudbury Restoration Workshop.*

BURTON, I. (2006) Adapt and thrive: options for reducing the climate-change adaptation deficit. *Policy Options*, December 2005 - January 2005**,** 32-38.

CANADIAN CLIMATE CHANGE SCENARIOS NETWORK (CCCSN) (2007). Environment Canada.

CANADIAN ENVIRONMENTAL ASSESSMENT AGENCY (2002) Evaluation of the ClimAdapt Guide to Incorporating Climate Change Into the Environmental Impact Assessment Process. IN CLIMADAPT, P. B. (Ed.) *Section 5.6 'Voisey's Bay Mining Project'.*

CANADIAN ENVIRONMENTAL ASSESSMENT AGENCY (CEAA) (2002) Evaluation of the ClimAdapt Guide to Incorporating Climate Change into the Environmental Impact Assessment Process. *Research and Development Monograph Series, 2002.*

CANADIAN MINING JOURNAL (2005) Mining matters: UN support for carbon capture and storage. *Canadian Mining Journal,* 6.

CANADIAN MINING JOURNAL (2006) The cost of less cold. *Canadian Mining Journal,,* 5.

CHIOTTI, Q., & LAVENDER, B (2008) Ontario. IN D.S. LEMMEN, F. J. W., J. LACROIX AND E. BUSH (Ed.) *From Impacts to Adaptation: Canada in a Changing Climate 2007.* Ottawa, ON, Government of Canada,.

COAL AGE (2007) News: Delegation announces contract to manage greenhouse gases. *Coal Age,* 112**,** 1.

COMISO, J. C., PARKINSON, C. L., GERTSEN, R. & STOCK, L. (2008) Accelerated decline in the Arctic sea ice cover. *Geophysical Research Letters,* 35.

COUTURE, R., SMITH, S., ROBINSON, S.D., BURGESS, M.M., AND S. SOLOMON. (2003) On the Hazards to Infrastructure in the North Associated with Thawing of Permafrost. *Third Canadian Conference on Geotechnique and Natural Hazards.* Edmonton.

CVRD INCO (2007) Towards Sustainability: 2006 Health, Safety, Community and Environment Report.

DELOITTE AND TOUCHE (2008) Smart risk managers think broadly about climate change.

DEMUTH, M. N., & PIETRONIRO, A., (2003) The impact of climate change on the glaciers of the Canadian Rocky Mountain eastern slopes and implications for water resource-related adaptation in the Canadian Prairies. *Prairie Adaptation Research Collaborative.* Regina, Saskatchewan.

DENNIS CONSULTANTS (2008) First National Engineering Vulnerability Assessment Report: Roads and Associated Infrastructure *Final Report. Prepared for the City of Greater Sudbury Infrastructure Services Department.*

DUERDEN, F. (1982) Structure of the Settlement System of the Yukon. IN SERVICES., D. O. L. (Ed.) *Government of Yukon.* Whitehorse.

DUERDEN, F. (2004) Translating climate change impacts at the community level. *Arctic*, 57**,** 204-212.

EBA ENGINEERING CONSULTANTS LTD (2004) Permafrost Considerations for Effective Mine Site Development In the Yukon Territory.

EDNIE, H. (2002) Climate change: Innovation and strategy paving the way for GHG reductions. *CIM Bulletin.*

EDNIE, H. (2004) Energy management: Increasing efficiency for a healthier bottom line. *CIM Bulletin.*

ENVIRONMENTAL ASSESSMENT PANEL (EAP) (1996) Decommissioning of uranium mine tailings management areas in the Elliot Lake area. *Report of the Environment Assessment Panel.* Canadian Environmental Assessment Agency.

FERNANDEZ, J. (2002) Design for change: Part 1: diversified lifetimes. *Architectural Research Quarterly,* 7**,** 169-182.

FORD, J. D. (2006) Vulnerability to climate change in Arctic Canada. *Department of Geography.* Guelph, University of Guelph.

FORD, J. D. & B. SMIT (2004) A framework for assessing the vulnerability of communities in the Canadian Arctic to risks associated with climate change. *Arctic,* 57**,** 389-400.

FORD, J. D., ET AL, (2008a) Climate Change Impacts on the Canadian Mining Sector. *The Canadian Mining Journal*.

FORD, J. D. & PEARCE, T. (2007) Planning for climate change in the mining sector. *Canadian Mining Journal,* 4th April 2007.

FORD, J. D., PEARCE, T., PRNO, J., DUERDEN, F., BERRANG-FORD, L. & D. MARSHALL (2008b) Stormy days ahead; Weather changes pose many threats to the mining industry. *Canadian Mining Journal* September 2008**,** 1-3.

FORD, J. D., PEARCE, T., SMIT, B., WANDEL, J., ALLURUT, M., SHAPPA, K., ITTUSUJURAT, H. & QRUNNUT, K. (2007) Reducing vulnerability to climate change in the Arctic: the case of Nunavut, Canada. *Arctic* 60**,** 150-166.

FORD, J. D., SMIT, B., WANDEL, J., ALLURUT, M., SHAPPA, K., ITTUSARJUAT, H. & QRUNNUT, K. (2008) Climate change in the Arctic: current and future vulnerability in two Inuit communities in Canada. *Geographical Journal,* 174**,** 45-62.

FURGAL, C. & PROWSE, T. (2008) Northern Canada IN LEMMEN, D., WARREN, F., BUSH, E. & LACROIX, J. (Eds.) *From Impacts to Adaptation: Canada in a Changing Climate 2007.* Ottawa Natural Resources Canada.

FUSSEL, H. M. & KLEIN, R. T. J. (2006) Climate change vulnerability assessments: An evolution of conceptual thinking. *Global Environmental Change,* 75**,** 301-329.

GAMEDA, S., QIAN, B. AND BOOTSMA, A. (2005) Climate change scenarios for agriculture *Adapting to Climate Change in Canada.* Montréal, Quebec, Agriculture and Agri-Food Canada.

GOVERNMENT OF CANADA (2006) The 2006 Report of the Commissioner of the Environment and Sustainable Development to the House of Commons, Chapter 2: Adapting to the impacts of climate change. IN GENERAL, O. O. T. A. (Ed.). Ottawa.

GOVERNMENT OF YUKON (2007) Climate Change in Yukon. IN ENVIRONMENT, D. O. (Ed.).

GOVERNMENT OF YUKON (2008a) History of Mining in the Yukon. IN DEPARTMENT OF ENERGY, M. A. R. (Ed.).

GOVERNMENT OF YUKON (2008b) Melting Permafrost and the Alaska Highway. IN WORKS, D. O. T. A. P. (Ed.).

HAYLEY, D., & S. PROSKIN (2008a) Managing the safety of ice covers used for transportation in an environment of climate warming. *Geohazards 2008, 4th Canadian Conference on Geohazards.* Quebec City.

HAYLEY, D. B. H. (2008b) Rationalizing climate change for design of structures on permafrost: A Canadian perspective. *Proceedings of the Ninth International Conference on Permafrost.*

HEALTH CANADA (2008) Adapting to the Health Impacts of Climate Change.

HENGEVELD, H., & B. WHITEWOOD, (2005) Understanding climate change - 2005. IN ENVIRONMENT CANADA, M. S. O. C. (Ed.).

HOLUBEC, I. (2007) Design requirements for climate warming in permafrost. *Canadian National Committee for the International Permafrost Association 2007 Symposium.* Yellowknife.

INFOMINE.COM (2007) Overview of Voisey's Bay.

INFRASTRUCTURE CANADA (2006) Adapting Infrastructure to Climate Change in Canada's Cities and Communities: A Literature Review. IN DIVISION, R. A. A. (Ed.). Government of Canada.

INSTANES, A., ANISIMOV, O. A., BRIGHAM, L., GOERING, D., KRUSTALEV, L. N., LADANYI, B. & LARSEN, J. O. (2005) Infrastructure: Buildings, Support Systems, and Industrial Facilities. *Arctic Climate Impact Assessment Scientific Report.* Cambridge, UK, Cambridge University Press.

INTERNATIONAL COMMISSION ON LARGE DAMS, I. (2001) Tailings Dams Risk of Dangerous Occurrences: Lessons learnt from practical experiences. United Nations Environment Programme and International Commission on Large Dams.

INTERNATIONAL COUNCIL ON MINING AND METALS (ICMM) (2006) Position Statement: Climate Change. London, UK, ICMM.

INTERNATIONAL JOINT COMMISSION (IJC) (2003) Climate Change and Water Quality in the Great Lakes Region: Risks, Opportunities, and Responses. Great Lakes Water Quality Board.

ION, P. (2004) The mining sector and the Kyoto Protocol: Burying our responsibilities. *Canadian Mining Journal***,** 16-17.

IPCC (2000) Special Report on Emission Scenarios.

IPCC (2007a) AR4 Synthesis Report: Summary for Policy Makers. Geneva.

IPCC (2007b) Climate Change 2007: Impacts, Adaptation and Vulnerability. Working Group II Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report. Geneva.

IPCC (2007c) Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva.

JIMENA, J. (2006) Ethical funds: Keeping and eye on companies. *Canadian Mining Journal,* 8.

KAUFMAN, M. A. (2007) Commentary: Climate change: 'Consensus?'. *The Northern Miner,* 93**,** 1.

KESKITALO, E. C. (2008) *Climate change and globalization in the Arctic: An integrated approach to vulnerability assessment,* Earthscan.

KHARIN, V. V., & F.W. ZWIERS, (2005) Estimating extremes in transient climate change simulations. *Journal of Climate,* 18**,** 1156-1173.

KHARIN, V. V., & ZWIERS, F.W. (2000) Changes in extremes in an ensemble of transient climate simulations with a coupled atmosphere-ocean GCM. *Journal of Climate,* 13**,** 3760-3788.

KYHN, C. & ELBERLING, B. (2001) Frozen cover actions limiting AMD from mine waste deposited on land in Arctic Canada. *Cold Regions Science and Technology,* 32**,** 133-142.

LEE, R. (2001) Climate Change and Environmental Assessment. Part 1: Review of Climate Change Considerations in selected Past Environmental Assessments. *Research and Development Monograph Series 2000.* Canadian Environmental Assessment Agency.

LEMLY, A. D. (1994) Mining in Northern Canada: Expanding the Industry while protecting the arctic fishes - a review. *Ecotoxicology and Environmental Safety,* 29**,** 229-242.

LEMMEN, D., WARREN, F., LACROIX, J. & BUSH, E. (2008) From impacts to adaptation: Canada in a changing climate 2007. Ottawa, Government of Canada.

LINDEBERG, J. D. & ALBERCOOK, G. M. (2000) Climate Change and Great Lakes shipping/boating. IN SOUSOUNIS, P. & BISANZ, J. M. (Eds.) *Preparing for a Changing Climate- Potential Consequences of Climate Variability and Change, Great Lakes.*

MACKASEY, W. O. (2000) Abandoned Mines in Canada. *Consulting report prepared by WOM Geological Associates Inc. for Mining Watch Canada.*

MILLS, B. & ANDREY, J. (2002) Climate change and transportation: potential interactions and impacts. *Federal Research Partnership Workshop on The Potential Impacts of Climate Change on Transportation.* Washington, District of Columbia, US Department of Transport.

MINING ASSOCIATION OF CANADA (MAC) (2003) An Action Plan for Reducing Greenhouse Gas Emissions: Mining Association of Canada's Action Plan and Annual Progress Report.

MINING ASSOCIATION OF CANADA (MAC) (2004) An Action Plan for Reducing Greenhouse Gas Emissions: Mining Association of Canada's Action Plan and Annual Progress Report.

MINING ASSOCIATION OF CANADA (MAC) (2007a) Facts and Figures: A Report on the State of the Canadian Mining Industry. Mining Association of Canada.

MINING ASSOCIATION OF CANADA (MAC) (2007b) Towards Sustainable Mining - Progress Report 2007.

MINING WATCH (2007) Yukon Faces Renewed Mining Problems.

MORTSCH, L., CROWLEY, T. & FAY, D. (2006) Impact of Climate Change on Hydro-electric Generation in the Great Lakes.

MORTSCH, L. & QUINN, F. (1996) Climate change scenarios for Great Lakes Basin ecosystem studies. *Limnology and Oceanography* 5**,** 903-911.

NATURAL RESOURCES CANADA (2007) From Impacts to Adaptation: Canada in a Changing Climate 2007.

NATURAL RESOURCES CANADA (NRCAN) (2004) Climate Change Impacts and Adaptation: A Canadian Perspective.

NATURAL RESOURCES CANADA (NRCAN) (2006) Canadian Minerals Yearbook 2006. Natural Resources Canada.

NATURAL RESOURCES CANADA (NRCAN) (2007) Sustainable Management and Rehabilitation of Mine Sites for Decision Support. Natural Resources Canada.

NATURAL RESOURCES CANADA (NRCAN) (2007a) Canadian Mineral Production Exceeds $40 Billion. . *Natural Resources Canada Information Bulletin.* Ottawa.

NATURAL RESOURCES CANADA (NRCAN) (2007b) Employment in Canada's mining and mineral processing industries remains robust in 2006. *Natural Resources Canada Information Bulletin.* Natural Resources Canada.

NATURAL RESOURCES CANADA (NRCAN) (2008a) Canadian Mineral Exploration and Deposit Appraisal: 2007 Expenditures and 2008 Intentions at Record Highs. *Natural Resources Canada Information Bulletin, March 2008.*

NATURAL RESOURCES CANADA (NRCAN) (2008b) Canadian Mineral Production Exceeds $40 Billion. . *Natural Resources Canada Information Bulletin.* Natural Resources Canada.

NEALE, T., AULD, H., BIZIKOVA, L., KLAASSEN, J. & MACIVER, D. Mining in a Changing Climate Impacts and Adaptation Needs in the Mining Sector.

NORTHERN CLIMATE EXCHANGE (2007) Northern Climate Change Schools Program: Community Profile: Faro, Yukon.

NYIRFA, W. A. H., W (2001) Assessment of climate change on the agricultural resources of the Canadian Prairies. *Project PARC QS-3, final report.* Regina, Saskatchewan, Agriculture and Agri-Food Canada.

ONTARIO MINING ASSOCIATION (OMA) (2006) Ontario Mining: A High-Tech Productivity Powerhouse, Economic Contribution Study.

ONTARIO MINISTRY OF NORTHERN DEVELOPMENT AND MINES (OMNDM) (2008a) Value of Ontario Mineral Production.

ONTARIO MINISTRY OF NORTHERN DEVELOPMENT AND MINES (OMNDM) (2008b) Abandoned Mines/Mine Hazards.

PIETRONIRO, A., TOTH, B., AND TOYRA, J. (2006) Water availability in the South Saskatchewan River basin under climate change. *Climate Change and Water in the Prairies Conference.* Saskatoon, Saskatchewan.

POPOVICH, L. (2007) Cooling the warming debate. *Coal Age,* 112.

POPOVICH, L. (2008) Common sense on climate change. *Coal Age,* 113.

POST, J. E. & ALTAMA, B. W. (1994) Managing the Environmental Change Process: Barriers and Opportunities. *Journal of Organizational Change Management* 4**,** 64-81.

PRNO, J. (2008a) We're breaking up: What does climate change mean for the mining industry? *Up Here,* November p.2008**,** 25-26.

PRNO, J., AND BRADSHAW, B. (2008b) Program evaluation in a northern, Aboriginal setting: Assessing Impact and Benefit Agreements. *Journal of Aboriginal Economic Development,* 6**,** 59-75.

QUINN, F. H. (2002) The potential impacts of climate change on Great Lakes Transportation. *The Potential Impacts of Climate Change on Transportation*

ROBERTSON, R. (2006) Early ice road closures could cool diamond operations. *The Northern Miner,* 92.

ROMANO, C. G., MAYER, K. U., JONES, D. R., ELLERBROEK, D. A. & BLOWES, D. W. (2003) Effectiveness of various cover scenarios on the rate of sulphide oxidation of mine tailings. *Journal of Hydrology,* 271**,** 171-187.

SAUCHYN, D. A. K., S. (2008) Prairies. IN D.S. LEMMEN, F. J. W., J. LACROIX AND E. BUSH (Ed.) *From Impacts to Adaptation: Canada in a Changing Climate 2007.* Ottawa, Government of Canada.

SCHRÖTER, D., POLSKY, C. & PATT, A. G. (2005) Assessing vulnerabilities to the effects of global change: an eight step approach. *Mitigation and Adaptation Strategies for Global Change,* 10**,** 573-595.

SHERWOOD COPPER CORP (2008).

SMIT, B., HOVELSRUD, G. & WANDEL, J. (2008) Community Adaptation and Vulnerability in Arctic Regions. University of Guelph, Department of Geography, Occasional Paper No. 28.

SMIT, B. & J. WANDEL (2006) Adaptation, adaptive capacity, and vulnerability. *Global Environmental Change,* 16**,** 282-292.

SMIT, B. & WANDEL, J. (2006) Adaptation, adaptive capacity, and vulnerability. *Global Environmental Change,* 16**,** 282-292.

SMITH, S. L. A. B., M.M. (2004) Sensitivity of Permafrost to Climate Change warming in Canada. *Geological Survey of Canada, Bulletin 579.*

STERN, N. & TAYLOR, C. (2007) Climate change: Risks, ethics, and the Stern Review. *Science,* 317**,** 203-204.

THE CANADIAN CLIMATE IMPACTS AND ADAPTATION RESEARCH NETWORK (C-CIARN) NORTH (2006) Five Year Compendium: Status of Climate Change Impacts and Adaptation from the Perspective of C-CIARN North-Yukon Node.

THE NORTHERN MINER (2000) Mining companies take on global warming. *The Northern Miner,* 86.

THE NORTHERN MINER (2007) Editorial: Feds unveil carbon emissions caps. *The Northern Miner,* 93.

THE NORTHERN MINER (2008) Commentary: US Senate report debunks ‘climate consensus’. *The Northern Miner,* 93.

THE NORTHERN REVIEW (2001) Uncertain Future: Deliberate Action. *Circumpolar Climate Change Summit* Whitehorse, Yukon.

TOWN OF FARO (2003) Town of Faro Official Community Plan.

TURNER, B., KASPERSON, R. E., MATSON, P. A., MCCARTHY, J., CORELL, R., CHRISTENSEN, L., ECKLEY, N., KASPERSON, J. X., LUERS, A., MARTELLO, M. L., POLSKY, C., PULSIPHER, A. & SCHILLER, A. (2003) A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences,* 100**,** 8074-8079.

UNITED NATIONS ENVIRONMENTAL PROGRAM - FINANCIAL INITIATIVE (UNEP FI) & STOCKHOLM INTERNATIONAL WATER INSTITUTE (SIWI) (2005) Challenges of Water Scarcity: A Business Case for Financial Institutions. .

VALE INCO (2003) 'The Gossan - Voisey's Bay Nickel Company Publication'. *Voisey's Bay Website*

VALE INCO (2009) 'Voisey's Bay - Mine FAQ'.

VOISEY'S BAY ENVIRONMENTAL IMPACT STATEMENT - 8.1.3.1 'CLIMATE CHANGE'.

VOISEY'S BAY NICKEL COMPANY LTD (2004) Environmental Progress Report 2004.

VOISEY'S BAY NICKEL COMPANY LTD (2005) Environmental Progress Report 2005.

VOISEY'S BAY NICKEL COMPANY LTD (2006a) 2006 Social Responsibility Report.

VOISEY'S BAY NICKEL COMPANY LTD (2006b) Environmental Progress Report 2006.

WISE, B. (2005) Emission offset projects: An opportunity for leadership. *Coal Age,* 110.

WISE URANIUM PROJECT (2006) Chronology of major tailings dam failures.

XSTRATA (2008) Sustainability Report 2007.

YAMAGUCHI, K., NODA, A. & KITOH, A. (2005) The Changes in permafrost induced by greenhouse warming: A numerical study applying multiple-layer ground model. *Journal of Meteorological Society of Japan,* 83**,** 799-815.

YUKON ZINC CORPORATION (2008).

ZHANG, X., VINCENT, L. A., HOGG, W. D. & NIITSOO, A. (2000) Temperature and precipitation trends in Canada during the 20th Century. *Atmosphere-Ocean* 38**,** 395-429.