A Practitioner's Guide to Climate Change Adaptation in Ontario's Ecosystems

Version 1.0

Ontario

OCCIAR

Ontario Centre for Climate Impacts and Adaptation Resources

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EXECUTIVE SUMMARY

Ontario's climate is warming and becoming increasingly variable. It is possible that temperature, precipitation, and wind patterns will continue to change for decades, perhaps centuries, affecting the way communities throughout Ontario manage their natural resources and infrastructure, and changing the lives of people who depend on these assets for health and well-being. Currently, Ontarians are responding to the known and potential impacts of climate change in two ways: mitigation through greenhouse gas emission reductions, and adaptation.

Integrating climate change adaptation into natural resource management requires an understanding of the known and potential impacts of climate change and the corresponding vulnerability of, and risks to, ecosystems and the people who rely on them. This guide was developed to help practitioners respond to and prepare for climate change. It was also prepared in response to the Expert Panel on Climate Change Adaptation (2009) recommendations, the commitments contained in *Climate Ready: Ontario's Adaptation Strategy and Action Plan* (Government of Ontario, 2011) and the Ministry of Natural Resources' strategic priorities on climate change.

This guide introduces the concepts of climate change adaptation, vulnerability, and risk. It also describes vulnerability and risk assessment tools and techniques, and a framework that can be used to support adaptive management in a rapidly changing climate. Ultimately, the guide seeks to assist natural resource managers to identify ways that climate change vulnerabilities and risks can be integrated into decision-making processes that include adaptation action plans, strategies, and policies.

SOMMAIRE

Le climat de l’Ontario se réchauffe et devient de plus en plus variable. Il est possible que les configurations des vents, des précipitations et des températures continuent de changer pendant des décennies, voire des siècles, ce qui influera sur la façon dont les collectivités à la grandeur de l’Ontario géreront leurs ressources naturelles et leur infrastructure et transformera la vie des gens qui dépendent de ces facteurs pour leur santé et leur bien-être. À l’heure actuelle, la population de l’Ontario réagit aux impacts connus et éventuels du changement climatique de deux façons: atténuation des impacts au moyen de la réduction des émissions de gaz à effet de serre et adaptation.

L’intégration de l’adaptation au changement climatique à la gestion des ressources naturelles exige une compréhension des incidences connues et éventuelles du changement climatique et de la vulnérabilité connexe des écosystèmes et des gens qui en dépendent, tout comme des risques qui les menacent. Le présent guide a été conçu afin d’aider les spécialistes à réagir au changement climatique et à s’y préparer. Il a également été rédigé pour donner suite aux recommandations du Comité d’experts sur l’adaptation au changement climatique (2009), aux engagements énoncés dans le document *Faire Face au changement climatique : Stratégie d’adaptation et plan d’action de l’Ontario* (gouvernement de l’Ontario, 2011) et aux priorités stratégiques du ministère des Richesses naturelles en matière de changement climatique.

Le présent guide présente les notions d’adaptation au changement climatique, de vulnérabilité et de risque. Il décrit en outre les outils et les méthodes d’évaluation de la vulnérabilité et du risque, ainsi qu’un cadre pouvant être utilisé à l’appui de la gestion adaptive dans un climat qui connaît une évolution rapide. Enfin, le présent guide vise à aider les gestionnaires de ressources naturelles à cerner des moyens d’intégrer aux processus décisionnels les vulnérabilités et les risques liés au changement climatique, notamment par l’adoption de stratégies, de politiques et de plans d’action axés sur l’adaptation.

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Note

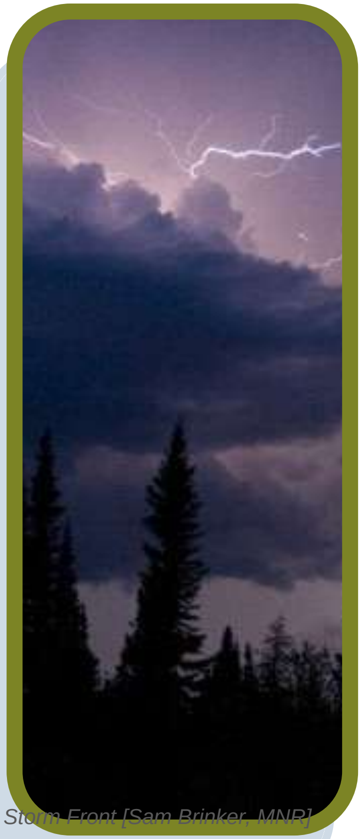
Climate change adaptation is a rapidly evolving area of practice. Literature and practical guidance continue to be published with new and innovative approaches and tools. This 'living' guide will be revised as new approaches are developed and tested in Ontario and other jurisdictions. Any questions or comments concerning the guide can be directed to Jenny Gleeson (jenny.gleeson@ontario.ca). An evaluation form to provide comments on the framework is also available to inform future versions of the guide.

CONTENTS

1.0 INTRODUCTION

A Changing Climate in Ontario

The average annual global temperature warmed by about 0.76°C over the last century (IPCC, 2007a), but average warming across Canada was more than double the world average (Environment Canada, 2011). In the last 63 years, the average temperature in Canada has increased about 1.6°C, although there have been differences in warming trends across the country. For example, average annual temperatures increased 2.3°C in the Mackenzie region of the Northwest Territories and part of Nunavut, whereas Atlantic Canada warmed by 0.5°C over the same period (Environment Canada, 2011). During this period, average temperatures across Ontario increased by 0.7 to 1.1°C, with higher temperatures occurring in the Boreal and Hudson Bay Lowlands regions (Environment Canada, 2011).


Storm Front [Sam Brinker, MNR]

Projections for Ontario suggest that average annual air temperature will increase, but given the uncertainty of human behaviour and associated greenhouse gas emission rates and magnitudes, it is not known by precisely how much. Generally, the average global temperature is projected to warm 1.1 to 6.4°C[1] during the next century, with land areas warming more than the oceans and higher latitudes warming more than lower latitudes (IPCC, 2007a). The additional heat in the atmosphere will likely increase variability in precipitation and wind patterns. For example, as more heat is trapped in the lower atmosphere by additional greenhouse gases, the frequency and size of extreme weather events such as ice storms, heavy rains, droughts, and wind storms are expected to increase (IPCC, 2007b).

Based on a scenario that assumes emissions at the current rate of global output (business-as-usual), the average annual temperature in Ontario is projected to rise by about 5.1°C by the end of the century (Figure 1) (McKenney et al., 2010). Other scenarios that assume that action is taken to reduce greenhouse gas emissions project a change of about 3.6°C. Across Ontario, precipitation is projected to increase; however, projections of changes in seasonal patterns of precipitation are uncertain at this time.

[1] The range of temperature change is due to differences in the projected warming for different greenhouse gas emission scenarios.

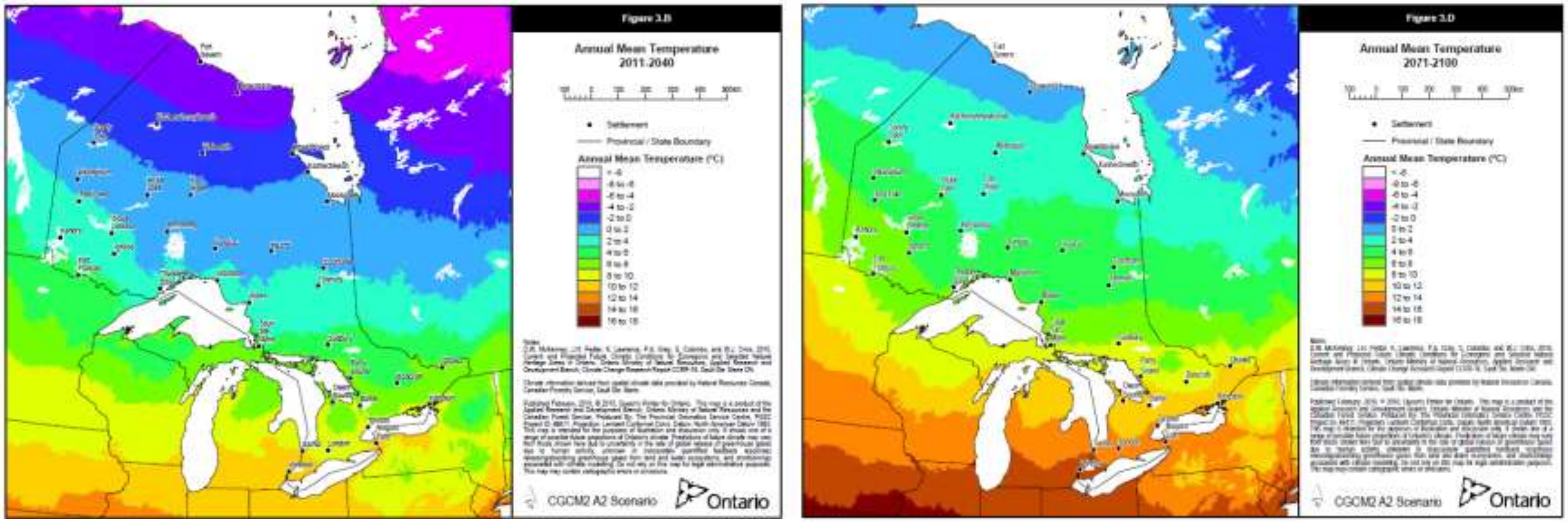


Figure 1. Annual mean temperature projections using Canadian Global Climate Model 2 (A2 scenario) for 2011-2040 and 2071-2100 (McKenney et al., 2010).

The changes in climate that have been projected for this century have major implications for the composition, structure, and function of ecosystems and natural resources in Ontario (Varrin, Bowman, and Gray, 2007). Some species will adapt – by migrating, altering phenology (e.g., breeding date), or seeking alternative food sources. Others that are less able to adapt to changing conditions will disappear from all or parts of their current range (Chen et al., 2011). For example, it is projected that the southern range of many Ontario species such as moose, gray jays, and polar bears will shift north (see, for example, Obbard et al., 2007; Lemmen et al., 2008).

Decreases in ice cover and changes to freeze-up and break-up times will have physiological impacts on aquatic species and will alter the food-chain dynamics in aquatic ecosystems. Over the past 40 years, a decrease in the maximum amount of ice that formed each year was observed on all the Great Lakes, ranging from a 17% decline to a 40% decline in the percentage of each lake that was covered in ice annually (Karl, Melillo, and Peterson, 2009). Additional information on the impacts of climate change on Ontario's natural resources is available from reports in the Ministry of Natural Resources (MNR) Climate Change Report Series and the academic literature.

In 2007, the Government of Ontario released *Go Green: Ontario's Action Plan on Climate Change*, with targets to reduce greenhouse gas emissions to mitigate the impacts of climate change (Government of Ontario, 2007). The target was to reduce greenhouse gas emissions to 6% below 1990 levels by 2014 (a reduction of 61 megatonnes relative to business-as-usual), 15% below 1990 levels by 2020 (a reduction of 99 megatonnes relative to business-as-usual), and 80% below 1990 levels by 2050 (Government of Ontario, 2007). These progressive targets were accompanied by a commitment to support adaptation programs to help Ontarians prepare for climate change. The Government of Ontario appointed the Expert Panel on Climate Change Adaptation in 2007 with a mandate to evaluate current government programs and recommend a path forward.

The Panel released its report in November 2009 with 59 recommendations, a number of which addressed the need for adaptive management supported by vulnerability analyses. For example, recommendation #21 called on the MNR to strengthen its capacity to develop and plan adaptation actions designed to increase the climate resilience of ecosystems and species at risk. Recommendations #19 and #28 suggested that Ontario complete vulnerability analyses in support of adaptive management for near-shore water quality in the Great Lakes and in the Boreal, Great Lakes-St. Lawrence, and Carolinian forested ecosystems (Expert Panel on Climate Change Adaptation, 2009). The Panel's recommendations provided the basis for the province's *Climate Ready: Ontario's Adaptation Strategy and Action Plan* (Government of Ontario, 2011).

This guide was prepared in response to the Expert Panel on Climate Change Adaptation recommendations, the commitments contained in *Climate Ready: Ontario's Adaptation Strategy and Action Plan* and MNR's strategic priorities on climate change. This guide is designed to assist natural resource managers in their work to integrate an adaptive approach to managing for climate change into policies and programs.

Adapting to Climate Change in Natural Resource Management

Adapting to climate change involves taking action to reduce or eliminate the negative effects of climate change or to take advantage of the positive effects. Adaptation complements commitments to reduce greenhouse gas emissions.

Climate change adaptation may require changes to existing policies and programs, and, in some cases, development of new policies and management approaches. Rather than dealing with adaptation in isolation from other management decisions or other factors, it is important to integrate (or *mainstream)* climate change adaptation into ongoing planning and decision-making. This can increase efficiency in the use of financial and human resources, and deepen our understanding of the interaction between climate change and the many other factors and forces that shape our world.

Climate change adaptation options come in all forms, shapes, and sizes, and are specific to any one study area. There is no single 'correct' procedure for undertaking climate change adaptation. Each method of developing adaptive responses has its inique strengths and its usefulness depends on the specific adaptation process and the stakeholders involved. Because of the uncertainties associated with some adaptation options, it is also important to build flexibility and 'learning-by-doing' approach into decisions.


Forest fire in Wawa, 2009 [Christine Rosche, MNR]

Generally speaking, options can include broad strategies, regional approaches, and site-specific management actions and tactics that seek to (1) reduce threats; (2) enhance resilience of species and systems; (3) engage people; and (4) improve knowledge.

This guide introduces a framework to assist natural resource management practitioners to mainstream climate change into decision-making and operations, and, where necessary, to develop new policies and management approaches. It describes tools and techniques for understanding the potential vulnerabilities and risks of a changing climate on natural systems in Ontario and a process to support adaptive management. While many of the tools described in this guide can be used by other sectors, it is not a tool intended for use for developing municipal or infrastructure related climate change action plans. The guide is focussed on adaptive planning and management of *social-ecological systems*.

Why Was This Guide Written?

Mainstreaming climate change adaptation requires an understanding of the known and potential impacts of climate change and the corresponding vulnerability of, and risks to, ecosystems and the people who rely on them for health and well-being. In natural resource management sectors such as fisheries, wildlife, forests, parks and water management, managing for climate change includes identifying impacts on natural resources over time and exploring the consequences to and impacts on ecological and social systems.

This guide was prepared to help practitioners respond to and prepare for climate change, and is organized around the following objectives:

- Introduce climate change adaptation, vulnerability, and risk;
- Describe vulnerability and risk assessment tools and techniques that can be used to support adaptive management in a rapidly changing climate; and
- Provide examples of assessments with information about how they were used to support adaptive management and decision-making.

How Can the Guide Be Used?

This guide demonstrates how a suite of tools (e.g., vulnerability assessments) can be used to inform adaptation efforts. It is not a prescriptive 'must-do' manual. It allows practitioners to select and combine tools and techniques to enhance their organization's ability to address threats and opportunities resulting from climate change that are unique to their location and/or sector (e.g., a forest management unit, a fisheries management zone, or a provincial park).

Given that assessments will be completed in many locations and on a variety of spatial scales (e.g., local to regional, sector to ecosystem-specific) and will include diverse expertise from various disciplines, the process is necessarily scalable. For example, a vulnerability assessment could focus on a specific thematic area, such as water or wildlife, to limit the size of the assessment team and to reduce the complexity of the overall process. Likewise, project teams could begin to highlight potential vulnerabilities and impacts by using the information currently available in literature.

The process described in this guide provides a general framework and examples of tools that can be used by practitioners from a variety of disciplines. Practitioners are encouraged to design their own approaches, based on the questions being asked and the context and focus of their assessment.

Observing a hawk's nest, [Scott McPherson, MNR]

2.0 AN OVERVIEW OF CLIMATE CHANGE ADAPTATION CONCEPTS

Adaptation is an adjustment in natural or human systems to moderate and cope with the consequences of climate change. The essence of adaptation is to “learn while doing” (Lee, 1999). Adaptation is characterized by actions that reduce negative impacts and risks caused by climate change and increase the magnitude and likelihood of preferred outcomes (Williamson et al., 2011). This process involves learning about vulnerabilities and risks, evaluating possible responses, implementing adaptation action, and revising choices with new learning (Leary et al., 2008). Adaptation can include but is not limited to specific actions (e.g., improvements to stormwater management), systematic change to organizational operations, and institutional reform.

Given the uncertainty of future conditions at specific locations or points in time, ***adaptive management*** is important because it is an iterative process based on monitoring, new learning, and the re-evaluation of management goals (Swanston and Janowiak, in review).

Several interrelated concepts of climate change vulnerability, risk, and uncertainty form the basis for practical, hands-on impact assessments. The concepts are fundamental components for mainstreaming adaptation initiatives into natural resource management.

Flooding in Peterborough, 2004 [MNR]

Adaptation can take many forms, anywhere along the spectrums below:

Anticipatory ⟷	**Reactive**
Activities that are taken before impacts are observed	Activities that are taken after impacts have occured
Planned ⟷	**Autonomous**
Deliberate actions aimed at adaptation	Activities to spontaneously cope with climate impacts

Anticipatory and planned ecosystem-based adaptation measures that use a range of opportunities for sustainable management, conservation, and restoration are the focus of this guide.

The guide provides tools and examples for identifying and prioritizing adaptation actions to reduce threats, enhance resilience of species and systems, engage people, and improve knowledge.

Vulnerability in the context of climate change is defined as "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, [and] the sensitivity and adaptive capacity of that system" (IPCC, 2007c). In other words, systems and species that will undergo the greatest change, are sensitive to that change, and have the least ability to adapt quickly are the most vulnerable (Lemmen and Warren, 2004).

Developing meaningful adaptation strategies requires an understanding of the vulnerabilities of species, ecosystems, and social systems to climate change. Vulnerability assessments can support adaptation planning in many ways:

- Identify species and/or ecosystems most likely to be most impacted by projected changes in climate;
- Build an understanding of why these species and/or ecosystems are vulnerable, including the interaction between climate change, non-climatic stressors, and cumulative impacts;
- Assess the efficacy of previous coping strategies in the context of historic and current changes in climate; and
- Identify and target adaptation measures to systems with the greatest vulnerabilty.

Caribou in the Far North of Ontario [Ken Abraham, MNR]

Assessing species' and ecosystems' vulnerability to climate change is a complex task. In addition to the complexity of the interactions of various components of the ecosystem, assessing climate change vulnerability involves understanding the degree of and interaction between exposure, sensitivity, and adaptive capacity to climate change in a system, as well as other non-climatic stresses. Each of these determinants of vulnerability is dynamic: they can vary over time, by type, and by stimulus, and can be place- and system-specific (Smit and Wandel, 2006).

A sensitive species example of vulnerability: Eastern Hemlock (*Tsuga canadensis*)

Hemlock, an important tree species found in the Great Lakes-St. Lawrence forest ecosystem, can be used as an example of how the components of vulnerability relate to one another. Brief definitions introduce each component.

Exposure: the nature and extent to which the species or system is exposed to significant climate variation. More extreme weather events, including extended droughts and heat waves, are projected with climate change throughout Ontario, including southern and central Ontario where hemlock grows.

Sensitivity: how affected a species or system is by being exposed to a stress. Eastern hemlock requires cool, moist sites to regenerate and thrive. It is quite sensitive to dry and hot conditions and experiences significant stress under these conditions. In addition, hemlock is a preferred browse species of white-tailed deer; since warmer winters result in less snow cover, hemlock seedlings would be exposed to more browsing pressure.

Adaptive Capacity: the ability or potential of a species or system to respond successfully to climate variability and change. Hemlock's natural ability to adapt to climate change stresses is limited. Its slow growth rate as a seedling makes it less adaptable to heat and drought conditions that would limit its growth, cause significant mortality, and make it less competitive than other Great Lakes-St Laurence tree species. Strategies to keep hemlock in the Great Lakes-St. Lawrence forest ecosystem could include management techniques such as seeding and planting of hemlock on suitable sites around water bodies and assisted migration to appropriate sites further north.

Hemlock [Stan Vasiliauskas, MNR]

Resilience is a synonym for some of the characteristics of adaptive capacity (the term used in this guide). From an ecological perspective, resilience is a tendency to maintain integrity when subject to disturbance (UNDP, 2005). A resilient ecosystem can withstand shocks and rebuild itself as necessary. The resilience of an ecosystem in a changing climate is determined by its components, function, and structure, and in particular by the diversity of species, the genetic variability within species, and the regional pool of species and ecosystems. Other influences include the size of the ecosystem (generally, the larger and the less fragmented, the better), past land use patterns, and the condition of the surrounding environment. ***Resistance*** is the capacity of an ecosystem to absorb disturbances and remain largely unchanged (Holling, 1973). In general, we use the term ***adaptive capacity*** to capture the system's ability to prepare for or adjust to stress.

Risk describes the likelihood (probability of occurrence) and the consequences of an adverse impact as a result of the interactions between climate change and society (UNDP, 2005). Risk assessment is based on people's perceptions of the adverse effect. It involves identifying and ranking risk issues and selecting the best risk-reduction strategies even when practitioners do not know what the future will look like because of climate change and other cumulative impacts.

Uncertainty is an "expression of the degree to which a value…is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. It can have many types of sources, from quantifiable errors in data to ambiguously defined concepts or terminology, or uncertain projections of human behaviour" (IPCC, 2007b).

Assessing how vulnerable species and ecosystems are to climate change involves uncertainty. The degree of uncertainty is partially based on the data, information, and expert knowledge available to assess that information. Uncertainty is also a function of the fact that by using climate models, we are making projections about future climate-induced change based on estimates of greenhouse gas emissions, and thus we are exploring what those projections could mean. We don't know the absolute magnitude of climate change and its potential effects or how systems may exactly respond to change. Uncertainty should not limit vulnerability assessment and the development of adaptation options, however. The guide presents a language for addressing uncertainty and methods for incorporating uncertainty into vulnerability assessments.

3.0 A CLIMATE CHANGE ADAPTATION FRAMEWORK FOR ECOSYSTEMS

A climate change adaptation framework (Figure 2) comprises a series of steps that serve as a roadmap for practitioners seeking to mainstream climate change into natural resource management. The framework is based on a conceptual model for adaptation that was derived from adaptive management principles. The framework is not strictly linear. It begins with the formation of a team and identification of a focus for the assessment, and then outlines assessment of existing vulnerabilities and the application of future climate scenarios in order to estimate future vulnerability and risks. The process then seeks to identify, prioritize, and implement adaptation measures. Where new data and learning can be integrated, re-evaluations and changes can be made over time.

The ability to know when to act and what actions to take depends on understanding and projecting the effects of climate change on ecosystems. Uncertainty about future greenhouse gas emissions and the spatial distribution of climate change effects requires that we use a dynamic and ongoing approach through adaptive management. Accordingly, monitoring and the acquisition of new knowledge enable practitioners to detect change, assess the success of actions, and modify and adjust decisions over time.

Dragon fly, [MNR]

This framework builds on existing frameworks and information in the literature (e.g., Glick, Stein, and Edelson, 2011; Kasperson and Berberian, 2011; Alberta Sustainable Resource Development, 2010; Williamson et al., 2007; Füssel and Klein, 2006; Smit and Wandel, 2006; UNDP, 2005), as well as guidance currently in development in Canada and the United States (i.e., Swanston and Janowiak, in review; CCFM, in prep). This framework also builds on the experience gained in a pilot vulnerability assessment project in the Lake Simcoe watershed in Ontario, which informed a local climate change adaptation planning process. The guide illustrates elements of the adaptation framework used in the Lake Simcoe pilot in a case study format.

This guide provides a step-by-step description of the framework and of tools and techniques available to practitioners. Worksheets provided in guide are intended as examples that practitioners can adapt and use to meet the specific needs of their sector or planning area.

Step	Activities
Step 1:* *Set Context and Build Team	• Define the study area and identify environmental themes (ie., ecological, social, and economic) and indicators • Build the team and engage experts, stakeholders, and partners
Step 2:* *Assess Current Vulnerability	• Describe the system's current sensitivity and exposure to climate and non-climatic stresses • Describe the degree of adaptive capacity of the system
Step 3:* *Develop and Apply Future Scenarios	• Develop and apply future climate scenarios • Consider anticipated non-climatic stresses (e.g., human population growth, land use)
Step 4:* *Estimate Future Vulnerability and Risks	• Identify and describe future impacts • Determine future vulnerability and categorize uncertainty • Describe the likelihood and consequences of vulnerabilities through socio-economic, political, and environmental evaluations • Determine areas at highest risk • Communicate initial findings to key organizations
Step 5:* *Develop Adaptation Options	• Based on the risk analysis, determine potential adaptation options • Prioritize adaptation options considering economic feasibility, social acceptability, ecological suitability, and technical and institutional feasibility (e.g., barriers and opportunities)
Step 6:* *Implement and Mainstream Adaptation	• Determine highest priority adaptation actions for implementation • Communicate accomplishments • Monitor adaptation actions and vulnerabilities over time • Acquire new knowledge, learning, and insights, and modify adaptation actions as required

ITERATIVE PROCESS

Figure 2. A climate change adaptation framework for ecosystems

STEP 1: SET CONTEXT AND BUILD TEAM

The first step in mainstreaming climate change adaptation is to build the project team, engage stakeholders and partners, and define the study area and the environmental themes and indicators that will be the focus of the vulnerability assessment.

Defining the Study Area, Themes, and Indicators

People engage in climate change adaptation for many reasons. Some are issue-related, such as losses resulting from an extreme weather event or perception of future risk (e.g., frequency of flooding or drought). Other reasons relate to a desire to better understand how climate change might affect a particular area, or concerns expressed by resource managers or the public. Identifying the reasons motivating the study can help to define the study area and determine the scale at which the issue is best addressed. In issue-driven studies, there may be less flexibility in selecting the study area and some data limitations may exist.

Climate change impacts occur across multiple scales. In situations where there is flexibility in defining the study area, the scale of assessment can vary:

- Local assessments, such as a watershed, ecodistrict, forest management unit, provincial park, fisheries management zone, or other resource planning areas;
- Regional assessments, such as an ecoregion or another regional boundary; and
- Provincial and jurisdictional assessments.

A study at the local level can be a useful scale for encouraging a range of interested parties to participate. Local studies are also more feasible if there are limited resources and/or a desire to gain experience in conducting vulnerability assessments. However, it is important to recognize that by its very nature, climate change will require that natural resource managers think and plan within the context of larger landscapes, even when adaptive management decision-making may occur on a local scale.

Geographic scale affects the usefulness of climatic projections modelled for the study area. At coarser, broader scales, climate projections are more robust, even with the availability of downscaled climate models (refer to Step 3, on models and scenarios). If a vulnerability assessment is conducted on a smaller, local scale, it is important to describe uncertainties and avoid over-interpreting fine-scale projections (Glick et al., 2011). Whatever level an assessment is conducted at, it is important to consider the geographic range of the species being examined, and how they may shift into or out of the study area under future climate scenarios.

Worksheet 1.1: Selecting the Study Area

Brainstorm the options for project areas, recognizing that boundary delineations can be at different spatial scales and will be uniquely affected by the issues motivating the study. Study designers should consider data and information availability. Considering the details of future implementation can also assist with the establishment of project boundaries (i.e., aligning with existing planning or management units to enable the mainstreaming of adaptation into existing plans).

Potential project area	Describe planning or operations that are defined by project area boundaries	Describe research sites, data, or climate analysis tools applicable to the project area	Identify motivating factors unique to the project area

Within the study area, it is important to identify environmental themes that are pertinent to the assessment. Availability and quality of data and availability of expertise should be considered in selecting themes. Examples of themes include:

- Hydrology;
- Fish and aquatic habitat;
- Wildlife;
- Forests;
- Wetlands
- Invasive species;
- Species at risk; and
- Parks and protected areas.

Broad-leaf defoliator [Will Byman, MNR]

There are many potential indicators associated with each theme that can be used to focus the assessment. Within the aquatic habitat theme for example, potential indicators include distribution of coldwater fish species in streams, or temperature and oxygen regimes in lakes and their associated habitat availability for fish species. Similarly, changes in bird species distribution could be an indicator within a wetland or forest theme.

Another approach involves a biodiversity-focussed analysis that assesses the vulnerability of various ecosystem services to a changing climate (Patt et al., 2009). Ecosystems provide food and fresh water, climate and disease regulation, cultural services such as recreational opportunities, and nutrient cycling and soil formation among other services (Millennium Ecosystem Assessment, 2005). All of these services are potentially vulnerable to climate change.

Worksheet 1.2: Selecting Themes and Indicators for Analysis

List the themes to be used in the study area and identify indicators. For example, within the theme of hydrology, indicators could include water quality, water quantity, and stream flow. Within a forest theme, indicators could include forest health, growth and productivity, disturbance regimes, and forest composition, among others.

As a starting point, investigate the themes and indicators used in other assessments, and/or review possible themes with researchers and experts. Ranking of potential themes can assist project teams in deciding which themes are most important to focus on, particularly in cases where there are too many themes to pursue given the resources, capacity, or time available.

Potential themes	Rank of importance for analysis	Availability of expertise	Potential thematic indicators	Availability and quality of data

Building a Project Team

A diverse set of skills, perspectives, and expertise will be required to complete a comprehensive vulnerability assessment process and to begin developing and implementing adaptation measures.

- ❑ Depending on the scale of the project, a team can comprise in-house staff, external experts, and other partners/stakeholders.
- ❑ As the scale and complexity of the assessment increases, greater diversity in expert opinion may be required.
- ❑ All members of the project team will have specific roles and responsibilities.
- ❑ Within the project team, a leader will be required to coordinate the project, work with the assessment team experts that are conducting thematic vulnerability assessments, and facilitate meetings.
- ❑ Assessment team contributors can help to identify the scope of the thematic vulnerability assessments and will conduct the assessments in their specific areas of expertise. Assessment team contributors will typically be scientific researchers with a specific area of expertise. Modelling experience is an important skill for contributors.
- ❑ Teams may also elect team members to engage partners and stakeholders.
- ❑ A steering committee made up of decision-makers and those who influence them can be formed to guide the assessment, help validate the outputs of the assessment, and prioritize and implement adaptation options.
- ❑ It is recommended that teams develop a project charter to ensure clear understanding of roles, responsibilities, and expectations.

Worksheet 1.3: Building Your Project Team

To identify the assessment team and to articulate the expectations and activities of each team member, consider the following:

Team roles and responsibilities	
What is the collective role and responsibility of the project team (e.g., team mandate)?	
Who is the team leader? Who is the outreach champion? What role do other project team members play?	
Who are the contributors leading the technical assessments and what resources/expertise do they have?	

(Source: adapted from J Edwards; pers. comm.)

Identifying and Engaging Partners and Stakeholders

Climate change adaptation is most effective when framed as a participatory, iterative, adaptive management process that builds strong working relationships with partners and stakeholders. When vulnerability assessments are participatory, they can enhance participants' understanding of the various actors' perspectives; help to develop and garner support for adaptation options, targets, and visions; and build capacity to implement results. In some cases, local participation can also help the project team build a strong portfolio of local observations that add value to the process, particularly where monitoring data are limited. Local participation may also allow recognition of interacting factors and stimuli beyond climate, including political, cultural, economic, institutional, and technological factors (Smit and Wandel, 2006). Many of the challenges of adapting to climate change can be managed by fostering effective working relationships with stakeholders and communities. Teams are encouraged to identify stakeholders and partners and discuss possible models for engagement.

Engagement techniques range from participation through consultation and giving information, to more interactive participation through joint action planning, to self-mobilization where stakeholders take the initiative (UNDP, 2005). Ultimately, it is important that stakeholders and partners understand how they are being involved in the process, how the information they provide will be used, and the degree of power they have in influencing decisions in the process. If stakeholders chose to abstain from the process, they may ask for regular updates, which may require a communication plan and a team member designated to oversee stakeholder communications.

Worksheet 1.4: Identifying Partners and Stakeholders

As a team, identify and list potential partners and stakeholders. Stakeholders can be individuals, communities, or groups that have an interest in how climate change is considered in natural resource management and who may be responsible for formal and informal dissemination of knowledge and/or implementation of policies and measures. Partners will play a more active role in the project such as contributing to vulnerability assessments and helping to identify adaptation options. Questions to consider include:

- ❑ How might each stakeholder and partner contribute to the planning process?
- ❑ Is there anyone on the partner and stakeholder list that you do not already have a relationship with?
- ❑ What information about understanding and acting on a climate change impact does the study team need? Who has (or has access to) this information?
- ❑ In what areas does the study team have influence? Is there anyone who can help the team use that influence?
- ❑ How will stakeholders use the vulnerability assessment information, and how will they contribute to reducing climate risk?

Burntbush Lake, Cochrane, [Scott Finucan, MNR]

Partner	Describe interests/ resources/expertise	Describe existing relationship	Possible role in project
Stakeholder	**Describe interests/ resources/expertise**	**Describe existing relationship**	**Possible role in project**

(Source: adapted from J. Edwards; pers. comm; ICLEI, 2010)

STEP 2: ASSESS CURRENT VULNERABILITY

Step 2 involves building an understanding of the study area, including the current exposure and sensitivity to climate, the adaptive capacity of the species or system, and other contextual information. With this information, a comparison to future vulnerabilities can be completed later in the process.

Assessing Current Exposure, Sensitivity, and Adaptive Capacity

To assess potential future vulnerabilities, it is necessary to understand the current vulnerability of the system. For example, understanding fire patterns and related contributing factors such as high temperature days and/or periods without rainfall could help in exploring what might happen if future conditions are hotter and/or drier. Additionally, systems that are already stressed are more likely to experience adverse effects from changing climatic conditions.

Vulnerability is determined by the degree of exposure, sensitivity, and adaptive capacity in a system.

Exposure is defined as the nature and degree to which a system is exposed to significant climatic variations (IPCC, 2001).

Sensitivity is the degree to which a system will respond to a change in climatic conditions. In many cases, sensitivity and exposure can be characterized jointly (Smit and Wandel, 2006).

Adaptive capacity is the ability or potential of a system to respond successfully to climate variability and change (IPCC, 2007c). This concept is related to many other commonly used concepts such as coping ability, robustness, and resilience (Smit and Wandel, 2006).

Janet Jackson, [MNR]

Worksheet 2.1: Assessing Current Exposure, Sensitivity and Adaptive Capacity

At this stage, experts on the assessment team will typically begin their assessments of sensitivity, exposure, and adaptive capacity using the best available information (e.g., studies, observations, expert judgement, datasets, model outputs, etc.). This simplified worksheet may be used either to guide experts in providing their final results or to summarize the analysis that experts provide.

To assess current exposure and sensitivity, gather information to describe the study area's historic and current climate, and observations of change to explore how climate has affected an indicator (or environmental theme more broadly) within the study area. Rank the current exposure and sensitivity to climate as High (H), Medium (M), or Low (L).

- ❑ ***High –*** Exposure and sensitivity to climate is the central driver or plays a significant role in the current state, structure or function of the indicator.
- ❑ ***Moderate –*** Exposure and sensitivity to climate plays a moderate role in the current state, structure or function of the indicator.
- ❑ ***Low –*** The indicator is currently not exposed or sensitive to climate. Its current state, structure or function shows very limited evidence of a relationship to climate.

The assessment of adaptive capacity is one of the more challenging aspects of vulnerability analysis. The measurement of adaptive capacity is a relatively new and evolving area of study; adaptive capacity has traditionally been examined from either an ecological or a social perspective. Efforts are underway to integrate knowledge of adaptive capacity of social and ecological systems (see for example Miller et al., 2010; Turner, 2010).

One approach is to examine multiple time periods before, during, and after a historic climatic event to see whether a system prepared for and/or adapted to the stress. If the system adapted or adjusted, whether or not it was negatively impacted to some degree, then some capacity to adapt had to have existed (Engle, 2011).

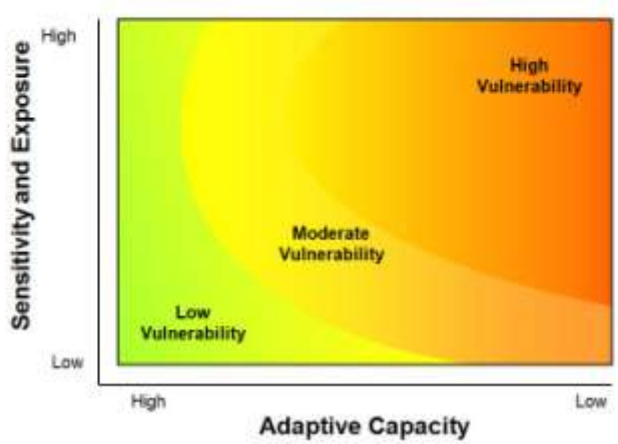


Figure 4. Alberta's Climate Change Adaptation Framework Manual illustrates one approach to depicting vulnerabilities. (Source: adapted from Alberta Sustainable Resource Development, 2010.)

To assess adaptive capacity, look at ecological adaptive capacity (e.g., plasticity, or how changes in temperature cause different genes to be expressed in tree species, dispersal abilities, etc.) and/or human adaptive capacity (e.g., the ability to implement planned adaptation measures to cope with changes as a result of economic resources, institutional capacity, infrastructure, technology, etc.).

For each indicator, rank the current adaptive capacity of the system as High (H), Medium (M), or Low (L).

- ❑ ***High –*** The indicator shows a high tolerance to change and a strong ability to adapt to new conditions or stresses.
- ❑ ***Moderate –*** The indicator shows a moderate tolerance to change and some ability to adjust or adapt to new conditions or stresses.
- ❑ ***Low –*** The indicator shows very little or no tolerance to change and limited ability to adapt to new conditions.

Indicator	Describe current sensitivity and exposure to climate	Rank (H-M-L)	Describe current adaptive capacity	Rank (H-M-L)

Canada Goose goslings [Scott Taylor, MNR]

Assessing Current Non-climatic Stresses

Assessing the vulnerability of species and ecosystems to climate change should also recognize the influence of non-climatic stresses. This assists in clarifying the relationships between various species and ecosystems, and their vulnerabilities to current climatic and non-climatic factors and stresses; it also helps to provide a foundation for the assessment of future vulnerabilities. Looking at climate change in isolation from the impacts of other stresses on a system may result in a failure to recognize the cumulative and synergistic effects that result from the interaction between climate change and other factors.

In some cases, there will be human activities that contribute to system stresses, such as changes to population and demographics, economic growth or diversification, land-use, or market fluctuations.

Worksheet 2.2: Describing Current Non-climatic Stresses

If possible, consider historical growth patterns in the project area, economic shifts, and historic and recent land-use changes. Information on existing stresses, as well as professional judgement and expert opinion, can help when considering many of the non-climatic factors that influence the current status of a system. Depending on what other non-climatic stresses may be present, a description of the stresses may be qualitative or quantitative. Describe whether and to what degree the non-climatic stresses are impacted by climate change.

Indicator	**Describe current non-climatic stresses**	**Relationship to climate**

With the information from Worksheets 2.1 and 2.2, a comparison to future vulnerabilities can be completed later in the process.

STEP 3: DEVELOP AND APPLY FUTURE SCENARIOS

Step 3 incorporates projections of future climate and, where possible, projections of other non-climatic factors such as population growth and development. All projections vary spatially and temporally, ranging from large scale global climate scenarios showing long-term changes to average temperature, precipitation and other variables, to impact assessments that integrate climate factors in regional or more localized ecological response models.

Climate Models and Scenarios

Climate models project the effect of higher concentrations of greenhouse gases based on increasing amounts of heat trapped in the atmosphere. Increased heat affects virtually all aspects of weather, including precipitation, wind, and humidity (Colombo et al., 2007). There are many ways to explore Ontario's future climate with global models that project change to a variety of climatic variables. For example, since climate change varies with the time of year and location, practitioners can use seasonal climatic variables (e.g., summer and winter) for different time periods (e.g., 2011-2040) and different spatial frameworks (Figure 3). Each climate model is unique, is based on different assumptions, and produces somewhat different projections of future climate when provided the same data. In total, 24 international centres provided Global Climate Model (GCM) data for the last IPCC assessment in 2007.

Accessing Climate Models

Models are readily available online at:

Canadian Forest Service at the Great Lakes Forest Centre website, Sault Ste Marie, Ontario: http://cfs.nrcan.gc.ca/subsite/glfc-climate; and

Canadian Climate Change Scenarios Network website maintained by Environment Canada, Toronto, Ontario: http://www.cccsn.ca.

Future levels of greenhouse gas in the atmosphere can be modelled with scenarios that describe different possible ways the world may develop in response to human activities. Forty scenarios have been approved by the IPCC for use in climate change impact and vulnerability assessments. Each scenario has a unique set of assumptions about future social and economic conditions. For example, the A2 scenario (one of the more commonly used scenarios) anticipates higher greenhouse gas levels by 2100, reaching 1,320 parts per million by volume (ppmv) in CO_2 equivalents[2] compared to 915 ppmv for the B2 scenario (Nakićenović et al., 2000). In the A2 world, the human population reaches 15 billion by 2100, and reliance on fossil fuels is higher than in the B2 world, which projects a world population of 10.4 billion people by 2100. In addition, environmental protection, resulting in lower greenhouse emissions, is more important in the B2 scenario than in the A2 scenario (Nakićenović et al., 2000).

It is important to note that current global anthropogenic greenhouse gas production exceeds levels used in the business-as-usual A2 scenario (IEA, 2011), and A2 is now considered to be somewhat conservative.

Scenarios are possible outcomes, not predictions, since the amount of greenhouse gas in the future depends on variable factors related to global population, human behaviour, technological development, and the carbon sink/source behaviour of ecosystems. Even if we could accurately predict the future amounts of greenhouse gases in the atmosphere, different climate models produce varying projections.

Alvar Grasslands [Wasyl Bakowsky, MNR]

[2] A *CO_2 equivalent* expresses the energy-trapping properties of any greenhouse gas and the length of time it remains in the atmosphere in terms of the equivalent amount of CO_2 that would be required to produce the same effect.

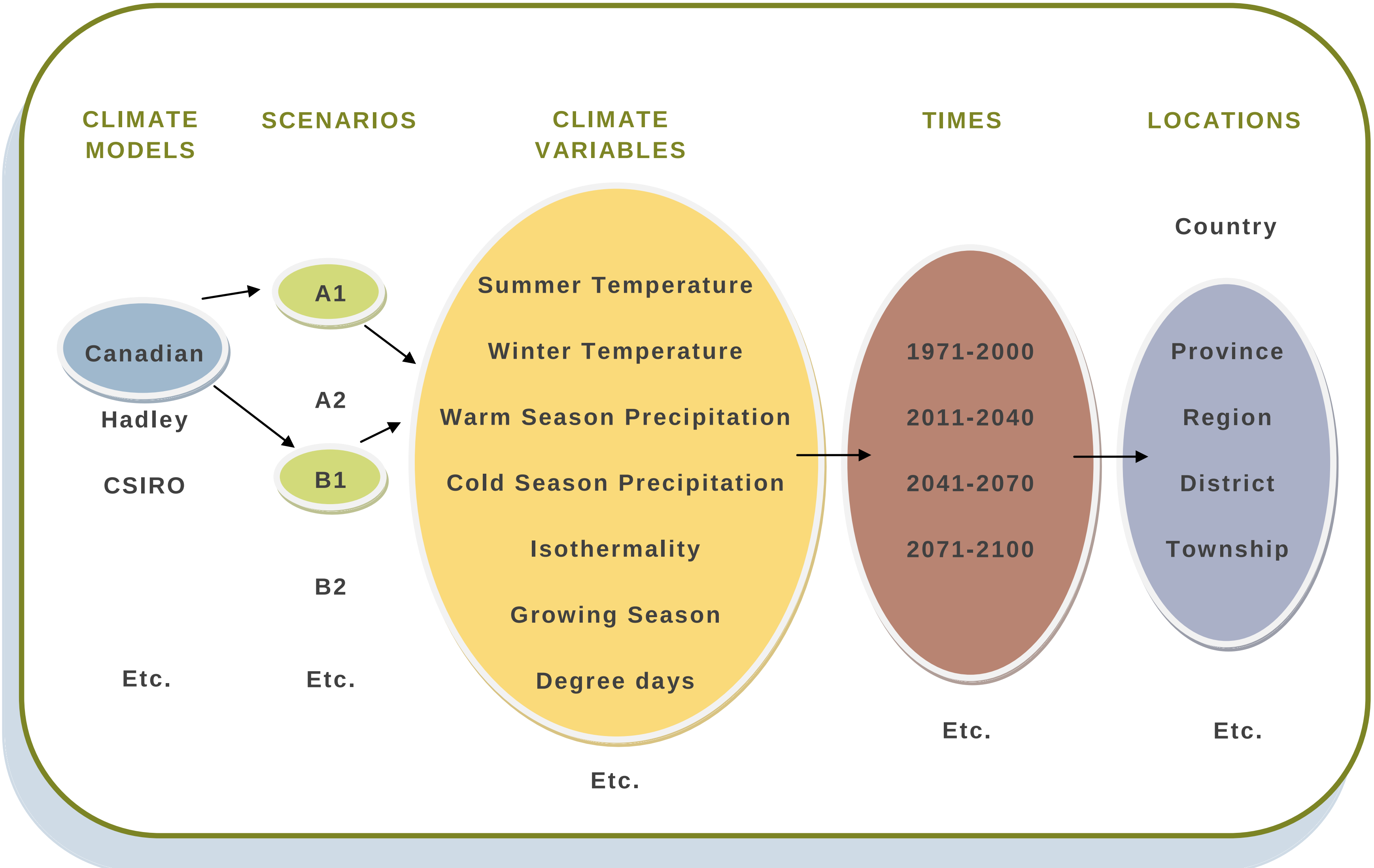


Figure 3. Examples of climate presentation options available to practitioners (Source: Colombo et al., 2007).

Accordingly, climate scientists are recommending the use of an ensemble of models to capture the range of potential climate change. Numerous studies show that the best approach when using models is to use an ensemble because, although each GCM represents the best effort of each modelling team, there are biases; the use of an ensemble (mean/median) of models tends to converge towards a best estimate by reduction of strong biases in single models. In addition, ensemble results can provide some indication of where the different models agree and disagree (Comer, 2009).

The IPCC has recommended that analyses should use at least 30-year averaging periods for GCM output data. Typically, model output is calculated according to a number of fixed time horizons (e.g., 2011-2040, 2041-2070, and 2071-2100).

The IPCC's fifth assessment report — due to be published in 2014 — will introduce a new approach. The current practice of starting with qualitative storylines of human behaviour will be replaced with a new generation of scenarios that will start out with greenhouse gas emissions trajectories known in IPCC terminology as *representative concentration pathways* (RCPs). The report is expected to focus on four emissions trajectories that produce different levels of heating at the end of the century — 8.5, 6, 4.5, and 2.6 watts per square metre ($W\ m^{-2}$). IPCC chose four trajectories to avoid the common misconception that the middle scenario is the most likely (Inman, 2011). Given the trends in human behaviour, the range covered by the representative concentration pathways is wider than that presented by earlier scenarios, reflecting a general shift in outlook to more extreme future emissions trajectories than were expected a decade ago.

Worksheet 3.1: Determining Climate Model Needs

Projections may already have been developed and applied to Ontario and for the selected study area. The assessment team should select projections and associated climatic variables that have the most relevance to the environmental themes and indicators being studied. To aggregate the results of multiple vulnerability assessments and determine adaptation options, project teams may seek to ensure that, wherever possible, experts use the same models (e.g., the Canadian Global Climate Model and an ensemble of other models), scenarios, and time periods (e.g., 2011-2040, 2041-2070, and 2071-2100) for modelling and reporting on vulnerabilities. However, it is also important to recognize that some thematic analyses may require use of projections not used in other themes.

To assist in determining what climate model inputs are required for the analyses, consider the following questions:

Climate model considerations (sample)	
What climate models and scenarios are available?	
What climatic variables do assessment team experts require (e.g., minimum and maximum monthly temperatures, annual mean temperature, annual precipitation, growing season length in days, and isothermality)?	
In what format do assessment team experts require climate projection data and information? (e.g., maps, and tabular data)?	
What projection scale(s) are preferred?	
How should the data be presented (e.g., percentage change, and incremental change)?	

Downscaling Global Climate Models and Use of Regional Climate Models

A number of methodologies also exist for downscaling global climate model (GCM) outputs for regional and local level analyses (refer to the Canadian Climate Change Scenarios Network website for more details).

An alternative to downscaling using statistical techniques is the use of a Regional Climate Model (RCM) such as the Canadian Regional Climate Model, which is available at a resolution of approximately 50 x 50 km. These numerical models are similar to GCMs, but are of higher resolution and may contain a better representation of, for example, the underlying topography within the model. In some cases, there can also be better representation of some weather extremes.

Despite the improvements in the spatial detail provided by the RCM scenarios, however, there are still limitations to their use (Comer, 2009). The use of regional models in generating climate scenarios can be computationally demanding if the modelled area is large, since the required spatial resolution is very high and the RCM must run for long time periods (i.e., greater than 20 years) and is dependent on the number of emission scenarios. Overall, global model results – particularly when based on an ensemble of models – are generally recognized as the best available method for projecting future climate conditions.

Impact Assessment Methodologies and Tools

Assessing the vulnerability of species and ecosystems to climate change can involve a range of methodologies, from qualitative assessments based on expert knowledge, to highly detailed quantitative analyses using ecological models that integrate climate models. The choice of approach may depend on many issues, including the availability and quality of information, the level of expertise, time and budget constraints, and other factors.

While a growing number of models are available for Ontario and other jurisdictions to project the impacts of climate change on ecosystems, the ability to conduct more detailed analyses such as modelling the dynamic ecological responses among diverse species within and among ecosystems is still relatively limited (see, for example, Glick et al., 2011). If possible, integrating local knowledge and science-based methods is recommended to provide a more comprehensive and effective basis for analysis (Williamson et al., 2007).

Shorebirds in Flight [Kim Bennet, MNR]

Quantitative analyses involve the formal assessment of climate, impacts, and outcomes within a modelling framework. Ecological response models provide a way to assess the sensitivity and potential adaptability or resilience of species, habitats, and ecosystems to climate change (Glick et al., 2011). Models should be suited to the local geographic and biophysical characteristics of habitats and ecosystems. Different types of response models can be used as part of a vulnerability assessment (see Appendix 1). The academic literature of individual disciplines also discusses how to carry out assessments, and relevant information can also be found in several reports in the MNR Climate Change Report Series. Rapid assessment tools also exist for some areas that can be used in conjunction with other analyses (for example, vulnerability ratings for Canadian tree species [Johnston et al., 2009]). It is important to note that models do have limitations and may not account for other factors that can affect vulnerability to climate change such as changes in interactions between species, including competitive interactions and disease, nonlinear, complex responses, and interactions between climate change and other important stressors such as land-use change.

Qualitative analyses can be completed using a number of methods, such as ranking information in order of importance, identifying critical control points within relationships, and quantifying interactions through sensitivity analyses (e.g., through workshops, focus groups and questionnaires) (UNDP, 2005). Engaging local communities through surveys using structured questionnaires can also provide information about observed changes and vulnerabilities. In many cases, scientific knowledge and expertise can be accessed by consulting with scientists and practitioners working for government agencies, industry, academic institutions and organizations.

An example of a qualitative analysis was conducted as part of the Kamloops Future Forest Strategy in British Colombia. The analysis used GCMs to project changes and impacts on 12 biogeoclimatic subzones in the Kamloops Timber Supply Area. Ecological sensitivities were discussed and assessed qualitatively in expert workshops. Input and advice were provided by local ecologists, resource specialists, practitioners, and academics. The study team synthesized this information into “ecological narratives” to generate plausible stories of how ecological conditions within these subzones may change over time with a warming climate, and the ecological sensitivities that could emerge (Zielke et al., 2009).

Assessing Non-climatic Factors

In addition to climatic factors, project teams are encouraged to assess non-climatic factors wherever possible as part of future vulnerability. In some cases, non-climatic factors such as habitat fragmentation may have greater impact on species and ecosystems than climatic factors. From a social perspective, teams can, for example, consider using local/regional population growth projections from the Ontario Ministry of Finance, the Ontario Ministry of Municipal Affairs and Housing (where available), or local planning authorities. Other factors can include information on economic shifts and anticipated land-use changes. For a review of the benefits and challenges of integrating non-climatic factors and methodologies for looking at regional economic impacts and landscape values, refer to Williamson et al. (2007).

STEP 4: ESTIMATE FUTURE VULNERABILITY AND RISKS

Step 4 builds on earlier steps during which current vulnerability was assessed and climate scenarios were applied. It combines the results of those analyses to develop estimates of future vulnerability.

Worksheet 4.1: Describing Future Exposure, Sensitivity, and Adaptive Capacity

Fill out the worksheet with the results of the analyses in Step 3 for each indicator. Depending on the analytical and methodological approach technical experts take in applying future climate scenarios, results describing potential future vulnerabilities will come in a variety of forms. With the results, work with technical experts to rank each indicator's anticipated exposure, sensitivity, and adaptive capacity to climate change as High (H), Medium (M), or Low (L). Use ranking descriptions included in Step 2. Descriptions can include specific impacts that may occur. Estimates of future adaptive capacity are not meant to include adaptive assistance that will be developed from this process.

Indicator	Describe future exposure and sensitivity to climate	Rank (H-M-L)	Describe future adaptive capacity	Rank (H-M-L)

Worksheet 4.2: Describing Other Future Existing Stresses

Depending on what non-climatic existing stresses may be projected, a description of the stresses on each indicator may be qualitative or quantitative. Assessments can consider human population growth patterns in the project area, economic shifts, and historic and recent land-use changes. Wherever possible, rank the degree of sensitivity to the stress as High (H), Medium (M), or Low (L).

Indicator	Describe non-climatic existing stresses	Rank (H-M-L)

Worksheet 4.3: Estimating Overall Future Vulnerability

To assign an overall vulnerability ranking, project teams rank each indicator's future vulnerability High (H), Medium (M), or Low (L), based on the collated rankings from Worksheets 4.1 and 4.2.

- ❑ ***High –*** Impacts are expected to cause widespread and severe-to-catastrophic damage to ecosystems, and ecosystems will be limited in their ability to buffer these impacts. Impacts will disrupt important ecosystem functions, alter species distribution and abundance, and lessen their ability to provide key environmental benefits.
- ❑ ***Moderate –*** Impacts are expected cause substantial damage to ecosystems, which may be isolated or widespread. Ecosystems will be limited in their ability to buffer these impacts, but some reversal of effects may be possible with major effort.
- ❑ ***Low –*** Impacts are expected to cause minor changes to ecosystems, but these changes can be reversed.

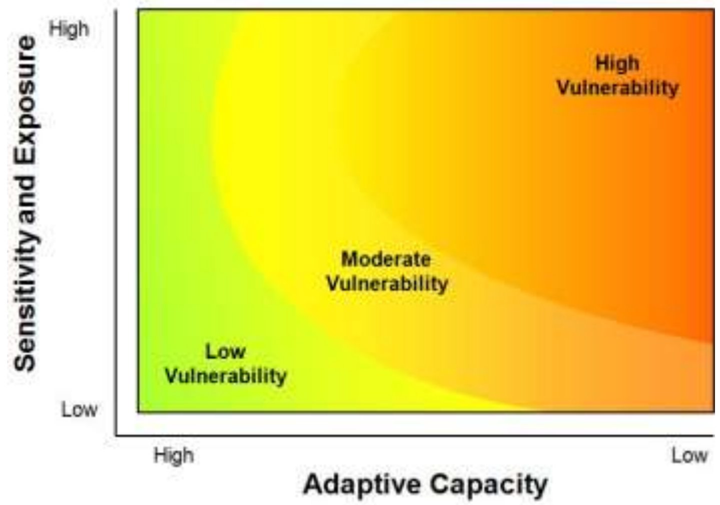


Figure 4. Alberta's Climate Change Adaptation Framework Manual illustrates one approach to depicting vulnerabilities. (Source: Alberta Sustainable Resource Development, 2010.)

Because vulnerability is a function of exposure, sensitivity, and adaptive capacity, it is helpful to consider the interactions between these three components. Project teams may consider describing vulnerabilities graphically (see Figure 4 for example) or using other approaches.

Understanding and Addressing Uncertainty

At their core, vulnerability assessments involve the synthesis of scientific information, experiments, and modelling efforts. In many cases, there will be healthy and lively discussions about analysts' confidence in the results of the assessments. As such, the team should consider approaches for acknowledging and communicating uncertainty.

The IPCC (2007b) defines uncertainty as an "expression of the degree to which a value…is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from quantifiable errors in data to ambiguously defined concepts or terminology, or uncertain projections of human behaviour."

Uncertainty can thus be described by quantitative measures (e.g., a range of values calculated by various models) and/or by qualitative statements (e.g., reflecting the judgement of a team of experts). Regardless of the method used, it is essential that practitioners consistently communicate uncertainty across vulnerability assessments completed for the study.

Depending on the level of detail in the assessment and the capacity of the team, qualitative descriptions of uncertainty are likely the most applicable here. Qualitative descriptions communicate the relative amount and quality of the evidence (i.e., "lacking," "not reported," "not available," "good quality," "anecdotal," and "expert opinion") and the degree of agreement (Table 1) with other results in the literature (i.e., "high agreement – much evidence," and "high agreement – medium evidence") (IPCC, 2007b). Avoid vague and/or overly broad statements that are difficult to support or refute.

Level of Agreement ↑	High Agreement, limited evidence	High agreement, medium evidence	High agreement, much evidence
	Medium agreement, limited evidence	Medium agreement, medium evidence	Medium agreement, much evidence
	Low agreement, limited evidence	Low agreement, medium evidence	Low agreement, much evidence
Amount of evidence (number and quality of independent sources) →			

Table 1. Qualitative terminology for uncertainty (Source: adapted from IPCC, 2007b).

Several quantitative techniques are available to describe and communicate uncertainty. Wherever possible, experts should seek to describe results in terms of likelihood of occurrence and degree of confidence in being correct. The IPCC's report (2007b) provides a comprehensive discussion of language for describing uncertainty and levels of confidence in climate change assessments, including quantitative terminology.

Some general strategies for describing uncertainty include the following:

- ❑ Identify the most important factors (e.g., processes, variables, data, interdependencies);
- ❑ Document ranges and distributions in the literature;
- ❑ Describe the state of the scientific information on which the conclusions and/or estimates are based; and
- ❑ Prepare a “traceable account” of how the estimates were constructed (Moss and Schneider, 2000).

An adaptive planning process, including vulnerability assessment, is an iterative process that allows the inclusion of new science and data that will reduce uncertainty over time. Even though uncertainty exists, it should not limit the exploration of vulnerabilities and implementation of no-regrets and priority adaptation options.

Assessing Risk

Risk is the severity of the consequences of climate change impacts and the likelihood that impacts will occur. Risk assessment is based on people’s perceptions of adverse effect and involves exploring what we should do about the vulnerabilities identified for projected future climates. It can help to inform how we deploy limited resources to deal with climate compared to other priorities. Through ranking methods, the project team builds an understanding of where to focus adaptation action.

In many cases, risk assessment is a qualitative exercise involving the project team, expert panels, and input from stakeholders, partners, and other specialists. A workshop or other collaborative format may be a suitable way to conduct the activities in the risk assessment or validate results of a risk assessment. Other tools, including quantitative assessments such as cost-benefit analysis, are described in Appendix 2. Worksheet 4.4 employs a qualitative approach to risk assessment.

Worksheet 4.4: Assessing Risk

For each indicator, consider the consequences of its vulnerability in a matrix like the example below. Other criteria can be developed for the evaluation as needed. A consequence is an outcome that leads to the general decline of a social-ecological system or species. There will be consequences in several areas, such as strategic, financial, operational, and environmental. Project teams can determine which potential consequences to rate and may identify other consequences (e.g., cultural consequences) not listed in the sample matrix. To assess risk, first determine the consequence rating, based on the numerical value in the first column. Then, determine the likelihood of this particular climate change impact occurring.

CONSEQUENCES (samples)						
Rating	**Strategic**	**Financial**	**Operational**	**Environmental**	**Public Perception**	**Safety**
Insignificant (1)	No impact.	No impact on financial resources.	No impact on execution of plans.	No impact on environment, ecosystem services, or resources.	Limited impact on public image. No media coverage.	No impact on human health or safety.
Minor (2)	Minor change in strategic direction.	Minor impact on financial resources.	Minor impact on execution of plans.	Minor impact on environment, ecosystem services, or resources. Easily rectified.	Some impact on public perception. Local media coverage for short period.	Minor injury or illness.
Reasonable (3)	Multiple changes in strategic direction.	Moderate impact on financial resources.	Moderate impact on execution of plans.	Moderate environmental impact with limited long-term effects on ecosystem services or resources .	Moderate impact on public image. Regional or national media coverage for a limited period.	Lost time, injury or illness.
Major (4)	Substantive revision to strategy required.	Substantive impact on financial resources affecting some programs.	Substantive impact on execution of plans.	Impact on environment, ecosystems services, or resources requires > 25 years to rehabilitate.	Substantive impact on public image. Regional or national media coverage for long period of time.	Permanent damage caused by injury or illness.
Severe (5)	Complete change in strategic direction and organizational objectives.	Significant impact on financial resources affecting multiple programs.	Critical implications for execution of plans.	Catastrophic impact on environment, ecosystem services, or resources requires > 100 years to restore, or is irreversible.	Severe impact to public image. Extended national or international coverage in media.	Fatality or other catastrophic impact to human health and safety.
LIKELIHOOD						
Likelihood Rating	Rare (1)	Unlikely (2)	Possible (3)	Likely (4)	Almost Certain (5)	
Note: Time horizon X should match time horizon in assessment	Very low probability that this risk will occur in the next X years.	Less than 50% chance that this risk will occur in the next X years.	50/50 chance that this risk will occur in the next X years.	More likely than not that this risk will occur in the next X years.	Very high probability that this risk will occur in the next X years.	

Table 2: Sample risk assessment matrix

(Source: adapted from Alberta Sustainable Resource Development, 2010)

Indicator	Consequence	Consequence rating	Likelihood of occurrence	Likelihood rating

Worksheet 4.5: Describing Risk

With information on the severity of consequences and likelihood of impacts, assign a qualitative classification of risk for each indicator as High (H), Medium (M), or Low (L).

Teams should use judgement when applying numerical risk ratings. Some risks that are classified as "low" may be safe to ignore or can be dealt with at a later time. However, it is important to remember:

- ❑ Several low risks can cumulatively pose significant challenges to the organization;
- ❑ There may be non-linear ecosystem responses as a result of impacts rated as low risk; and
- ❑ Over time risks may become more severe. Therefore, even low risk climate change impacts may require monitoring.

Project teams could consider describing risks graphically or using other approaches.

Communicating Findings

Throughout the process, it is important to communicate findings to key organizations, staff, and decision-makers so that they are aware of the potential climate impact within their spheres of influence and responsibility. Action will be required by government agencies, industry, communities and organizations. Engaging these groups early in the process will help build support for adaptation planning and implementation.

At this stage, the team can develop impact statements of vulnerability and risk to communicate findings to key organizations. Teams can elect to host a workshop to present findings of the vulnerability and risk assessment. Alternatively, teams may decide to briefing notes to communicate findings. Both options can also be used to communicate with stakeholders and at other stages in the process to ensure transparency.

Communicating and discussing findings [MNR]

STEP 5: DEVELOP ADAPTATION OPTIONS

Step 5 identifies potential adaptation options to help practitioners reduce or eliminate vulnerabilities and risks. Measures can seek to reduce sensitivity and exposure or to enhance adaptive capacity. As part of the process, adaptation options can be assessed for desirability, feasibility, practicality, and other consideration that meet the unique needs of their organization. Ultimately, practitioners select and prioritize a suite of options that will be implemented.

Identifying Adaptation Options

Climate change adaptation options come in all forms, shapes, and sizes, and are specific to the study area. Likewise, there is no single 'correct' procedure or process for generating adaptive responses to the identified climate vulnerabilities and risks. Each method of developing adaptive responses has strengths and, consequently, each method's utility depends on resources, the specific adaptation process, and the stakeholders involved.

Generally speaking, options can include broad strategies, regional approaches, and site-specific management actions and tactics that seek to (1) reduce threats; (2) enhance resilience of species and systems; (3) engage people; and (4) improve knowledge. Because of the uncertainties associated with some adaptation options, it is also important to build flexibility and 'learning-by-doing' into the measures.

Electrofishing [Nick Jones, MNR]

Examples of Adaptation Approaches and Examples of Specific Measures in Natural Systems

Reduce Threats	Climate change will exacerbate many existing vulnerabilities in natural ecosystems and species and will contribute significantly to cumulative effects. Existing threats may be reduced through such measures as invasive species research, prevention, and education.
Enhance Resilience	An ecosystem's resilience in changing environmental conditions is determined by its biological and ecological resources, including diversity of species, genetic variability within species, and condition and connectivity with other ecosystems. Measures to reduce habitat fragmentation enhance species' access to critical habitats (e.g., access to coldwater refuges, and spawning areas) and can facilitate species' ability to shift ranges as climatic conditions change. Measures to maintain genetic and species diversity in ecosystems can have a positive effect on adaptive capacity.
Improve Knowledge	Communities and agencies that take proactive steps to prepare for climate change will be more resilient to change. Engage people and focus on identifying the most important impacts and investing in adaptive capacity.
Engage People	Acquiring new knowledge and experience over time is an important component of adaptive management. Monitor impacts of climate change and effectiveness of adaptation measures; seek out new data, and scientific and local knowledge and perspectives.

Adaptation options falling into the *no-regrets* and *low-regrets* categories may be the most implementable of all options.

No-regrets actions provide benefits regardless of the rate and magnitude of climate change and can be further justified when there is no cost or risk of negative impact. For example, increasing tree species diversity within a forest range could improve the resilience of a forest to climate change by reducing the threat of an insect outbreak targeting a particular species. Similarly, increasing the connectivity between habitats can be considered a no-regrets adaptation option with multiple benefits, including greater ability for populations to shift and protection of essential ecosystem services.

Low-regrets actions are those made because of climate change, but at a minimal cost or risk of negative impact. In other words, there is low regret if the investment or change in management practice proves redundant or impractical under future climate conditions.

Some adaptation actions have ***mitigation co-benefits***. These measures simultaneously reduce vulnerability to climate change and decrease greenhouse gas emissions or sequester carbon from the atmosphere, and therefore may be desirable options.

Tools for Identifying Adaptation Options

Several approaches are available to help identify adaptation options and support strategic thinking. Idea-generation tools such as a policy Delphi tool can solicit suggestions regarding adaptation options from experts, partners, and stakeholders. Project teams may also prepare a menu of possible adaptation options in order to solicit feedback relating to identified vulnerabilities.

Tools and resources to identify and evaluate adaptation options are described in Appendix 2. Many of these techniques can be used in various combinations.

Project teams should carefully select tools to identify adaptation options that best match the needs and expectations of the stakeholders and organizations responsible for implementation. Every situation and strategic planning process is unique.

Worksheet 5.1: Developing Adaptation Options

For the vulnerabilities and risks identified in the assessment, list possible adaptation options. The four general categories – reduce threats, enhance resilience, engage people, and increase knowledge – are intended to guide the identification of adaptation options for each theme. To stimulate ideas, it may also be useful to consider measures relating to legislation and policy, strategic planning processes, and management and operations. An example of a critical risk and potential adaptation options is given below.

Once adaptation options have been identified, the team should collate all of the options and eliminate redundancies and overlap in ideas before proceeding to evaluate adaptation options.

High vulnerabilities/ risks	Adaptation approach	Possible adaptation measures and tactics	Timeframe
Introduction of new forest pests/pathogens *(example)*	*Reduce threats*	1. *Adjust rotation age lengths to alter age-class distribution*	*Long-term*
		2.	
		3.	
	Enhance resilience	*1. Maintain or improve tree species diversity and native species that are under-represented and/or better adapted to future conditions*	*Ongoing*
		2.	
		3.	
	Engage people	*1. Develop an education and outreach program for public to assist in detection*	*Short-term/ ongoing*
		2.	
		3.	
	Increase knowledge	*1. Share information and experience with other local, provincial, and federal agencies/sectors*	*Short-term/ ongoing*
		2.	
		3.	

Evaluating Adaptation Options

Once a list of potential adaptation options is developed, each must be assessed. A range of assessment perspectives can be applied:

- Implementation costs;
- Technical and institutional feasibility;
- Likely benefits
- Social acceptability;
- Ecological suitability; and
- Degree of risk in acting on adaptation options compared to the consequences of not acting.

Workshop, [Lyn Thompson, MNR]

Several methods can be used to prioritize adaptation options. Worksheet 5.2 (below) provides criteria for evaluating adaptation options. It is important to recognize and attempt to mitigate potential shortcomings (e.g., low participation, skewed expertise) of any evaluation. At this stage, the project team may want to call on select stakeholders who may be responsible for implementation though not previously engaged in the process. Appendix 2 lists several evaluation and prioritization methodologies, such as cost-benefit analysis, expert judgement, multi-criteria analysis, and cost-effectiveness analysis.

Worksheet 5.2: Evaluating Adaptation Options

To evaluate adaptation options, participants assess each option against the criteria in a matrix like the example below. Other criteria can be developed for the evaluation as needed. Participants are asked to exercise expert judgement and/or use their professional experiences to inform their evaluations. The project team then collates the input to determine which adaptation options should be considered first-order priorities.

Criteria (sample)	Feasibility Ranking (High [1] to Low [4]) 1	2	3	4
Priority	**First-order priority:** A most relevant point; has direct bearing on major issues; must be resolved, dealt with or treated.	**Second-order priority:** Relevant to the issue; has significant impact but not until other items are treated; does not have to be fully resolved.	**Third-order priority:** Insignificantly relevant; has little importance; not a determining factor to major issue.	**No priority; no relevance:** No measurable effect; should be dropped as an item to consider.
Feasibility: Affordability	**Definitely affordable:** Can be implemented within current fiscal realities . **AND/OR** High cost-sharing opportunities.	**Some indication adaptation is affordable:** Possibility that adaptation can be implemented within current fiscal realities. **AND/OR** Some cost-sharing opportunities.	**Some indication adaptation is unaffordable:** Additional financial resources or reallocation required to implement. **AND/OR** Low cost-sharing opportunities.	**Definitely unaffordable:** Adaptation cannot be implemented within current fiscal realities. **AND/OR** No cost-sharing opportunities.
Feasibility: Legal, political, institutional, and social barriers	**No identifiable internal or external:** Can definitely be implemented.	**Some identifiable internal or external barriers:** Barriers most likely can be overcome.	**Some identifiable internal or external barriers:** Barriers too significant to overcome.	**Obvious and significant internal or external barriers:** Cannot be implemented.
Degree of ecological suitability (risk)	**No risk:** Rigorous science and information show no ecological risk in implementing. **AND/OR** Vulnerability assessment is highly certain.	**Low risk:** Some information is available showing potential ecological effects of option. **AND/OR** Vulnerability assessment is fairly certain.	**Moderate risk:** No information on the ecological effect of this option for local conditions. **AND/OR** Vulnerability assessment is moderately uncertain.	**High risk:** Little to no information at all on the ecological effect of option. **AND/OR** Vulnerability assessment is highly uncertain.

STEP 6: IMPLEMENT AND MAINSTREAM ADAPTATION

In Step 6, the adaptation measures that have been evaluated and selected are considered for implementation. While this is a final step in the process, the elements of this step form a critical part of a broader adaptive management process that has no end point. Over time, as measures are implemented and adaptation is mainstreamed into policies and programs, monitoring, acquisition of new knowledge, and periodic re-assessments will be required.

Implementing Adaptation Measures

Once priority adaptation measures have been selected (refer to Step 5), the project team should identify who is responsible for implementation and who will fund those measures that have fiscal implications. This step also identifies opportunities to integrate adaptive responses into existing programs. As part of this process, the team must also establish the timing of the implementation and develop a plan for how the actions will be measured, monitored, and evaluated. Sometimes, it is only through the team's effort to implement adaptive measures that key limitations in adaptive capacity become evident.

In some cases, the implementation of adaptation measures may lend itself to development of an adaptation plan, with goals, objectives, targets, and actions. In other cases, adaptation measures can be implemented and mainstreamed into existing plan and programs.

Monitoring, [Marilyn Twiss, MNR]

Monitoring

Tracking the effectiveness of the adaptation action and the progress of its implementation is important in the adaptation process. Questions about outputs, outcomes, and impacts should be considered, including the following:

- Has the adaptation effort generated outputs (e.g., new decision-support tools, policy changes, guidelines on “how to”, or reports and papers detailing process)?
- What outcomes have been achieved (e.g., stakeholders formally participating in decision-making, and planning processes that integrate climate change considerations)?
- What impacts have arisen (e.g., a flood early warning system that saved X lives)?
- Considering indicators used to assess vulnerability, has there been ecological improvement in any of areas of study?
- Has vulnerability been reduced or eliminated?

Assess whether the appropriate information has been collected about the success or failure of the adaptation actions being implemented. Tracking the progress that has been made towards adaptation may reveal, for example, that a given adaptation action is ineffective in improving the adaptive capacity of the system. Conversely, an action may be very successful and, with additional funding, could be replicated in other locations by other agencies. The information collected as part of the project’s monitoring efforts can also be useful for future reviews, updates to public reports, budget requests, and policy decisions.

For many reasons, it is important to integrate existing monitoring programs with climate change monitoring. Existing programs can provide information to help to monitor climate change impacts on natural resources. These programs should be recognized and supported. Conversely, there may be gaps in monitoring that that should be identified. Wherever possible, enhancing efficiencies to monitor climate change and a range of other objectives (e.g., biodiversity and forest health) on the landscape will maximize the program’s effectiveness. Seek to align monitoring efforts for indicators that have been identified as important climate change impacts indicators.

Another element of ongoing monitoring involves re-evaluating vulnerabilities that were assessed in the initial assessment and modifying or updating adaptation actions as necessary.

New Information and Research

Climate change adaptation is an ongoing process. Assessing new information and research as it emerges can help the team re-evaluate both the results of initial vulnerability assessments and the adaptation options that were identified as priorities. Project teams can consider planning a review every few years to explore some of the following questions:

- What societal, economic, or political factors have changed since the process began? Do any changes affect the successful implementation of adaptation actions (e.g., funding, public perception, or political support)?
- Have new scientific findings improved or changed the understanding of vulnerabilities to climate change? Update the relevance and accuracy of information to inform future decisions.
- Based on changes in scientific information, have vulnerabilities or high-risk areas changed? A re-evaluation of scientific information may lead your community to change the focus of priority actions.

Depending on the information derived from monitoring and research, some modifications to adaptation actions may be justified.

Agawa Canyon, (Gilbert Racine, MNR)

Communicating Accomplishments

As noted previously, it is important to communicate with organizations, staff, stakeholders, and decision-makers throughout the adaptive management process.

The implementation of adaptation actions is a success that should be communicated to those involved in the project and others that may potentially help effect change within their spheres of influence and responsibility. Communication at this stage is also an opportunity to build momentum for ongoing implementation. Some tools that teams can consider include annual progress reports, press releases, briefing notes, website updates, workshops, 'lunch-and-learns,' and celebration events.

4.0 CASE STUDY: THE LAKE SIMCOE VULNERABILITY ASSESSMENT AND ADAPTATION STRATEGY

Background

The Government of Ontario appointed the Expert Panel on Climate Change Adaptation in 2007 with a mandate to evaluate current government programs and recommend a path forward. The panel released its report in 2009 with 59 recommendations including recommendation #34, which states that the *"climate change adaptation strategy called for in the Lake Simcoe Protection Plan should be considered as a pilot project with potential application to strategies for increasing the climate resilience of other watersheds"* (Expert Panel on Climate Change Adaptation, 2009). The Lake Simcoe Protection Plan also contains a dedicated climate change policy that commits the Ministry of the Environment, in collaboration with Ministry of Natural Resources, Ministry of Agriculture, Food, and Rural Affairs, First Nations and Métis communities, the Lake Simcoe Region Conservation Authority, municipalities, and interested academic institutions to develop a climate change adaptation strategy for the Lake Simcoe Watershed.

Lake Simcoe, [MNR]

With this direction, MNR and MOE co-led an ecosystem-focussed climate change vulnerability assessment for the Lake Simcoe Watershed. Additional areas of analysis included infrastructure, agriculture and tourism. *Adapting to Climate Change: Recommendations to Inform Development of a Climate Change Adaptation Strategy for the Lake Simcoe Watershed* (Douglas et al., 2011) describes the process used to gather and summarize adaptation recommendations to support development of the Lake Simcoe watershed climate change adaptation strategy. The process involved engaging experts, assessing current and future vulnerabilities of selected natural and built systems' assets, and generating adaptation recommendations. This work is ongoing, and has provided the foundation for learning and future efforts on ecosystem-focussed vulnerability assessments.

Lake Simcoe Climate Change Vulnerability Assessments

The project team engaged scientists and practitioners to complete preliminary vulnerability assessments for 11 themes and established a forum of climate change experts to generate adaptation options for addressing the known and potential vulnerabilities of natural assets and infrastructure to climate change described by the scientists. The environmental themes included:

- ❑ Hydrology;
- ❑ Aquatic habitat;
- ❑ Wildlife;
- ❑ Insects;
- ❑ Species-at-risk;
- ❑ Invasive species;
- ❑ Vegetation cover;
- ❑ Natural heritage areas;
- ❑ Agriculture;
- ❑ Tourism and recreation; and
- ❑ Infrastructure.

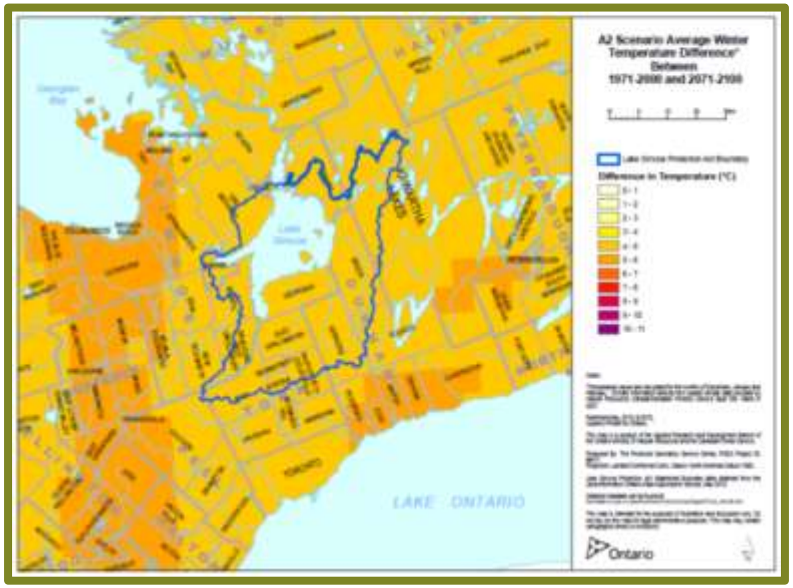


Figure 5. Projections of future climate for the Lake Simcoe Protection Act study area (Source: Douglas et al., 2011).

Scientists completed assessments by examining indicators to assess vulnerabilities based on future climate projections (see Figure 5). Indicators were chosen that were most appropriate for the theme being examined, such as impacts of warmer temperatures on riparian vegetation, coldwater fish habitat, wetland water levels, tourism activities (e.g., skiing, snowmobiling, and ice fishing), and the composition of tree species in the forest. Each team of scientists prepared a background discussion paper describing methods and results. In addition, they provided a list of three primary consequences of climate change for their theme or sector; these were communicated to the forum of climate change experts at a workshop (refer to Step 5, above).

Developing Adaptation Options

Many different types of decision-facilitation tools can be used to identify and evaluate adaptation options, including scenario planning, emerging issues analysis, multi-criteria analysis, and idea-generating strategies using expert judgement such as workshops, focus groups, and the policy Delphi. Each technique has strengths and weaknesses depending on the required outcome, the location, and the stakeholders involved in the process. For the purposes of the Lake Simcoe Climate Change Adaptation Strategy, the policy Delphi tool was used to generate a list of adaptation options. The project team convened a meeting of experts in November 2010 to review the results of the vulnerability assessments, facilitate an initial round of discussion about adaptation options, and introduce the policy Delphi procedure.

Invasive species awareness in Lake Simcoe, [MNR]

The project team elected to use an electronic survey with two rounds of questions for the Delphi process. The first round provided survey participants with climate change vulnerability reports prepared by the scientists, including the list of three primary consequences of climate change. The survey presented 11 questions organized according to 7 general categories of action: legislation and policy, strategic planning, land-use and/or resource management planning, management and operations, monitoring, research, and knowledge dissemination. Recommendations generated by the workshop breakout groups and the first-round Delphi survey were used to develop a synthesized suite of adaptation options for each of the 11 themes. These ideas were then evaluated in the second-round survey for their perceived priority and feasibility (affordability and ease of implementation). The first priority options were identified, aggregated, and edited for presentation at a second workshop. In total, 92 recommendations were identified as first-order priorities and 48 recommendations were identified as first-/second-order priorities. Participants evaluated the 92 recommendations at the second workshop and selected 27 strategies for consideration in the development of the Lake Simcoe climate change adaptation plan. The report details the process and reveals the adaptation recommendations that informed the strategy; it can be found at:

http://www.climateontario.ca/doc/workshop/2011LakeSimcoe/Lake%20Simcoe%20Adaptation%20Options%20Final%20Report%20June%20%202011.pdf (Douglas et al., 2011).

Lessons Learned from the Lake Simcoe Vulnerability Assessment and Adaptation Strategy

A number of observations and recommendations about project design and implementation were collected by the project team:

- ***Use an ensemble of climate models and scenarios when possible:*** Access to a number of climate change projections and scenarios can significantly improve the robustness of analyses and strategic planning discussions. Finding ways to consider extreme weather events is also important.

- ***Engage stakeholders and experts early and substantively:*** The success of any project with outcomes that will impact the daily lives of people living and working in an area will, in large measure, depend on the participation of and uptake by stakeholders.

- ***Scope:*** Given the complexity of ecosystem composition, structure, and function, and the human position in it, it is important to complete as extensively as possible vulnerability assessments for the suite of forces and factors that shape the ecosystem and affect human health and well-being.

- ***Carefully select idea-generation tools to match needs and expectations:*** Every situation and strategic planning process is unique. A variety of idea-generation tools and techniques are available to support strategic thinking and option development, and many of these can be used in combination. For example, the Lake Simcoe process involved the use of workshops (including a global café approach), face-to-face meetings, email surveys, and a policy Delphi process.

- ***Provide incentives to participants:*** The policy Delphi is an idea-generating technique that often places substantial time and intellectual demands on participants. Incentives could improve survey response rates. In addition, experience with the use of incentives in other jurisdictions suggests that they will increase respondents' willingness to participate in future studies and follow-up activities, including workshops.

- ***Improve the capacity of the online survey engine:*** The online surveys were cost effective and efficient. However, the first-round survey, which used a web-based browser application, did not allow respondents to save their responses. Consequently, respondents were forced to complete their surveys in a single session. Given the time and intellectual demands placed on respondents, a word processor or Adobe® version of the software is recommended for online surveys.

- ***Engage communities on an ongoing basis:*** Given the site-specific and dynamic nature of climate change impacts, ongoing planning and management strategies developed at the local level are key.

The Lake Simcoe Climate Change Adaptation Strategy

The commitment contained in the Lake Simcoe Protection Plan led to the development of a climate change adaptation strategy for the Lake Simcoe watershed. The Ministry of the Environment continues its work to complete the Lake Simcoe Climate Change Adaptation Strategy, and it is hoped that a draft will be available by the spring of 2012. To follow the progress on the strategy, refer to the Ministry of Environment's website.

Shoreline naturalization in Lake Simcoe watershed, [MNR]

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6.0 GLOSSARY

Adaptation	Initiatives or actions to reduce the negative effects of climate change or take advantage of the positive effects. A process by which individuals, communities, and resource managers seek to moderate and cope with the consequences of climate change (UNDP, 2005).
Adaptation co-benefits	Measures that simultaneously reduce vulnerability to climate change and decrease greenhouse gas emissions.
Adaptive capacity	The ability or potential of a system to respond to climate variability and change.
Adaptive management	A systematic process for continually improving management policies and practices by learning from the outcomes of previously employed policies and practices. In active adaptive management, management is treated as a deliberate experiment for purposes of learning (Millennium Ecosystem Assessment, 2005: 599).
Climate change	Any change in climate over time whether due to natural variability or as a result of human activity.
Exposure	The nature and extent to which the system is exposed to significant climate variation.
Impact	The effects of existing and projected changes in climate in natural, built, and human systems.
Mainstreaming	The integration of climate change considerations into a range of policies, programs, and decision-making processes.
Mitigation	Actions to reduce the sources or enhance the sinks of greenhouse gases.
Resilience	The ability of a social or ecological system to maintain integrity when subject to disturbance (UNDP, 2005). For example, a resilient ecosystem can withstand shocks and rebuild itself when necessary.
Resistance	The capacity of the ecosystem to absorb disturbances and remain largely unchanged (Holling, 1973).

Risk	The severity of consequences of climate change impacts and the likelihood that impacts will occur.
Sensitivity	The degree to which a system is affected when exposed to a stress.
Social-ecological systems	Complex, integrated systems in which humans are part of nature (Berkes and Folke, 1998)
Vulnerability	The degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, the sensitivity and adaptive capacity of that system (IPCC, 2007c).

APPENDIX 1: ECOLOGICAL RESPONSE MODELS TO ASSESS VULNERABILITY

Model Type	Description	For more information
Conceptual models	• Qualitative descriptions and diagrams of key attributes and processes related to species, habitats, or ecosystems • Can illustrate important linkages to stressors and how changes in stressors affect important attributes (e.g., soil texture) and functions (e.g., nutrient uptake, water flux).	• For a review of conceptual model development, see Heemskerk, Wilson, and Pavao-Zuckerman (2003). • Various types of conceptual modelling tools and software can be found at http://www.fileheap.com/software/conceptual_data_model.html).
General characterization models	• Represent broad groups (e.g., amphibians, riparian species) or generalized traits to identify how groups of species might respond to climate and/or habitat change by applying the classes of vulnerability to species distribution maps. • Another characterization approach involves meta-analyses that collate information to estimate common responses of species (especially effective at validating responses over large areas) (e.g., CCFM Tree Vulnerability Ranking Index and NatureServe Climate Change Vulnerability Index).	• NatureServe Climate Change Vulnerability Index: (http://www.natureserve.org/prodServices/climatechange/ClimateChange.jsp).
Habitat and occupancy models	• Expressed as ranges in specific biophysical attributes (e.g., climate, soils, vegetation or land cover, and elevation) that a species will occupy (e.g., suitable habitat). • Uses GIS to determine the spatial distribution of suitable habitat for individual species. • Niche-based models are also used to estimate species distributions and habitat suitability: they generally involve more quantitative approaches with estimates of the probability of occurrence of a species.	• Software used to develop niche and occupancy models can be downloaded from the Internet: • Genetic Algorithm for Rule-set Production (GARP) (http://www.nhm.ku.edu/desktopgarp/); • Maximum Entropy Modeling (Maxent) (http://www.cs.princeton.edu/~schapire/maxent/); • Regression Trees and Random Forests (http://rattle.togaware.com/rattle-download.html); and • Bioclim (http://software.informer.com/getfree-bioclim-download-software/).

Vegetation / habitat response models	• Include statistical species distribution models, GAP models, landscape models, biogeochemical models, and dynamic global vegetation models.	• Robinson et al. (2008) provide an extensive review of vegetation climate models.
Physiological models	• Incorporate sensitive aspects of physiologies that influence foraging, nesting/reproduction, thermoregulation, and migration. • Relate physiological traits and processes to climate change variables; can be used as part of general characterization models or as part of habitat models. • Complex; most commonly built for specific species in specific locations or habitats because of data requirements.	• No known off-the-shelf software or tools that permit development of physiological climate response models.
Ecological models	• Evaluate how climate change variables affect fundamental ecological processes.	• Some models can be downloaded from the Internet, including RHESsys (http://fiesta.bren.ucsb.edu/~rhessys/), PnET (http://www.pnet.sr.unh.edu/), CENTURY model http://www.nrel.colostate.edu/projects/century5/).
Expert opinion models	• Constructed from the opinions of experts on a particular species, habitat, or ecosystem. • Used when existing data preclude or are insufficient to develop a quantitative model. A series of workshops and/or surveys are often used to gather data from experts that are then used in model development. • In some cases, results from expert input are combined with other data (e.g., from existing publications).	• Lemieux el al. (2011) used expert opinion to assess the state of climate change adaptation in Canada's protected areas sector

(Source: adapted from Glick et al., 2011)

Policy Delphi

In its broadest sense, a policy Delphi is an iterative, group-oriented, idea-generating strategy that seeks to identify the strongest possible opposing views on the potential resolutions of a policy issue. The approach permits a diverse group of experts, stakeholders, and partners to interact anonymously on a policy issue and provides a structured method for assembling ideas and recommendations (Donohoe and Needham, 2009). By design, participants are provided the freedom to present and challenge alternative viewpoints and to think reflectively and independently between iterations.

A policy Delphi overcomes many of the limitations associated with workshops and focus groups, including the propensities for:

- One or a few vocal individuals to dominate the discussion;
- People to remain silent, possibly due to shyness or fear of censure;
- The 'rut effect' (i.e., participants getting hung up on one thought and staying in that rut for the duration of the discussion);
- The power of persuasion and the 'bandwagon' effect;
- The unwillingness to abandon 'norms';
- Geographic isolation; and
- Cost.

Because a policy Delphi is anonymous, it provides respondents with the opportunity to present innovative and sometimes controversial ideas to the panel without fear of repercussions. This is particularly important in the area of climate change adaptation, as some adaptations may require fundamental changes in the way in which agencies have traditionally planned and managed lands, waters, and the built environment.

There are many possible designs to a policy Delphi. Figure 6 illustrates an approach that uses two survey iterations. The first survey iteration presents the experts with climate change vulnerabilities and consequences for several sectors, and solicits their recommendations on possible adaptations. The second survey iteration focusses on evaluating the recommendations for their perceived desirability (or importance) and feasibility. Refer to Worksheet 5.2 for a multi-criterion feasibility matrix that can be used (and adapted) to conduct the evaluations. Tools such as Survey Monkey are available to help conduct survey processes.

There is no doubt that assessment teams may identify a large suite of potential adaptation options. Measures may span a variety of themes and approaches – from changes to policy, management, and practices, to public awareness and communications, to monitoring and scientific research.

Prioritize Risks

- Collate vulnerability assessments and summarize results from risk assessment

Plan Delphi Process

- Determine sampling strategy and questions
- Identify and secure committed participants

Delphi Round 1: Identification of Adaptation Options

- Circulate vulnerability assessment results and key risks
- Solicit adaptation recommendations via questionnaire
- Analyze responses

Delphi Round 2: Evaluation of Adaptation Options

- Establish evaluation criteria
- Solicit ratings based on Round 2 questionnaire
- Analyze responses for consensus/disagreement

Analysis and Final Report

- Analysis of results (e.g., simple statistics, and tabulation, etc.)
- Prepare final consensus statements of first and second priority adaptation options
- Distribute final report to stakeholders

Figure 6. Example of a policy Delphi approach to identify and evaluate climate change adaptation options.

Using a Delphi approach: Sources of information

- "Changing Climate, Challenging Choices: Ontario Parks and Climate Change Adaptation" (2008, by Lemieux et al.)
- "Protected Areas and Climate Change in Canada: Challenges and Opportunities to Adaptation" (2010, by Lemieux et al.)
- "Adapting to Climate Change: Recommendations to Inform Development of a Climate Change Adaptation Strategy for the Lake Simcoe Watershed" (2011, by Douglas et al.)

Menu Approach

Climate change adaptation actions and strategies are widely discussed in academic literature, applied case studies, and an array of other information sources. To assist in identifying adaptation options applicable to particular impacts or a particular study area, project teams can develop a menu of possible adaptation options from the literature and/or from targeted review by experts (Swanston and Janowiak, in review)..

With this menu, teams can seek input from natural resource managers and stakeholders to determine whether the adaptation options list is complete and which actions may be most realistic and feasible for their needs.

Wherever possible, efforts should be made to refine adaptation approaches by aligning actions with existing management planning and decision-making (e.g., forest management planning) and working with those responsible for implementing the plan to determine next steps (Swanston and Janowiak, in review).

Such an approach can use a menu approach and integrate methods such as online survey (e.g., Survey Monkey) and ranking methods (e.g., Flash-Q), workshop facilitation, and a variety of other decision-making and input-seeking methods.

Creating an Adaptation Menu: Sources of Adaptation Approaches

- MNR has supported diverse research programs to better understand and adapt to climate change. The MNR Climate Change Report Series includes recommended adaptation strategies.
- *Strategies for Managing the Effects of Climate Change on Wildlife and Ecosystems* (2008 by Heinz Center, Washington D.C).
- "Adaptation to Climate Change in Forest Management." (2003, by D.L. Spittlehouse and R.B. Stewart, *BC Journal of Ecosystems and Management* 4[1]).
- "Incorporating Climate Change Adaptation Considerations into Forest Management and Planning in the Boreal Forest." (2007, by A.E. Ogden and J.L. Innes, *International Forestry Review* 9[3]: 713-733).
- *Preliminary review of adaptation options for climate-sensitive ecosystems and resources* (2008, ed. S.H. Julius and J.M. West, US Climate Change Science Program).
- "Biodiversity Management in the Face of Climate Change: A Review of 22 Years of Recommendations ." (2009, by N. Heller and E. Zavaleta, *Biological Conservation* 142[1]: 14-32).
- The Climate Adaptation Knowledge Exchange website highlights case studies of adaptation measures and projects across North America.

Other Tools for Scoping and Evaluating Adaptation Options

TOOLS	APPLICATIONS					
	Current vulnerability	Future vulnerability	Risk assessment	Scoping adaptation options	Evaluation of adaptation options	Strategic planning and implementation
Expert judgement: Assessment by experts in the field of probabilities and risks	X	X	X	X	X	X
Focus groups: Groups of stakeholders that discuss their opinions on specific topics	X			X	X	X
Brainstorming: Free-flowing lists/diagrams of all ideas and options				X		X
Cost-benefit analysis: Assessment of economic efficiency, assigning a monetary value to the measure of effect, etc.					X	
Cost-effectiveness: Economic analysis that compares the relative costs and outcomes (effects) of two or more courses of action.					X	
Multi-criteria analysis Examination of more than one and some non-monetary criteria involving subjective judgement					X	
Decision/probability trees: Charts of relationships between decision modes; helpful in generating expected value					X	
Influence diagrams/mapping tools: Graphic identification of options; particularly useful when there are many options				X	X	X
Monte Carlo analysis: Computer-based analysis that explicitly assesses uncertainty			X			

(Source: adapted from UNDP, 2005)