Canadian Council of Ministers of the Environment
Le Conseil canadien des ministres de l'environnement

IMPLEMENTATION FRAMEWORK FOR CLIMATE CHANGE ADAPTATION PLANNING AT A WATERSHED SCALE

PN 1529
ISBN 978-1-77202-011-3

TABLE OF CONTENTS

Table Of Contents ii
List Of Figures iii
List Of Tables iii
Executive Summary iv
Preface v
Acknowledgements v
Introduction 1
- Adaptation at a watershed scale 3
- Target audience 3
- Top-down and bottom-up approaches to climate change adaptation 3
- Adaptive management 5
- Methodology 5

Step 1 – Initiate Adaptation Process 7
- Examine and set the context 7
- Build awareness 10
- Identify a champion or leader 10
- Define and build team(s) 10
- Engage Experts 12
- Develop a record-keeping system 12

Step 2 – Increase Knowledge And Collect Data 13
- Evaluate and increase climate change knowledge 13
- Gather historical data 14
- Develop baseline data and indicators 14
- Obtain future climate projections 17
- Develop an inventory of climate change impacts 18

Step 3 – Assess Current Vulnerability 19
- Determine the degree to which the watershed is sensitive and exposed to climate 20
- Determine the adaptive capacity to address historic and current climate change impacts 23
- Assess vulnerability 24
- Review results and communicate findings 26
- Update the record-keeping system 26

Step 4 – Assess Future Risk 27
- Conduct risk analysis 28
- Conduct risk evaluation 30
- Communicate findings 30
- Review results 31

Step 5 – Generate Adaptation Solutions 32
- Establish goals and objectives 32
- Identify adaptation options 33
- Evaluate adaptation options 35
- Review and communicate results 36

Update record-keeping system ... 37
Develop adaptation plan ... 37
Step 6 – Implement Adaptation Solutions ... 38
Develop implementation plan ... 38
Initiate implementation ... 39
Update record-keeping systems ... 40
Communicate results ... 40
Step 7 – Monitor And Review ... 41
Develop a tracking, monitoring and evaluation plan ... 41
Assess new information ... 42
Update adaptation plan ... 43
Communicate accomplishments ... 43
Update record-keeping system ... 43
Conclusion ... 44
Endnotes ... 45
Appendix A ... 48
Appendix B ... 50

LIST OF FIGURES

Figure 1: Graphic illustration of the Implementation Framework for Climate Change Adaptation Planning at a Watershed Scale. ... 2
Figure 2: Top-down and bottom-up approaches to climate change adaptation. Source: Dessai and Hulme 4
Figure 3: Sensitivity and exposure matrix ... 21
Figure 4: Vulnerabilities ranked according to sensitivity/exposure and adaptive capacity ... 24
Figure 5: Overall risk matrix ... 31
Figure 6: Policy Delphi methodology used in the Lake Simcoe Climate Change Vulnerability Assessment to generate adaptation options ... 35

LIST OF TABLES

Table 1: Differences between Top-down and Bottom-up approaches to adaptation planning ... 4
Table 2: Exhibit 5.1 - example approaches to develop vulnerability indicators ... 16
Table 3: Sensitivity and exposure worksheet ... 21
Table 4: Overview of models and tools to be used to assess exposure ... 22
Table 5: Overview of tools available to assess sensitivity ... 23
Table 6: Examples of indicators of adaptive capacity for human communities, and resilience of freshwater ecosystems ... 23
Table 7: Assessment of adaptive capacity ... 24
Table 8: Overall assessment of vulnerability ... 25
Table 9: Worksheet to document the estimate of likelihood ... 29
Table 10: Worksheet to document estimate of consequence ... 30

EXECUTIVE SUMMARY

This *Implementation Framework for Climate Change Adaptation Planning at a Watershed Scale* (Framework) was developed by the Water Monitoring and Climate Change Project Team of the Canadian Council of Ministers of the Environment (CCME) Water Management Committee (WMC). The Framework provides watershed managers with a structured process to identify and reduce climate vulnerability and risk, and build resiliency within the watershed. The Framework presents a methodology through which a group of individuals can come together to assess and manage vulnerabilities and risks stemming from climate change at a watershed level. It is informed by existing international and domestic climate change adaptation frameworks that appear in published literature and a jurisdictional survey of climate change adaptation practitioners from across Canada. The Framework lists seven key steps, each with a series of tasks and outcomes. Inherent to the process is the intention of adaptive management. The method of managing adaptively is appropriate for this context in dealing with uncertainty in climate change as well as the importance of tracking, monitoring and evaluating adaptive measures designed to reduce climate risk.

The Framework encompasses aspects of both top-down and bottom-up planning, with the majority of the steps common to both types of adaptation planning processes.

- Step 1 is designed to build the climate change adaptation planning team and set the bounds of the project.
- Step 2 collects information necessary for the process and builds knowledge among the adaptation planning team.
- Steps 3 and 4 utilize the data and knowledge gathered in Step 2 to assess aspects of climate change vulnerability and risk within the watershed.
- Step 5 responds to those assessments of vulnerability and risk by building a portfolio of adaptive actions that intend to reduce climate risks.
- Steps 6 and 7 complete the process by implementing the risk-reducing measures and monitoring and evaluating their effectiveness respectively.

PREFACE

The Canadian Council of Ministers of the Environment (CCME) is the primary minister-led intergovernmental forum for collective action on environmental issues of national and international concern. The 14 member governments work as partners in developing nationally consistent environmental standards and practices.

ACKNOWLEDGEMENTS

This document was prepared by the Water Monitoring and Climate Change Project Team of CCME's Water Management Committee. CCME gratefully acknowledges the Ontario Centre for Climate Impacts and Adaptation Resources at Mining Innovation Rehabilitation and Applied Research Corporation (MIRARCO/Laurentian University) for their contributions to this document.

INTRODUCTION

Climate change is expected to further impact water quantity and quality (hydrologic cycle) in ways that are uncertain. The likelihood and frequency of extreme weather events, including heavy precipitation, flooding, droughts, and heat waves are expected to further increase in a variety of locations across Canada. The challenge for water managers is determining the natural variability of water quantity and quality as these past patterns are changing. As such, water managers will need to adapt their programs to meet the needs of an uncertain future.

Managing water quantity and quality is best done at a watershed scale. However a change in one part of the watershed may have consequences in other parts of the watershed. A climate change adaptation plan concerning water quantity and quality will provide the basis for climate change adaptations for other ecological systems and economic activities that are dependent on water.

This Framework was informed by a review of climate change adaptation, risk assessment, and vulnerability assessment frameworks literature from various sectors (e.g., watershed, regional, municipal and community, provincial and federal government, natural resources). Designed for application in a Canadian context, the Framework was also informed by a jurisdictional survey of adaptation implementation frameworks in development or in use across Canada. The Framework entails seven steps, each with tasks or activities that address goals or desired outcomes as the process advances. Each step references Canadian and international literature that include similar steps and/or tasks in implementing an adaptation plan.

Figure 1 outlines the Framework. Encompassing both 'top-down' and 'bottom-up' aspects of adaptation planning, this Framework is designed to be a standalone process, or have aspects of it mainstreamed into existing policies, procedures or management functions. It is also an iterative process, allowing users to revisit some or all of the steps in light of new information, or in light of measured watershed responses to the implemented adaptation actions. The process is meant to be flexible, so users can determine which steps, or components of steps, are most suitable and will provide appropriate results for their project. The overall goal of the Framework is to provide watershed managers with a structured process to identify and reduce climate vulnerability and risk, and build resiliency within the watershed. While the steps of the Framework are general and common to steps in adaptation planning frameworks in other sectors (e.g., community), the flexibility of the process, aspects of bottom-up and top-down, and water-specific inputs into the process are what make it applicable for adaptation planning at a watershed scale.

<u>Steps of the Implementation Framework for Climate Change Adaptation Planning at a Watershed Scale:</u>

The following are the key steps of the Framework:

Step 1 - Initiate Adaptation Process
Step 2 - Increase Knowledge and Collect Data
Step 3 - Assess Current Vulnerability
Step 4 - Assess Future Risk

Step 5 - Generate Adaptation Solutions
Step 6 - Implement Adaptation Solutions
Step 7 - Monitor and Review

Figure 1: Graphic illustration of the Implementation Framework for Climate Change Adaptation Planning at a Watershed Scale.

This process can be used as a stand-alone adaptation framework, or be mainstreamed into existing planning frameworks. The Framework progresses through successive steps in a clockwise direction. Although progression is unidirectional, revisiting previous steps in light of new developments or inputs is encouraged. Arrows leading in toward the mainstreaming circle demonstrate how the results from each step can contribute to adaptation within existing policies, procedures or management functions. The over-arching concept of adaptive management encourages subsequent iterations of the process 1) in light of new inputs such as science, data or knowledge; 2) in light of new or changed risks or vulnerabilities and 3) in order to alter adaptive responses based on the outcomes from monitoring effectiveness of adaptation measures.

Adaptation at a watershed scale

Climate change adaptation in watersheds requires consideration of many factors. Climate directly affects the hydrologic cycle which has consequences for water dependent systems and sectors, such as ecosystems, agriculture, infrastructure, power generation, fisheries and forestry. All of the traditional watershed issues of flood, drought, erosion, stormwater and fisheries need to be evaluated and robust but flexible adaptation measures need to be identified.

The interconnectedness of a watershed and the broad range of scientific, social, cultural and economic issues that water managers deal with require a watershed approach to adaptation planning. While adaptation plans or activities will need to address the broad nature and challenges associated with these watersheds, specific adaptation actions are required to respond to impacts on specific ecosystem components. In addition, when evaluating the adaptation actions, adaptation planners should be careful to ensure that an adaptive response that reduces the risk in one area does not increase the risk in another.

The adaptation process as a whole, including implementation of adaptation actions can take several years. The size of the project will help determine how long it will take to complete. For example, a very detailed, science-based, technical process would have a different timescale from a participatory process involving observations from local stakeholders.

Target audience

The audience for this Framework is informed, but non-specialist water managers and those planning for climate change adaptation. This Framework will assist jurisdictions developing climate change adaptation strategies or plans at a watershed scale, with a focus on adaptation issues related to water quantity and quality.

Top-down and bottom-up approaches to climate change adaptation

Climate change adaptation planning can be undertaken in two general forms – bottom-up and top-down (3) (Figure 2). A bottom-up approach is considered participatory as it relies on knowledge and expertise from local stakeholders, and instead of using climate models for looking into the future, assessments examine vulnerability to current climate (4, 5). This approach can also consider past efforts to cope with or respond to impacts related to climate variability and climate change. It assumes that in the face of uncertainty over climate change projections and its impacts, adapting to present day climate variability/change is a good proxy for near term climate change (3). Top-down approaches are technical, science and scenario driven. This approach relies on scientific research and climate model projections of future climate change to assess the risks associated with future climate change. Dessai and Hulme (3) suggest that the two approaches are not necessarily contradictory. They can, in fact be complementary, but do have different climate information requirements (e.g., climate projections vs. historical climate). The goals, time and resources of each project will ultimately determine which approach should be used (Table 1).

Figure 2: Top-down and bottom-up approaches to climate change adaptation. Source: Dessai and Hulme (3)

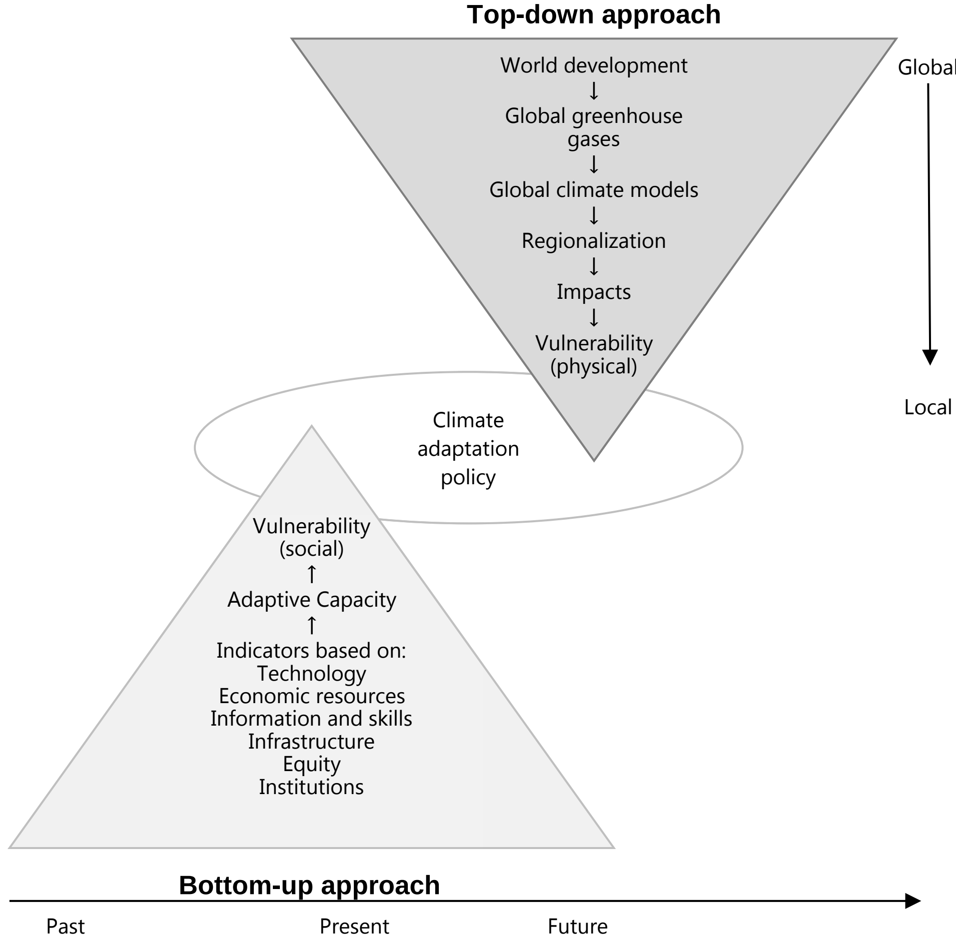


Table 1: Differences between Top-down and Bottom-up approaches to adaptation planning – sources include Dessai and Hulme, Burton *et al*., and van Aalst *et al*. (3, 4, 6)

Top-down	Bottom-up
Bio-physical vulnerability	Social vulnerability
Physical or natural exposure units (e.g., watersheds, ecosystems)	Social exposure units (e.g., households, communities)
Ignores humans	Considers humans
Driven by federal or provincial legislation	Driven by local stakeholders or agencies
High-level policy-makers, technical analysts	Broad stakeholder engagement
Uses climate projections	Uses historical climate data
Focus on mid- and long-term future (e.g., 2050s or 2080s	Focus on past and present conditions to inform policy-making today and in near-term
Financial and human resources in place	Limited financial and human resources

The Framework encompasses aspects of both top-down and bottom-up approaches and is designed so that each step contains actions that can be used in either approach. Involving stakeholders throughout the process and assessing current vulnerability are actions generally associated with a bottom-up approach. Assessing current vulnerability can be considered top-down if researchers are engaged and scientific research on vulnerabilities is conducted. The use of technical expertise throughout the process, as well as climate projections when assessing future risk is often indicative of a top-down adaptation approach.

When using this Framework to undertake watershed-based climate change adaptation planning, the majority of Steps are appropriate in both the top-down and bottom-up settings. If adaptation planning in a watershed is driven by local stakeholders, it is considered a bottom-up approach and would include aspects of local stakeholder knowledge and historical climate data to assess vulnerability to current climate. These specific aspects are identified in Steps 1 and 3 respectively. A top-down approach however, would see stronger emphasis on Step 2 (collection of climate projection data) and Step 4 (assessing future climate risks).

Adaptive management

An adaptive management approach to climate change planning within the watershed allows decision-makers to manage in the context of uncertainty. Adaptive management enables flexible and nimble decision making to respond to management outcomes, new scientific or climate information or changes to other non-climate factors (7). Adaptive management seeks to improve scientific knowledge, and to develop management regimes that consider a range of possible futures outcomes and even take advantage of unanticipated events (7). Adaptive management is a structured, iterative approach that promotes long-term monitoring, modeling and assessment. In the context of climate change adaptation planning, adaptive management promotes consistent and targeted monitoring of implementation and subsequent results of the effectiveness of adaptation measures. Results contribute to a better understanding of the issue and inform adjustments to the adaptation plan as part of the iterative learning process – it is not a 'trial by error' process but rather learning while doing (7).

Methodology

Development of this Framework was informed by two different research inputs: a literature review of existing adaptation planning frameworks both domestic and international and a survey of Canadian jurisdictions to identify specific watershed-based adaptation planning frameworks in development or use. The Framework also draws upon the organizational experiences of watershed-based adaptation planning in Ontario.

Literature Review

A scan of online climate change literature and existing internal databases was conducted to compile a list of references pertaining to climate change adaptation implementation frameworks. Results from this search yielded examples of various domestic and international frameworks used to develop and implement adaptation plans and strategies within various levels of government and sectors (e.g., communities, forestry, developing nations). Placing stronger emphasis on the Canadian examples, the various frameworks were used to inform a survey that polled the different jurisdictions in Canada on the existence, awareness and usage of various adaptation implementation frameworks and development of the framework. A second literature review was conducted to support each step of the Framework.

Jurisdictional Survey

To help inform the development of this Framework, surveys were conducted with all jurisdictions in Canada. The surveys were conducted through one-on-one interviews over the phone, and group interviews via conference call. The interviews helped gauge the existence, usage and benefits of watershed-based climate change adaptation frameworks. The survey revealed many common messages, some of which are listed below. These observations stem from the interviewees' experience in applying various forms of climate change adaptation frameworks at a watershed and/or community level and were considered in the development of the Framework.

- Adaptation capacity levels differ significantly across jurisdictions which in turn can be reflected in the level of adaptation activity.
- Not all jurisdictions have an organized and funded management structure for watersheds. This can either discourage or enable accounting for climate change impacts at a watershed scale.
- Taking steps to incorporate climate change into existing planning tools, frameworks and process (mainstreaming) at both the watershed and municipal level is seen to be an effective way to manage climate change risks. This is occurring in all jurisdictions in Canada.
- Both bottom-up (community-based, local stakeholder-driven) and top-down (climate models, projections and scenarios) approaches to climate change adaptation planning are occurring in almost all jurisdictions in Canada. Each approach has inherent strengths and weaknesses.
- Climate data and science, when included as part of the adaptation planning process, require a degree of interpretation to make the information more understandable by local decision-makers. It is also important to be able to explain how to use the climate change information in the context of adaptation planning at the watershed level.
- The jurisdictional survey garnered few examples of adaptation planning processes that have moved from impact, risk, and vulnerability assessment to the generation of adaptation actions, plans and/or strategies. There are even fewer examples of implementation of adaptation actions and evaluation of their effectiveness.
- There are many jurisdictions that set the context of adaptation planning by discussing changed weather and climate and current coping mechanisms. Climate change impacts and projections of future change are incorporated later in the discussion.

STEP 1 – INITIATE ADAPTATION PROCESS

Purpose

The purpose of Step 1 is to develop the adaptation planning team as well as the context for the adaptation planning process.

Tasks

- Examine and set the context
- Build awareness
- Identify a champion or leader
- Define and build team(s)
- Engage experts
- Develop a record-keeping system

Outcomes

- Context defined, terms of reference developed, budgets and work plans in place
- A general outline developed about climate change, and climate change impacts being experienced in the watershed
- Champion or leader identified and on board
- Teams(s) defined and in place
- List of possible experts to engage
- A record-keeping system chosen and developed

The Watershed Context

The activities in Step One are common to watershed and other types of adaptation planning. For both top-down and bottom-up approaches, building the adaptation team should consider technical, operational and management expertise related to different attributes within the watershed. For the bottom-up approach, a greater emphasis may be placed on engaging stakeholders who are knowledgeable about the watershed.

Examine and set the context

Setting the context is important for the planning process as it lays the foundation for progression through the subsequent steps. Setting the context should include defining the scope of work (i.e., spatial and temporal) to ensure clarity among the adaptation planning team, establishing project goals and objectives, and developing a communication plan (8, 9, 10, 11, 12). Ultimately, the intention is to put in place an effective project plan so that adaptation strategies, policies and measures can be implemented (6).

Defining the scope

Climate change will impact many watersheds in Canada, and managers within each watershed will have their own reasons for considering climate change adaptation planning. Defining the scope of the project will set the geographic bounds of the project, specific planning horizons, governance composition of the watershed (which may include transboundary issues), sectoral/thematic bounds and other necessary limitations. Understanding these bounds will ensure that all project participants are following the same basic premises for climate change adaptation planning.

It is important to determine the various drivers that are encouraging the process. Drivers could include recent climate and weather events causing damage, pressure from stakeholders in the watershed, legislative or regulatory conditions or simply heightened awareness of the need for due diligence. Knowing the main drivers will make it easier to establish objectives and goals of the process. In addition, developing terms of reference will define roles, responsibilities and authority of the adaptation planning team members (11). Defining the roles and responsibilities of the adaptation planning team members is also important to do at the onset of the project to avoid delays throughout the process. In the case of adaptation planning within a watershed, adaptation planning team members from different agencies may have roles in different steps of the process (e.g., water practitioner may be required for some of the technical aspects of the process, while municipal planners and engineers will be involved in generating adaptation solutions and implementation).

It is helpful to conduct background research in order to develop a description of the watershed. This description could include geographic location and limits (e.g., community, watershed, subwatershed), governance and transboundary issues, existing hazards, main economic drivers, development and social setting, timeline for the project, and the future time horizon to be considered (e.g., 2050s) (9, 10, 11, 13, 14, 15).

If applicable, and with a focus on issues related to water quality and quantity, the project scope should also include the systems (or themes) within the watershed that will be assessed. Gleeson, *et al*. suggest considering the availability and quality of data, availability of expertise, time available or special interest when choosing systems (or themes). The location, existing stressors, economics, and diversity of users of the watershed will also help define the areas to be assessed. For example, an assessment conducted in the Eco-district 3E-1 of northeastern Ontario examined vulnerability in nine different systems (or environmental themes) – aquatic habitat, forest windthrow, forest fire, forest productivity and composition, hydrology, peatlands, paludification, socio-economics, and wildlife (16). Forestry is of particular economic importance to northeastern Ontario, which imparted a stronger focus on aspects of the vulnerability of trees to climate change within the watershed. A similar adaptation planning exercise conducted in the Lake Simcoe watershed in Ontario assessed vulnerability in eleven themes – hydrology, aquatic habitat, wildlife, insects, species-at-risk, invasive species, vegetation cover, natural heritage areas, agriculture, tourism and recreation, and infrastructure (17). The Lake Simcoe watershed is heavily populated and projections suggest continued growth. In addition, it is highly sought after for recreational purposes, and almost half of its area is currently agricultural. The reasons for choosing systems (or environmental themes) may be clear on the onset of the process, while a meeting to brainstorm may be required to determine and prioritize others (9). It is important to keep records of the rationale for choosing watershed assessment themes.

The climate change adaptation planning process may also be undertaken alone or as part of an existing process (e.g., integrated watershed planning) (14). At times, other watershed planning processes may be underway and present an opportunity to combine efforts, notably to capitalize on already harnessed expertise. The project scope should also define the timeline for the project (e.g., 2 years, 5 years), define when the project should be reviewed (e.g., every 5 years after completion, as new information becomes available), and the time horizon into the future that will be considered (e.g., 2020s, 2050s). Aligning the planning horizon with current climate model projection periods can be helpful.

Establish goals and objectives

Objectives help to define questions of what, when, who, where, and how much for the adaptation planning process (18). Clear goals and objectives, and expected outcomes will help the adaptation planning team focus and drive toward common targets (19, 20). For example, a goal may be to sustain a cold water fishery. An objective to help achieve that would be to reduce nutrient loading into the lake, or river – a ‘no-regrets’ action as it would provide benefit to the watershed regardless of how the climate changes. Ranger, *et al.* (21) suggest that objectives do not necessarily have to be adaptation-specific and using broader objectives can be useful in helping to mainstream adaptation into organizational decision making, however they need to be achievable within project constraints (e.g., available funding) (22).

A top-down, bottom-up or combination approach to climate change adaptation planning can be considered at this time. The approach will depend on the goals, available expertise, data, time and resources for the project.

Develop a communication plan

A successful adaptation planning process requires effective communication of results to stakeholders, decision-makers, and the general public (22). Facets of ecological and jurisdictional complexity will require strong communication between the varieties of stakeholders. An effective means of ensuring that accurate and appropriate information is developed and disseminated at the right time is the development of a communication plan. It should include a clear message about the importance of climate change adaptation, and address key activities around the engagement of stakeholders for adaptation plan input and communication of project reports to the public and others. The plan should outline who will be responsible for the communication process, the target audiences, how the information will be communicated, and how the communication will be evaluated (22).

The International Council for Local Environmental Initiatives (ICLEI) Canada has developed a resource that describes how to effectively communicate climate change (23). Even though it is written for municipal staff, many of the ideas are transferrable to a watershed context. The resource focuses on the why, who, what, when, and how of communicating climate change in order to best inform and educate local stakeholders within the community. It also outlines challenges in communicating climate change, and how these challenges can be overcome.

Build awareness

The person initiating the adaptation planning process should be aware of the types of weather and climate-related changes that have been experienced in the area (11, 24, 25), and how these changes have impacted the watershed. Preliminary discussions of changing weather with potential adaptation planning team members and other stakeholders can stimulate interest and engage people/organizations. This information can also contribute to heightened awareness of climate changes and impacts within the watershed.

Once the adaptation planning team is in place, determining its level of knowledge of climate change impacts and adaptation, and how it perceives how climate change has or will affect the watershed will help identify the types of resources needed to increase knowledge levels.

Identify a champion or leader

A leader or champion is often identified to coordinate and drive the process forward (9, 24, 26, 27). The champion may be an instigator (often a political figure who recognizes the importance of adaptation and champions the cause to initiate the process), or a hands-on driver who initiates and leads the adaptation planning throughout the entire process. The climate change champion will, in part, identify and overcome barriers, engage multiple stakeholders, communicate successes, and most importantly, facilitate group interaction. The lead can also engage specific technical expertise as needed throughout the process.

Define and build team(s)

Adaptation Planning Team

When undertaking an adaptation planning project within a watershed, a diverse set of skills, perspectives, and expertise may be required to complete the process (9, 12, 22). A core adaptation planning team should be developed with these requirements in mind (8, 9, 11, 12, 24, 25, 28, 29). The adaptation planning team may consist of in-house staff representing various functions and levels, external experts, local government staff, and other stakeholders. As the scale and complexity of the project increases, other experts or teams may be added as necessary (e.g., technical experts, or technical teams) (8, 9, 12). A team leader, often the champion as defined above, should be chosen who is responsible for assembling the team(s) and leading its efforts (24).

Roles and responsibilities of the adaptation planning team can be included as part of the project terms of reference. These should be communicated and understood by all adaptation planning team members (12). In situations where adaptation planning team members are volunteering their time, a good understanding of the time requirements early on is crucial. In general, the adaptation planning team is responsible for overseeing, coordinating and conducting the climate change adaptation process from initiation through to implementation, along with monitoring and reviewing of results. At each step of the adaptation process, the adaptation planning team can consider whether the appropriate people, technical capabilities, and resources are involved in the adaptation planning process (12). If an important skill set appears to be missing, the adaptation planning team can take steps to enlist members with required credentials.

Steering Committee

Community engagement is a critical component of successful adaptation planning (30). Typical bottom-up approaches to climate change adaptation planning harness and transfer watershed knowledge developed on climate risks (30). Establishing a local steering committee can help to guide the process, ensure that local knowledge is included in the process and links watershed support to the project outcomes and implementation (8, 9, 19, 30). The need for a steering committee would be defined by the type of project undertaken. For example, if the outcomes of the process impact aspects of local livelihood, culture, recreation or others, a steering committee comprised of those affected would account for such needs or values.

Stakeholder Engagement

According to Conde and Londsdale (32) stakeholders are individuals or groups who have current and past experience coping with, and adapting to, climate variability and extremes. This knowledge can be very valuable to the adaptation planning process. How to engage stakeholders depends on the complexity of the project and the purpose of the engagement, both of which should be determined in Step 1 of the process.

Stakeholder engagement can range from simply providing information to the adaptation process, to a situation where the stakeholders themselves initiate and design the process. Including local stakeholders in the adaptation planning process not only allows for the inclusion of local knowledge, it allows participants to have ownership in the decisions – making them more likely to comply with them. In a watershed setting, local farmers may be a stakeholder important to the process – both for providing knowledge and complying with adaptation actions that require changes to their farming practices.

Considerations for effective engagement include:

- clear objectives and goals
- understanding how it fits into the process
- information in plain language
- training if necessary
- transparency
- value and respect for every participant's view
- allow time for the process
- receive feedback and change technique if necessary.

Engage Experts

When defining the scope of the project, the adaptation planning team should discuss how and when to engage local experts, stakeholders and other partners whose work is related to adaptation and who could be a good source of information and support (9, 15, 17, 24, 26, 31). Climate change adaptation is most effective when framed as a participatory, iterative, adaptive management process that builds strong working relationships with partners and stakeholders (9). Typically, experts include subject matter experts, but often local stakeholders can provide expert opinion on how climate change is impacting the watershed. These stakeholders are seen as those who can, or will, be affected by the implementation of adaptation decisions or those who can act as an advisory or coordinating committee for the climate change planning effort (19, 26). Experts and stakeholders can offer data, analytic capabilities, insights, and an understanding of the problems that can contribute directly to the adaptation project (22). Determining which experts and/or stakeholders may be interested in the project, and how they will be involved in the process, should be undertaken as part of Step 1. Both types of experts can provide valuable input in areas of vulnerability assessment and efficacy of aspects of adaptation (9).

Develop a record-keeping system

Documenting the adaptation planning process is important. Tracking, citing and documenting the provenance of the data and information used as well as decisions stemming from use of those resources brings transparency to the process and allows for easy access of documents into the future (12, 19). Records such as terms of reference, internal meeting minutes, correspondence, emails, memos, research documents, communication documents, contact lists, planning documents, analysis results, methodologies, work plans, risk data, records of decisions made, views of people or groups involved in the process, etc., should be entered as they are developed in each step. This will make it easy to trace the logic behind decisions made, allowing the adaptation planning team to review the process if additional information becomes available (19, 33). A record-keeping system can be simple, e.g., a wiki for basic information sharing and document storage (19), or more complex as in the case of the United Nations Design and Implementation of Recordkeeping Systems (DIRKS), which is an eight step methodology to be used for the design of systems that create, capture and maintain records (34).

STEP 2 – INCREASE KNOWLEDGE AND COLLECT DATA

Purpose

The purpose of this step is to increase climate change knowledge, either for climate change adaptation planning team members or other stakeholders in the watershed, and to begin the process of collecting all available data that will help inform subsequent steps in the process.

Tasks

- Evaluate and increase climate change knowledge
- Gather historical data
- Develop baseline data and indicators
- Obtain future climate projections
- Develop an inventory of climate change impacts

Outcomes

- Increased awareness of climate change among adaptation planning team members, and others involved or impacted by the project
- A collection of historical data which will be used to inform the remaining steps of the process
- Baseline watershed data, and a list of indicators that yield the state of vulnerability to climate change
- An inventory of climate change impacts within the watershed
- Climate change projections, whether regional or global, for the area

The Watershed Context

The activities in Step Two are specific to climate change adaptation planning in a watershed context. For both top-down and bottom-up approaches the collection of historic trends and future projections of climate and hydrology provide necessary details of the trajectory and magnitude of change. The indicators used to assess the impacts of climate change are specific to attributes of the watershed and baseline health is measured on a watershed scale.

Evaluate and increase climate change knowledge

In Step 1, the level of climate change knowledge among the adaptation planning team was determined to ensure adequate expertise to participate in the adaptation planning process. Here, additional efforts can be undertaken to build knowledge among the adaptation planning team, as well as other stakeholders who may be involved or impacted by the adaptation planning process. Special information sessions, reading assignments or webinars from climate change impact and adaptation experts can build knowledge on the general topic of adaptation or raise awareness of more specific climate related impacts within the watershed (24). A compendium of resources could be created, and made available to adaptation planning team members in order to increase knowledge and understanding of the topic (8, 24, 35, 36, 12). For example, the Climate Insights 101 website developed by British Columbia's Pacific Institute for Climate Solutions (PICS) lists a series of brief videos on climate change impacts and adaptation, broken into numerous lessons (8).

Gather historical data

A significant amount of information can be gleaned about how climate has changed in a watershed by analyzing historic climate and hydrologic data. Researching and gathering all available historical information and data is encouraged. Historical climate data (i.e., historical temperature and precipitation data) may be available from Environment Canada's National Climate Data and Information Archive, or from local sources such as conservation groups, universities, etc.

In addition to historical weather and climate data, other historical data such as hydrology, land cover, information on water users (e.g., residential, recreational) and water use sectors (e.g., forestry, hydropower, agriculture), water quality, demographic and socioeconomic data, water demand projections, population growth and economic development data, paleoenvironmental data, and cumulative effects information could be useful in demonstrating changes within the watershed. Some of the above data can be derived from existing water monitoring networks within the watershed, recognizing the importance of long-term data sets to establish baselines and identify impacts stemming from climate change.

Data can be collected through standard research methods as well as engagement with the local watershed community (8, 19, 26, 37). The northern community of Dawson, Yukon filled data gaps in their community adaptation plan through the addition of local knowledge and accounts of past climatic changes (24).

Develop baseline data and indicators

Baseline watershed health can be assessed using indicators that measure physical, chemical and biological characteristics of the watershed. The baseline can be measured against known standards, requirements or guidelines to identify the health of the watershed and often provide a resiliency objective. Baselines are observable, present day conditions (31) or a snapshot of the system over a period of time. Baseline conditions represent how well adapted the watershed is to current climatic conditions (22), and this information is often used to help monitor and evaluate adaptation options and measure overall success (9, 29, 31, 36). Based on the systems (or themes) defined in Step 1, the adaptation planning team should develop an inventory of baseline data. From the data, watershed managers and others can understand the range of natural variability within systems over the period of record. This task will be constrained by the amount of data available within the watershed.

Indicators for assessing watershed vulnerability to climate change can measure aspects of both natural (ecosystem-based) and built (infrastructure-based) systems. Numerous themes and specific components (indicators) of the themes may be evaluated in the context of climate change. For example, when assessing the vulnerability of water quality and quantity to climate change for Lake Simcoe and its watersheds, nine indicators were chosen, including water use/availability, baseflow index, wetland cover, groundwater vulnerability, forest cover, phosphorus loading, variability of streamflow, floodplain area, and sewage bypass (38). Mortsch and Hebb (39) used variables from the Canadian Census as indicators to assess adaptive capacity with respect to flooding in Upper Thames River Basin. In this case, indicators included ability to cope and respond, differential access to resources, and level of situation exposure. Other non-climate indicators included number of people over the age of 65, number of people under the age of 19, number of low income households, housing type, and period of construction (39). These two studies provide examples of different types of indicators that were applied to measure facets of vulnerability within watersheds.

Indicators are often used in vulnerability assessments to:

- help quantify the state of various watershed characteristics
- assess the exposure and sensitivity of the watershed to climate change impacts
- assess the capacity of the watershed to adapt (40).

As part of a climate change adaptation project on water monitoring data requirements and indicators, a list of vulnerability indicators of climate change sensitivity that specifically require hydrologic data has been developed (41). Research was undertaken in the following categories to identify these indicators:

- vulnerability of water resources
- watershed health/ecosystem
- sustainability
- ecosystem service
- water use.

Numerous indicators were found within each of the five broad categories but very few indicators requiring hydrologic data were found in any but the first.

A list of indicators of climate change sensitivity is presented in Appendix B. The table includes a description of how each indicator is calculated, identifies jurisdictions or organizations that are known to utilize the indicators and provides reference information.

The majority of indicators identified are related to precipitation, snow, flows, temperature, soil moisture and water levels. However, the indicators can also be used to quantify information on other parameters (e.g., frequency of ice jam floods). Table 2 provides some example indicators taken from Appendix B.

Table 2: Example Vulnerability Indicators

Parameter Category	Indicator	Hydrologic Parameters Needed	Non-hydrologic Parameters Needed
Ice	Change in freezing/melting dates	First date of permanent ice/date of complete freezing/maximum thickness/date of first melt/ice-free date	Not applicable
Precipitation	Average 30-year precipitation	Total precipitation	Not applicable
Temperature	Permafrost distribution	Ground Temperature	Area of continuous permafrost, discontinuous permafrost and permafrost-free land
Snow	Snow cover season	Areal extent of snowpack	Not applicable
Groundwater Quality	Groundwater under human stress quality problems index	Groundwater quality parameters	Studied aquifer area
Soil Moisture	Change in Soil Moisture Percentile	Soil moisture content	Not applicable
Water Level	Surface water resources	Total surface water area	Total land area

The adaptation planning team should choose indicators of adaptive capacity. These are defined as the characteristics of communities or watersheds that influence their ability to adapt (42). From a social perspective, indicators could include levels of technology, financial resources, and social capacity (42), while genetic diversity may be an indicator for ecological adaptive capacity (40). To assist in identifying indicators and metrics for watershed sensitivity and exposure, as well as indicators of adaptive capacity, the adaptation planning team can review information such as journal articles, grey literature, government reports, online resources and other vulnerability and adaptive capacity assessments. Various databases of climate, weather or hydrologic data can also be of help to identify states of the watershed. CCME's *Tools for Climate Change Vulnerability Assessments for Watersheds* (40) provides guidance on choosing indicators for conducting vulnerability assessments.

Tools for Climate Change Vulnerability Assessment for Watersheds

This compendium of tools was prepared for use by technical experts, adaptation planners, resource planners, and others involved in assessing vulnerability to climate change, and implementing climate change adaptation in rural, urban and remote watersheds across Canada. The compendium includes a varied and diverse range of tools, ranging from indicator based approaches (bottom-up) to sophisticated hydrological models (top-down). The compendium also includes case studies, and examples of watershed-scale vulnerability assessments from Canada and other jurisdictions around the world (40).

Obtain future climate projections

Projections of future climate help give a sense of the trajectory of change as well as the context for continued/new impacts within the watershed. There are numerous resources available that can help define future climate conditions using climate models under a variety of different scenarios of economic and environmental change (12, 17, 19, 26, 29, 35, 36). Since climate scenarios are only possible outcomes, the adaptation planning team can consider using an ensemble of models and scenarios to capture the range of potential climate change (9).

Climate projections and data are available from several sources within Canada, including:

- Canadian Climate Change Data and Scenarios website, Environment Canada
- Consortium on Regional Climatology and Adaptation to Climate Change (OURANOS)
- Pacific Climate Impacts Consortium
- Scenarios Network for Alaska and Arctic Planning.

Inherent within the models and their output is uncertainty. Often viewed as a barrier to climate change adaptation planning, the lack of exact definitions of future change leads some decision-makers to refrain from proactive planning. Advances in the science of global and regional climate modeling will continue to refine the output and define finer resolution into the future. While scenarios of climate change cannot exactly predict future climate conditions, and caution on the use of model output should be exercised, modeled climate data, combined with our knowledge of how systems are affected by weather and climate, should translate into prudent adaptation planning.

There are many aspects of global climate models that may seem confusing to someone not familiar with the terminology of modeling. If members of the adaptation planning team are not familiar with the various decisions that are required in choosing models, they should consider consulting climate modeling resources or consult with experts to enhance their level of knowledge. In order to assist in deciding what climate projection may be required for the project, Gleeson, *et al.*, (9) suggest developing a series of questions, for example:

- What climate models and scenarios are available
- What climatic variables do adaptation planning team experts require (e.g., changes in temperatures, changes in precipitation)

- In what format do adaptation planning 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)?

The adaptation planning team should create a list or description of possible climate futures using the available information and data on projected climate change. This information will be used to help define risk or climate events in order to assess future risk (Step 4).

Some groups may want to delve deeper into the impacts of climate change on specific aspects of hydrology for their vulnerability assessments (Step 3) (40). Models that project parameters such as stream flow, water quality, soil moisture or evaporation/evapotranspiration may already be used in watershed planning and management. Incorporation of climate change projections into these models can often yield information that can help identify specific changes to hydrology at a localized scale. As long as watershed planners, engineers and managers are aware of the caveats of these results, the modeled data can be very helpful in adaptation decision-making.

Develop an inventory of climate change impacts

Developing an inventory of potential climate change impacts for the watershed can:

- assist with gaining an understanding of how climate change is already impacting the watershed
- aid in risk and vulnerability assessments and
- help identify appropriate adaptation measures later in the planning process (9, 11, 12, 24, 25, 26, 35).

This information will help the adaptation planning team identify and understand the range of potential focus or priority impact areas within the watershed (19).

Bottom-up adaptation planning processes will often use local knowledge of climate change impacts, comprised of observations of change and its effect on the values of the watershed. Stakeholders can often, and with ease, offer ways in which their property, business or personal life has been affected by climate variability, climate change and/or extreme weather events. One-on-one meetings, workshops, and online surveys are a few examples of effective methods to collect this information. Some stakeholders may have a low level of knowledge about climate change, or do not believe it is actually happening. In this case, it can be advantageous to begin the conversation about changing weather and how they've coped in the past. Workshops are a good venue to invite experts to speak about climate change impacts and adaptation, focusing on the local area when possible. Gathering local knowledge about changing weather and climate will help the adaptation planning team determine how climate change has impacted the watershed, inform key areas of vulnerability, and identify key indicators to measure watershed health (31).

STEP 3 – ASSESS CURRENT VULNERABILITY

Purpose

The purpose of this step is to identify how the watershed is vulnerable to the changes in climate that have already occurred.

Tasks

- Determine the degree to which the watershed is sensitive and exposed to climate
- Determine the adaptive capacity to address historic and current climate change impacts
- Assess vulnerability
- Review results and communicate findings
- Update the record-keeping system

Outcomes

- An assessment of sensitivity and exposure
- A broad understanding of the adaptive capacity within the watershed
- A list of vulnerabilities within the watershed

The Watershed Context

The activities in Step Three are common to watershed and other types of adaptation planning. However a potential challenge to assessing the vulnerability of a watershed may be obtaining relevant data to determine its adaptive capacity. Assessments of adaptive capacity are conducted using indicators or determinants that rely on data about human communities and watershed ecosystems. Watershed ecosystem data can be obtained for the watershed but data for human communities may not be available on a watershed scale. Data for human communities may be based on municipal boundaries or census tracks and may need to be converted to a watershed scale.

Including CCME's *Tools for Climate Change Vulnerability Assessments for Watersheds* (40), the climate change adaptation literature holds many different approaches for assessing vulnerability (43). Vulnerability is defined as the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes (44), and is driven by dimensions of sensitivity, exposure and adaptive capacity (40). In order to inform development of adaptation solutions to reduce the risks stemming from climate change, it is important to understand how the watershed is vulnerable to the changes in climate that have already occurred. While important for informing future risk, assessing current vulnerability also has the benefit of identifying ways to improve the management of systems to current climate risks (45).

Depending on the scope of the project and the resources available, the adaptation planning team can undertake the assessment relying on expert knowledge and judgment, or can engage technical experts to undertake vulnerability assessments on a variety of systems or themes (e.g., water, wildlife, infrastructure, etc.) within the watershed. The results from this step will provide the baseline against which future climate change impacts will be measured, as noted in Step 4. Determining the degree to which systems are currently sensitive and exposed to climate change, and the adaptive capacity of the systems to address existing climate change impacts (9, 12, 24, 25, 46), provides an overall assessment of vulnerability. Understanding the relationship between current climate and aspects of the watershed and its ecosystems, will help define how existing stresses within a watershed could potentially be exacerbated into the future as a result of climate change.

Assessing vulnerability involves uncertainty. Gleeson *et al*., (9) provide guidance on how to address uncertainty and methods for incorporating uncertainty into vulnerability assessments. They state that it is important to consider approaches for acknowledging and communicating uncertainty, however, uncertainty should not limit or discourage assessment of vulnerability. Continuous advances in climate science as well as an improved understanding of the effect of climate change on the system will contribute to a reduction in uncertainty.

In Step 2, key indicators associated with the systems (or environmental themes) to be assessed were identified. Within this step, the assessment of sensitivity, exposure, and adaptive capacity will determine the extent to which the indicators are affected by both climatic (e.g., temperature, precipitation) and non-climatic stressors (e.g., urban pressuressuch as urbanization, population increases, water demands, etc.) (9). As a case study example and using a framework developed for natural resource practitioners (9), technical experts conducted vulnerability assessments in the Eco-district 3E-1 of Northern Ontario (16, 47, 48, 49) through the use of select theme indicators.

Determine the degree to which the watershed is sensitive and exposed to climate

The first task in assessing current vulnerability is determining the degree to which the watershed (e.g., systems or environmental themes) is sensitive and exposed to climate. For the purposes of this document sensitivity is defined as the degree to which a system is affected, either adversely or beneficially, by climate variability or change (44); a measure of how a system is likely to respond when exposed to induced stress (40). For the purposes of this document, exposure is defined as the presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected by changes in climate (50). Exposure is also a measure of the magnitude and extent (i.e., spatial and temporal scales) of climate change impacts (40). Systems that are currently experiencing stress and are exposed are more likely sensitive to current climate.

Using the indicators and data collected in Step 2, the adaptation planning team and/or technical experts can define how sensitive and exposed the various watershed components are to both current climatic and non-climatic conditions. To help assess sensitivity and exposure, the adaptation planning team could develop a series of questions (19). For example:

- Is the system subject to existing stress?

- How exposed is the system to the impacts of existing climate change?
- What metrics can be used to quantify exposure/sensitivity?
- Are there thresholds that can be identified?

Developing and defining a ranking system will help prioritize the results of this assessment. For example, high, moderate and low, where:

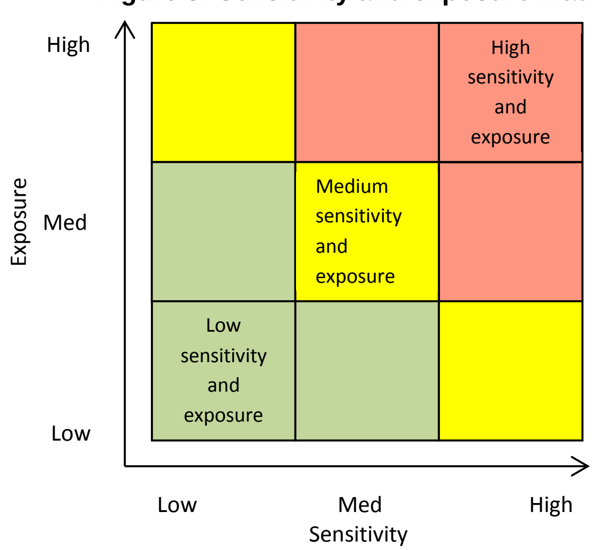
- high (H) – the exposure and sensitivity to climate is the central driver or plays a significant role in the current state, structure or function of the indicator
- moderate (M) – the exposure and sensitivity to climate plays a moderate role in the current state, structure or function of the indicator
- low (L) – 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 (9).

Developing worksheets to guide the process and document results (Table 3) can be helpful. Sample sensitivity and exposure matrices listed in Figure 3 are also helpful to visualize and compare results.

Table 3: Sensitivity and exposure worksheet

Indicator	Describe Existing Sensitivity	Rank Sensitivity (H,M,L)	Describe Existing Exposure	Rank Exposure (H,M,L)	Rank Overall Sensitivity and Exposure (H,M,L)

Figure 3: Sensitivity and exposure matrix



Alternatively, the adaptation planning team can utilize a variety of modelling tools to assess vulnerability. The document titled Tools for Climate Change Vulnerability Assessment for

Watersheds developed by CCME (40) provides a very thorough summary of modelling tools for assessing vulnerability. In this case, the modelling tools treat sensitivity and exposure separately. Table 4 provides an overview of the tools highlighted in the compendium that may be used to assess exposure of a watershed to climate change (40).

Table 4: Overview of models and tools that may be used to assess exposure (40)

Model	Description	Tool
Lumped Models	Tend to have minimal data requirements, are fast to setup and calibrate, and are simple to apply, yet provide less information than fully-distributed models	CANWET (Canadian Water Evaluation Tool)
		ForHyM (Forest Hydrology Model) and For WaDy (Forest Water Dynamics Model)
		HELP (Hydrologic Evaluation of Landfill Performance)
		Thornthwaite Monthly Water Balance Model
		WRENSS-ECA AB (Water Resource Evaluation of Nonpoint Silvicultural Sources methodology)
Semi-distributed Models	Tend to be more physically based than lumped models, but less data intensive than fully-distributed models	HSPF (Hydrological Simulation Program – FORTRAN Model)
		WEAP (Water Evaluation and Planning System)
Fully-distributed models	Tend to provide the highest accuracy and/or the most spatially intensive information, but require considerable data and expertise	MIKE SHE (System Hydrologique European)
		VIC (Variable Infiltration Capacity Model)
Indicators, indices, and statistical models	Vary widely in their structure, information needs, and output	Statistical modelling

Table 5: Overview of tools available to assess sensitivity (40)

System	Tool
Watershed	Indicators of watershed condition or function
	Biological indicators (bioindicators)
	Coupled or integrated watershed models
Human Conditions	Social vulnerability analysis
	Engineering vulnerability assessment
	Risk assessment
Freshwater ecosystems	Bioclimate envelope models
	Species or life history susceptibility
	Habitat or species models

Determine the adaptive capacity to address historic and current climate change impacts

The ability of a system to respond to climate change is determined in part by its adaptive capacity. If a system can cope with changes in climate, it is considered to have a high adaptive capacity, while a system that cannot respond to changes in climate has a low adaptive capacity. Adaptive capacity, in some cases termed resilience (40), is evaluated through the use of indicators of adaptive capacity. Adaptive capacity within natural assets, species or ecosystem components is often viewed as inherent traits that allow them to act or react to climate change. Built systems or communities often use indicators such as economic resources, technology, and social capital to define adaptive capacity (9, 12, 24, 33). Tools for Climate Change Vulnerability Assessment for Watersheds (40) provides a thorough overview of adaptive capacity of human communities and the resilience of freshwater ecosystems (Table 6).

Table 6: Examples of indicators of adaptive capacity for human communities, and resilience of freshwater ecosystems (40)

Adaptive capacity of human communities – example indicators	Resilience of freshwater ecosystems – example indicators
Economic resources	Genetic diversity
Technology	Integrity of landscape mosaic
Information, skills, and management	Biological diversity
Infrastructure	
Equity	

Using a ranking scale, and building on the indicators of adaptive capacity developed in Step 2, the adaptation planning team can apply these indicators to assess levels of adaptive capacity within the watershed. For example, high, moderate and low ranking could be chosen, where:

- high (H) – The indicator shows a high tolerance to change and a strong ability to adapt to new conditions or stresses
- moderate (M) – The indicator shows a moderate tolerance to change and some ability to adjust or adapt to new conditions or stresses
- low (L) – The indicator shows very little or no tolerance to change and limited ability to adapt to new conditions (9).

Like with sensitivity and exposure, the use of worksheets can help guide the process and document the results (Table 7). It is also helpful to describe any measure currently in practice that intends to increase the capacity of the system.

Table 7: Assessment of adaptive capacity

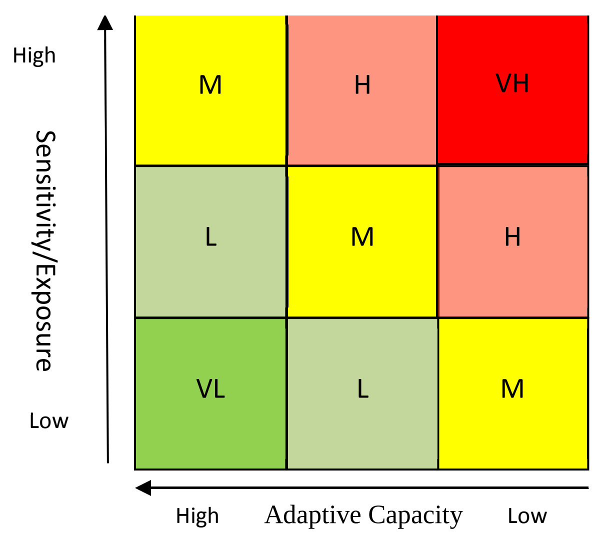
Indicator	Indicators of adaptive capacity	Description of current adaptive capacity	Rank Adaptive Capacity (e.g., H, M, L)

Assess vulnerability

Once sensitivity and exposure, and adaptive capacity are identified the results can be combined and the overall vulnerability of the system can be determined (9, 19, 24). As a function, vulnerability is the relationship between sensitivity and exposure divided by adaptive capacity.

A vulnerability matrix (Figure 4) and ranking system is helpful to define levels of vulnerability and display them in graphic form. For example:

Figure 4: Vulnerabilities ranked according to sensitivity/exposure and adaptive capacity



- very low = low sensitivity and exposure/high adaptive capacity
- low = low sensitivity and exposure/moderate adaptive capacity

- low = medium sensitivity and exposure/high adaptive capacity
- medium = medium sensitivity and exposure/moderate adaptive capacity
- medium = high sensitivity and exposure/high adaptive capacity
- medium = low sensitivity and exposure/low adaptive capacity
- high = high sensitivity and exposure/moderate adaptive capacity
- high = medium sensitivity and exposure/low adaptive capacity
- very high = high sensitivity and exposure/low adaptive capacity.

Results can also be tabulated into a worksheet (Table 8).

Table 8: Overall assessment of vulnerability

Indicator	Sensitivity/Exposure H, M, L	Adaptive Capacity H, M, L	Vulnerability VL, L, M, H, VH

Another ranking method to assess overall vulnerability would be to aggregate individual indicators into an overall score, or index (40). This task can provide valuable information about overall vulnerability; however users of this method should be aware of the challenges and assumptions associated with it. CCME provides a thorough overview in the compendium of tools for vulnerability assessments (40). Methods for developing aggregate indices include:

- simple averaging technique
- weighted averaging technique
- pareto ranking
- data envelopment analysis (DEA)
- vulnerability maps
- vulnerability profile.

Geographical Information System (GIS) mapping is a common and effective way to communicate the results of the assessments of sensitivity, exposure, adaptive capacity, and overall vulnerability (40) within the watershed.

While the results of the assessment of adaptive capacity are under current climate, the adaptation planning team is encouraged to consider how non-climate stressors will impact the watershed. These stressors can be significant and alter vulnerability regardless of the contribution from climate change.

Review results and communicate findings

When the assessment is complete, the final task in Step 3 is to review the results from the evaluation of sensitivity and exposure, adaptive capacity, and evaluate the overall vulnerability ratings for the watershed (12). This task is most appropriate in situations where outside parties such as contractors or researchers are conducting the vulnerability assessments. Reporting back to the adaptation planning team through meetings, workshops or webinars will present the opportunity to understand aspects of watershed climate change vulnerability and to probe or challenge the work of the contractors or adaptation planning team members (12). Communication of the results to other stakeholders who are not part of the adaptation planning team may also be undertaken as part of this step.

Update the record-keeping system

As with all previous steps in the adaptation planning process, activities and results stemming from the analyses in Step 3 should be carefully documented in the record-keeping system developed in Step 1. Notably indicators of sensitivity, exposure and adaptive capacity as well as the metrics used to quantify them should be documented.

STEP 4 – ASSESS FUTURE RISK

Purpose

The purpose of this step is to identify and prioritize the risks associated with future climate change.

Tasks

- Conduct risk analysis
- Conduct risk evaluation
- Communicate findings
- Review results

Outcomes

- Assessment of future vulnerabilities
- Prioritized risks
- Results communicated to stakeholders

The Watershed Context

The activities in Step Four are common to watershed and other types of adaptation planning. However the assessment of future risk in a watershed context will use consequences that pertain to aspects of the natural and built system of the watershed. Systems within a watershed are strongly interconnected and looking at one system or area can very easily grow to include additional systems or areas resulting in scope creep. In order to maintain scope it is extremely important to have clearly articulated goals and objectives and keep this at the forefront of the work.

For the purposes of this document risk is defined by the likelihood (or frequency) and consequences (or severity) of impacts associated with climate change on watershed or community systems (9, 12, 25, 33). Defining future climate risks helps to prioritize responses to both reduce levels of threat and to capitalize on opportunities as a result of climate change. In the context of existing vulnerabilities, projections of climate change as well as scenarios of hydrologic/ecosystem change present the range of possible future impacts on facets of the watershed, such as impacts to water quality, water quantity, aquatic habitat, aquatic species, etc. These data help inform both continued and potential new impacts within the watershed.

Conduct risk analysis

Assessing future risk helps watershed practitioners understand, analyze, and treat risks (33) associated with climate change.

In order to initiate the risk assessment process, the adaptation planning team should develop a climate change event likelihood rating scale. Definitions of likelihood can be developed by the adaptation planning team, or can be modified from other examples to suit specific applications (12). The analysis can identify the likelihood of the indicator being impacted by both single events (e.g., intense precipitation) and/or cumulative or ongoing occurrences (e.g., extended dry period) (33). The scale used to measure likelihood should align with the planning time horizon chosen at the beginning of the project (e.g., 30 years into the future; 40 years in to the future) (12, 33). Once the scale has been developed, likelihood of specific climate events or risk events can be estimated (9, 12, 33). For the purposes of this document, risk events are defined as the combination of the climate event and the resulting impact.

Creating a worksheet similar to Table 9 (33) can help guide the process and keep record of estimates of risk event likelihood. Notes should be taken and saved in order to document the reasoning behind all decisions during this stage of the process. Beginning with the indicators that scored the highest for vulnerability, the adaptation planning team can use expert judgment to estimate the likelihood of occurrence, or the likelihood of the indicator being impacted by future climate change (i.e., climate or risk event). At this stage, projections of future climate should be

Risk Management Guiding Principles

According to Black *et al.*, (33) the risk management process is built upon several important principles:

- **Identifying and engaging important affected or involved groups -** These groups and individuals should be identified and involved during the entire process. The project team may be modified to include members of these groups if it will help deal with the particular issue being addressed.

- **Communication -** The project team should develop an open and trustful dialogue with groups and individuals who may be affected or involved with the risk. This dialogue should continue throughout the process.

- **Documentation -** Records of important meetings, information sources, and all activities should be thoroughly and carefully taken. A data-storage system should be established so that the information is available in the future. This will help to:
  - review how risk rankings and risk control options were derived
  - provide baseline information for future iterations of the process and
  - promote accountability and transparency.

- **Use of existing tools, human and technical resources -** The project team should make maximum use of existing resources, such as data, local knowledge and technical expertise, and previously documented experiences.

- **Education and Awareness -** Municipal staff should have awareness and a good level of knowledge about climate change impacts and adaptation measures. This will help them successfully complete the risk management process. When adaptation measures are implemented, there may be a need to provide some education and awareness for stakeholders, and possibly the general public, to obtain their support.

used. Those projections will define the likelihood of the climate event/occurrence.

Table 9: Worksheet to document the estimate of likelihood

Climate or risk event:
Indicator:
Description of vulnerability:

Type of climate or risk event		**Estimate of Likelihood for time horizon (e.g., time horizon 2013 – 2053)**				
		Very Low	Low	Moderate	High	Very High
		Not likely to occur in time horizon	May occur once in time horizon	May occur once every 20 years during the time horizon	Likely to occur at least once every 10 years during time horizon	Likely to occur once or more annually during time horizon
Significant, single event						
Ongoing, cumulative event						

Next, the consequences stemming from the climate or risk event are estimated. Similar to the process for estimating likelihood, the adaptation planning team will develop, and define a consequence rating scale. Consideration can be given to categories similar to those developed by Black, *et al.*, (33) including social, economic, environmental, cultural and/or political consequences. Each category can also be expanded to delineate specific aspects. Table 10 (33) is an example of one way to track and evaluate consequences in the different categories.

Once the consequence under each category is estimated, an overall score for consequence can be determined. A blending or averaging of the individual consequence results will help determine the overall score for that risk event. Estimates of likelihood and consequence should be undertaken for all vulnerabilities identified in the previous step.

Table 10: Worksheet to document estimate of consequence

Climate or risk event:
Indicator:
Description of vulnerability:
Overall consequence score:

Consequence ranking	People				Economic			Environment			Other (e.g., cultural, political)		
	Health and Safety	Displacement	Loss of livelihood	Reputation	Infrastructure Damage	Financial impact		Air	Water	Land			
Very Low													
Low													
Moderate													
High													
Very High													

Conduct risk evaluation

The next task in this step is to evaluate the risk. The combination of likelihood and consequence establishes a risk score for indicators analysed under each climate/risk event. It is useful to develop a risk matrix comprised of axes for likelihood and consequence (Figure 5) that allows for a graphical display of the relative levels of risk for each risk event (12, 33). Upon completion of evaluations of likelihood and consequence, each risk event can be placed inside the risk matrix to visualize relative risk scores.

After the overall risk has been determined, the adaptation planning team should review each risk rating to determine if the risk score assigned is appropriate and realistic. For that reason, it is important to keep detailed notes of the process in order to revisit the decision-making rationale if necessary. If the ranking is deemed inappropriate, or unrealistic, the adaptation planning team can review the rationale for the ranking and make adjustments if necessary.

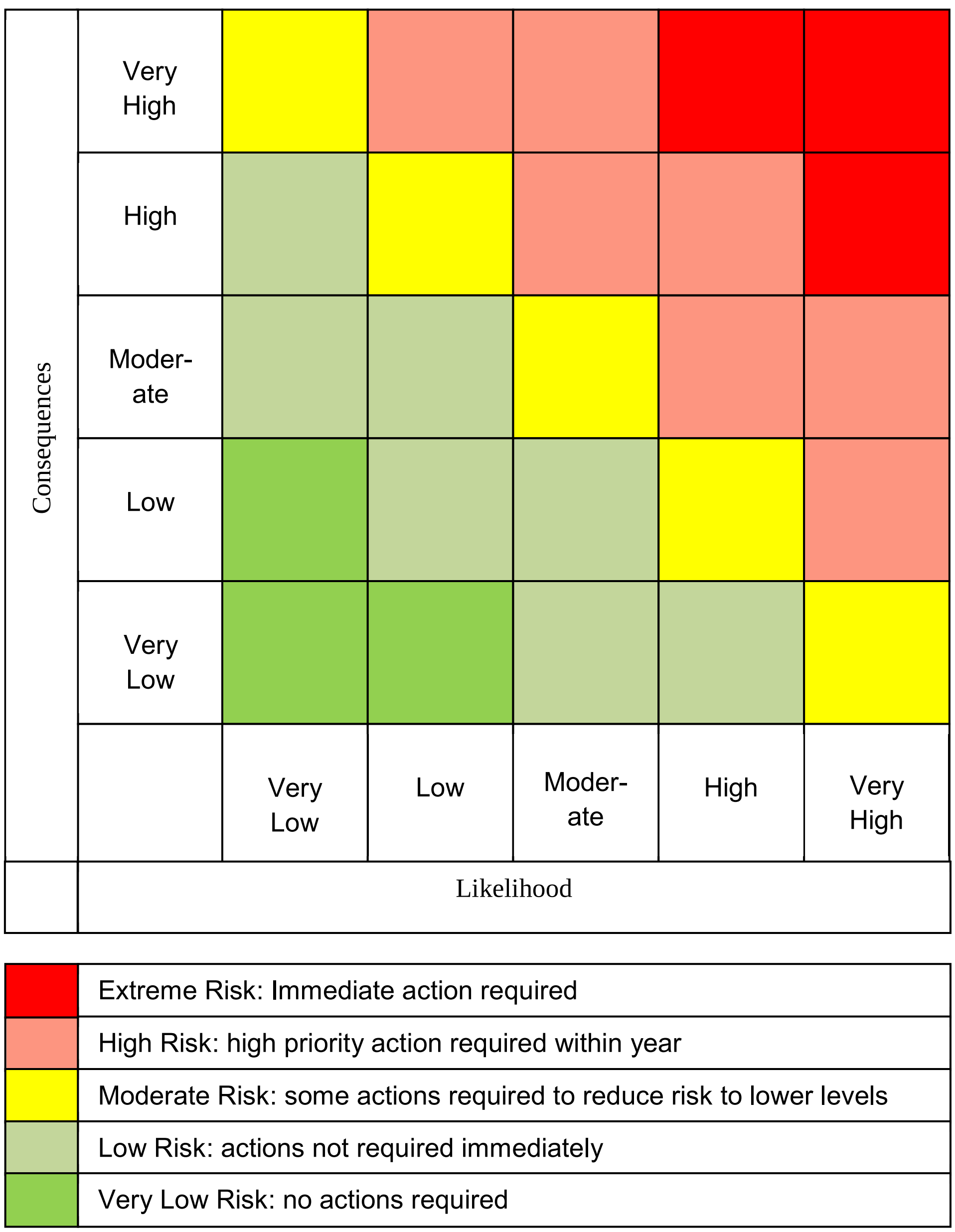
Communicate findings

Climate change adaptation risk guides emphasize the importance of communicating results throughout the process. Similar to the stakeholder communications mentioned in Step 3, the adaptation planning team is encouraged to bring results to outside parties, notably those who may be affected most by the climate change risks. Their individual values and perceptions of risk will help to reinforce or challenge the assessments undertaken as part of this step (9, 12, 33).

Review results

Following the communication of risk assessment results with the adaptation planning team and other stakeholders, a review exercise can be conducted. Chief considerations including potential loss of life, high financial costs of the impacts, or threats to valued ecosystems may be used to confirm or challenge the pending actions. Levels of risk tolerance or acceptability can also be assessed in this final part of Step 4 (12, 33). Tasks in this step should be carefully documented in the record-keeping system developed in Step 1.

Figure 5: Overall risk matrix



STEP 5 – GENERATE ADAPTATION SOLUTIONS

Purpose

The purpose of this step is to develop responses to the vulnerabilities and risks that were identified in previous steps through the generation of adaptation solutions. These measures are designed to reduce climate risk and to build resiliency within the watershed.

Tasks

- Establish goals and objectives
- Identify adaptation options
- Evaluate adaptation options
- Review and communicate results
- Update record-keeping system
- Develop adaptation plan

Outputs

- List of goals and objectives
- List of adaptation options
- Evaluation of adaptation options
- Results reviewed and communicated
- Adaptation plan developed

The Watershed Context

Generating a wide range of adaptation options or solutions to increase the capacity of systems to cope with climate change and reduce risks to acceptable levels is common to watershed and other types (regional/community or sector) of adaptation planning. Although generating adaptation solutions is common to adaptation planning regardless of a top-down or bottom-up approach, experience with the watershed and expertise in water and climate is needed to generate adaptation solutions at the watershed scale.

Establish goals and objectives

In order to focus adaptation solutions to respond to the risks identified in Step 4, goals and objectives to maintain focus should be established (19, 24, 51). Goals for this step could include overarching methods for developing adaptation solutions, ideals about the change in watershed resiliency, statements about engaging stakeholders, and the inclusion of different values or the timeliness of dealing with the risks identified. Goals are general, often broad statements that make reference to climate change, while objectives are more specific, and refer to how to reduce the risks associated with climate change. For example, the Climate Change Adaptation Plan for the Hamlet of Arviat, Nunavut (52) set out a series of overarching goals, with objectives specifying how to achieve the goals for the Hamlet of Arviat:

Project goals:

- increase awareness about the potential impacts of climate change
- assist the watershed in preparing for potential impacts (positive and negative)
- ensure that information is shared effectively with the watershed community and key stakeholders
- develop adaptation measures for climate change based on accurate information and prioritized watershed concerns.

To achieve these goals, specific objectives included:

- identification of how climate change will affect the community, based on community input, Traditional Knowledge/Inuit Quajimajatuquangit (IQ) and scientific analysis
- consideration of a range of issues and potential impacts including sea level rise, water supply, landscape hazards and other social, environmental, physical and economic factors
- development of a Climate Change Adaptation Action Plan to respond to these effects.

Goals can also help direct longer-term implementation of adaptations solutions, while objectives deal with short-term and medium-term solutions (19).

Identify adaptation options

With goals and objectives in place, the adaptation planning team can begin to consider developing a process by which adaptation actions will be generated. Although there are many different types of decision-facilitation tools available (scenario planning, emerging issues analysis, multi-criterion analysis) there are few clearly articulated examples of such tools applied to climate change adaptation planning. While there is no standard, agreed-upon method for generating adaptation options, methods chosen will likely align with the process to date. That is, adaptation planning methods that have engaged local stakeholders throughout the process will most likely continue to invite local input. This method also has the ability to harness local knowledge of historic methods used to deal with changing climate and their effectiveness as a continued solution. Top-down methods that use more sophisticated levels of science will often look to engage other experts such as consultants or watershed managers. Climate change literature has more recently begun to develop lists of adaptation options, most of which are divided into different categories corresponding to context, theme or level of application.

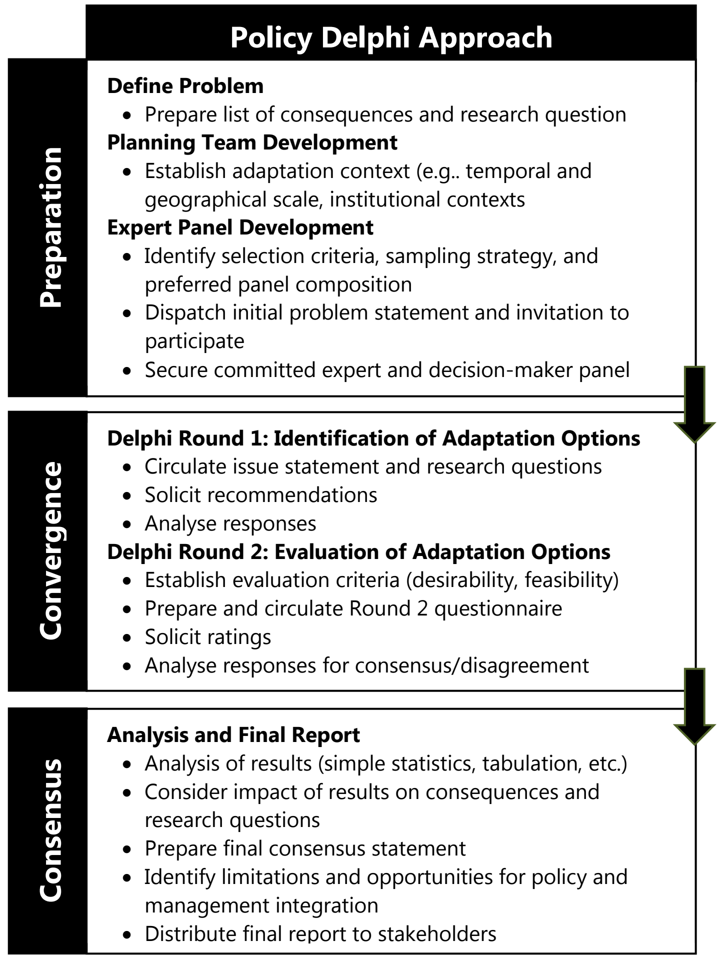
In general, the adaptation planning team will initiate the adaptation idea generating process focusing on the highest priority risks identified in the previous step. The adaptation planning team is encouraged to develop a full range of adaptation options, and not immediately consider constraints such as time, financial resources, or expertise to implement. Evaluation of the list of actions can be undertaken later in this step. Adaptation solutions should include short, medium and long-term options, the process should consider low cost solutions, no regrets and low regrets options (resiliency-building actions in the absence of climate change) and win-win options (actions that also mitigate greenhouse gas (GHG) emissions).

One common method of developing options for adaptation uses the expertise of the adaptation planning team, and technical experts who may or may not have been part of the planning process to date. Technical experts associated with the process to date or familiar with the watershed and its vulnerabilities should be invited to participate. These could include watershed stewardship group managers and staff, local stakeholders and/or government staff. Often a group setting such as a workshop or focus group can be used to bring people together to consider options. Starting with the highest priority risk, the adaptation planning team, and selected technical experts use their knowledge to develop a full list of adaptation options that could reduce the likelihood and consequences of the risk. Often, the actions developed turn out to be known best practices, or actions or programs that should be currently in place (e.g., in-stream nutrient monitoring).

The Policy Delphi presents an example of a published methodology used in many situations where ideas need to be generated. It is a useful methodology that can be applied in the context of adaptation planning. A Policy Delphi is an anonymous, group-oriented, idea generating strategy that seeks to enlist a diverse group of experts to interact anonymously to evaluate options for policy issues. The process is iterative and participants are requested to consider alternative points of view on the policy topic and work toward common agreement for solutions (17, 36, 51). Utilized in the Lake Simcoe (Ontario) Climate Change Vulnerability Assessment and Adaptation Planning Project, the Policy Delphi approach generated more than 900 recommendations for adaptation in seven categories. Subsequent iterations of the process resulted in 30 recommendations that helped inform the development of the Lake Simcoe Climate Change Adaptation Strategy (17).

Figure 6: Policy Delphi methodology used in the Lake Simcoe Climate Change Vulnerability Assessment to generate adaptation options

Case Study - Policy Delphi



The Lake Simcoe Climate Change Vulnerability Assessment used a Policy Delphi Method to develop risk reducing or adaptation measures. Policy Delphi is an iterative group-oriented Idea Generating Strategy (IGS) that seeks to generate the strongest possible opposing views on the potential resolutions of a major policy issue (17). The approach permits a diverse group of people, selected for their expertise, to interact anonymously on a defined policy issue, and provides a constructive forum and a structured method for correlating views and information pertaining to a specific policy issue (17). Participants are afforded the freedom to present and challenge alternative viewpoints, and to think reflectively and independently between iterations (17).

The Lake Simcoe Climate Change Vulnerability Assessment used two survey iterations (Figure 6) for their Delphi process. The first survey iteration presented their experts with the climate change vulnerabilities and consequences for several focus areas and asked for their recommendations on possible adaptation options. A workshop was also held to develop a comprehensive list of adaptation options for each of the focus areas. The second survey iteration focused on evaluating all of the recommendations for their perceived importance and feasibility (affordability and ease of implementation). The first priority results were identified, aggregated, and edited for a second workshop where participants were asked to evaluate the results and provide recommendations regarding a final suite of adaptation options. The process resulted in 30 recommendations to inform the development of the climate change strategy for Lake Simcoe.

Evaluate adaptation options

Once the adaptation planning team has generated a list of options that respond to the climate risks, the options should be reviewed, critiqued and evaluated. Developing a series of adaptation evaluation criteria can be helpful to make this exercise more structured (17, 51). It is appreciated that not all adaptation options will be immediately fully implemented. Criteria could include desirability (or importance), effectiveness, regulatory constraints, cost or affordability, stakeholder acceptance, ease of implementation, co-benefits, and institutional capacity or readiness (9, 51, 53). This evaluation helps prioritize the different adaptation options and the results will be useful if they become part of an adaptation plan. If required, the adaptation planning team can call on local stakeholders to help with the evaluation, notably those who will be responsible for implementing the adaptive measures or monitoring their effects (9). Douglas *et al*. (2011) developed a feasibility matrix to help assess the options against the criteria, dividing the adaptation options into first-, second- and third-order priority, and no priority. Similarly, Major and O'Grady (2010) developed a priority matrix to rank and evaluate adaptation options that divided them into near-, mid- and long-term priorities based on funding needed to implement and the timing of the climate change impact (e.g., impacts that are already being felt compared to impacts expected into the future).

The critical review of adaptation options may be complex. Ideas that are vetted by larger groups can bring significant differences of opinion on criteria such as political support, cost, and effectiveness. While there is no simple solution to this challenge, expertise in the area of question (e.g., stream rehabilitation specialist, hydrologist, elected officials, etc.) can often provide the best information to guide the decision.

The evaluation should also identify opportunities to integrate or coordinate adaptation into existing plans. This notion of mainstreaming climate change into existing policies, planning or programming will allow more of the regular day-to-day watershed decisions to be made with due consideration of the impacts of climate change. Understanding and engaging the groups responsible for implementing some of the adaptation actions will help to define with greater precision, considerations such as cost, timing and effectiveness. Coordinating with other stakeholders has the potential of lowering the cost of adaptation for an individual stakeholder, and helps to avoid the unintended consequences of implementing adaptation options that may negatively impact systems beyond the boundaries of the study area (35, 53, 54).

The results of this step are designed to generate a list of immediate actions that can be undertaken to deal with high climate risks. Following their evaluation, the adaptation options can then become part of a larger adaptation plan which would include aspects of implementation (Step 6).

Review and communicate results

Once the adaptation options have been generated and evaluated, the adaptation planning team should review the results to ensure they address the goals and objectives outlined at the beginning of the step. Upon completion the adaptation planning team may communicate the results to stakeholders. The actions generated, notably ones that will surface as high priority, may receive a variety of feedback from different stakeholder groups. Communicating the plan to different groups provides an opportunity to assess whether some adaptation actions could increase climate risk in certain areas. Cross-disciplinary evaluation will help identify conflict in implementing actions that may have been developed by only one sector or watershed theme.

Update record-keeping system

Again, all activities and outcomes in this step should be carefully documented in the record-keeping system developed in Step 1.

Develop adaptation plan

At this point, depending on the project, the adaptation planning team may want to develop an adaptation plan or strategy document. An adaptation plan document could provide a brief summary of the project, including the goals and objectives, vulnerabilities of the watershed, risks to the watershed as a result of climate change, and the actions proposed to address these risks. The adaptation plan could also include information on progress reporting and review. If the adaptation planning team decides to construct an adaptation strategy or plan, Steps 6 and 7 provide the final piece - the implementation and monitoring components.

STEP 6 – IMPLEMENT ADAPTATION SOLUTIONS

Purpose

In this step, the adaptation planning team works with pertinent stakeholders to develop an implementation plan and begin the process of implementing the adaptation activities defined in the previous step.

Tasks

- Develop implementation plan
- Initiate implementation
- Update record-keeping system
- Communicate solutions

Outcomes

- Implementation plan developed
- Implementation initiated
- Record keeping system updated
- Solutions communicated to stakeholders

The Watershed Context

The activities in Step Six are common to watershed and other types of adaptation planning. Various activities related to water resources management can occur within the same watershed, such as development of natural resources, agriculture, urban development and fisheries. Although the adaptation team consists of various technical, operational and management expertise it is important to include key stakeholders who work or reside in the watershed and who can successfully carry out the necessary activities and implement the plan. These key stakeholders may include multiple jurisdictions within and outside the watershed. One challenge will be undertaking integrated actions across the watershed that may include multiple jurisdictions.

Develop implementation plan

The purpose of an implementation plan is to break down the adaptation options into what actions will be taken and when, and who will carry out the tasks. For example, the implementation plan could outline who is responsible for implementing the adaptation measures, who will fund the adaptation measures, when the measures will be implemented, and how it will be measured (17). Depending on the scope of the project, the implementation plan could include:

- A list of staff that will be responsible for implementation of specific measures and their key roles and responsibilities (26, 35).
- Reference to how implementation will be funded (9, 26, 35). Funding adaptation can be one of the biggest challenges to implementation (56).
- Timeframe and schedule for implementation (e.g., short, medium, and long-term) (26, 33). The timeframe should be further defined in number of months or years. For example, climate change adaptation in the Region of Peel will be initiated over a 5 year period (57). It defines the actions as ongoing, short-term (to be initiated within 1 to 2 years), and medium-term (to be initiated within 2 to 5 years).
- List of the resources that are committed to implement the adaptation measures (e.g., human and material resources) (9, 35, 36, 53).
- Identification of where adaptation measures could be incorporated into existing plans, policies and budgets (9, 26, 28, 55).
- Reference to whether implementation has support from all decision-makers within the watershed (e.g., council, senior management, operations, etc.) (35).
- Opportunities for collaboration with nearby communities or organizations that may be involved in adaptation planning (28, 35, 55). For example, facing increased wildfire risks in the region, the City of Kamloops, British Columbia recognized the need to work with the Thompson-Nicola Regional District, the Ministry of Forests and the Kamloops Indian Band to develop cross-jurisdictional community fuel breaks along municipal boundaries (55).
- Identification of where expertise may be required (28).
- Conducting training of staff, elected officials, and key stakeholders (24).
- Development of internal and external education, communication and outreach strategies (28) (24). For example, the Okanagan Basin Water Board produced a Homeowner's Guide to Using Rain as a Resource in order to educate and engage the general public and complement regulatory measures (55).

Once a draft implementation plan is complete, it may be beneficial to review similar implementation plans in order to compare the processes and results and identify best practices (24, 28).

Initiate implementation

Once the implementation plan is complete, key personnel can begin implementing the adaptation measures (28, 35). The adaptation planning team could start with no regrets and low regrets options as they are usually easiest options to implement (9).

Update record-keeping systems

Similar to previous steps, continue to log the details of this step within the record-keeping system.

Communicate results

Once the implementation plan is in place, the adaptation planning team should present the plan to stakeholders who are not part of the team.

STEP 7 – MONITOR AND REVIEW

Purpose

The purpose of this step is to develop a plan to monitor the progress of implementation and the effectiveness of the adaptation measures.

Tasks

- Develop a monitoring and evaluation plan
- Assess new information
- Update adaptation plan
- Communicate accomplishments
- Update record-keeping system

Outcomes

- Monitoring and evaluation plan developed
- New information documented
- Adaptation plan updated
- Accomplishments communicated
- Record-keeping system updated

The Watershed Context

Monitoring and evaluating the success of adaptive actions is one of the least practiced aspects of climate change adaptation and is not specific to the watershed scale. Adaptation activities that are carried out as part of the adaptation plan will require proof of their effectiveness, especially if the costs of such activities are large. Tracking and monitoring implementation of the plan will i. ensure that risk-reducing measures are being put into place, ii. capture and report back any implementation challenges that are encountered and iii. gauge the effectiveness of the risk-reducing measures.

Develop a tracking, monitoring and evaluation plan

The adaptation planning team can develop a robust, long-term monitoring and evaluation plan in order to define what will be monitored, how it will be monitored, how it will be linked with reporting procedures, when the adaptation process will be reviewed or repeated, and when and what to record in the data-storage system (26, 35). The plan should also monitor the progress of the implementation plan, and be designed to capture and report to the adaptation planning team any problems that were encountered during implementation (24, 56). The adaptation planning team can establish a team to oversee this process (28).The implementation plan can also lay out details of how to deal with delays, changes to the delivery mode, reduced or increased funding, or new/competing priorities.

Monitoring and evaluation of the plan brings the concept of adaptive management to a practical level. Monitoring and evaluating the results of the adaptive actions and a method to return that information to the decision-making process is instrumental to continued reduction of climate risks. Monitoring and evaluating the impacts or effectiveness of the adaptation actions can be accomplished using the baseline data, key indicators and metrics that the adaptation planning team defined in Step 2, as well any new watershed indicators (9, 28, 31). The indicators can be used to monitor changes to aspects of the watershed in the context of adaptation measures that were implemented. Monitoring and evaluation of adaptation measures also help the adaptation planning team determine whether or not an adaptation measure has reduced or eliminated climate vulnerability and risk, and increased the capacity of the watershed to cope with climate change. A green roof that was installed at the British Columbia Institute of Technology Centre for Architectural Ecology in Burnaby, British Columbia was monitored to assess its effectiveness at reducing run-off from the roof top. Results showed that the green roof delayed the run-off from the roof for up to three hours and reduced peak flow by 90% (55).

The monitoring program should also be well coordinated with other monitoring initiatives in the watershed. Long-term hydrologic and/or ecosystem datasets can provide the backdrop for pending changes associated with adaptation plans.

Selected Tools to Evaluate Water Monitoring Networks for Climate Change Adaptation (31)

This document describes proven and practical ways for jurisdictions to set priorities for water monitoring networks for climate change adaptation, and then evaluate the ability of these networks to provide the data needed to support climate change adaptation needs.

Assess new information

Maintaining relevant and accurate information throughout the adaptation process is essential as changes in climate and resulting watershed impacts can happen quickly (24, 35). Capturing and utilizing new watershed science, research and information, or additional local knowledge as it emerges helps in the re-evaluation process for watershed vulnerability, risks and the adaptation options that were identified as priorities (9, 35). The amount and relative significance of the new information will help determine when the iterative adaptation implementation process can be revisited.

Update adaptation plan

Climate change adaptation plans should undergo review on a regular basis (e.g., every three to five years) to avoid becoming obsolete (33). The adaptation planning team is encouraged to use results from the monitoring program to revisit the vulnerability and risk assessments that were conducted in the initial steps of the adaptation implementation process. The adaptation planning team can also make changes to the assessments based on monitoring results, observed changes, new climate science, recent climate events, changes to exposure and/or adaptive capacity, and completed actions (56). Once the plan is updated, the next round of implementation can be launched with these new goals and objectives in mind.

Communicate accomplishments

The results of improved watershed resiliency and reduced risk from climate change are worthy of communicating to outside groups. Accomplishments can be communicated to stakeholders, decision-makers, organizations, or other staff that have an interest in the project, participated in the project or are affected by the adaptation activities. This can be accomplished through ongoing public education and outreach, annual or semi-annual progress reports, press releases, briefing notes, website updates, or workshops (9, 24, 26, 28).

Update record-keeping system

Step 7 has produced the monitoring and evaluation plan for the adaptation implementation process. Like other steps, this piece of information should be included in the record-keeping system. With the process complete, consideration should be given to who will store the records and where they will be stored. Back-ups of the records can be developed for security purposes and members of the adaptation planning team should be apprised of their whereabouts (24, 28).

CONCLUSION

The process of watershed-based climate change adaptation planning can be tailored to meet the needs of every watershed. This Framework defines a literature-supported series of steps that will help identify climate change impacts and effectively manage them. It also logically builds on previous CCME research on water monitoring networks and vulnerability assessment.

Mainstreaming and adaptive management are two principles of adaptation planning that are central to this process. Although this process, by design, is a stand-alone, independent exercise that is undertaken by watershed managers, mainstreaming climate change into existing policy, plans or programs is an effective way to identify potential threats from climate change. Accessing and using climate information in the context of watershed decision-making will capitalize on existing efforts and stimulate broader adaptation planning in other sectors, themes, departments, etc. Mainstreaming climate change into existing decision-making also ensures that future processes account for climate change impacts and the adaptation within the decision-making structure.

Adaptive management pertains to the ability to monitor progress, evaluate results and revisit aspects of the decision-making process when necessary. Adaptive management is referred to as 'learning by doing'. In the context of less than perfect certainty about future climates, using the best science to proceed with decision-making requires results evaluation, a feedback mechanism and nimble decision-making. Organizational readiness for adaptation planning and implementation is also considered instrumental to success in dealing with climate change impacts. The complexity of watersheds combined with their dynamic nature will require continuous adaptation in order to achieve the goals of resiliency, health and functionality.

This Framework can help governments, watershed agencies and organizations understand the impacts of climate change, assess watershed vulnerabilities and risks, and adaptively manage the natural assets in order to sustain ecosystem resiliency.

ENDNOTES

1. **Conservation Ontario.** What is a Watershed. *Conservation Ontario.* [Online] 2009. http://www.conservation-ontario.on.ca/what-is-a-watershed
2. **BC Water & Waste Association.** *BCWWA Position Statement - Watershed Management Planning.* 2011. p. 12.
3. **Dessai, S. and Hulme, M.** Does climate adaptation policy need probabilities? *Climate Policy.* 2004, Vol. 4, pp. 107-128.
4. **van Aalst, M. K., Cannon, T. and Burton, I.** Community level adaptation to climate change: The potential role of participatory community risk assessment. *Global Environmental Change.* 2008, Vol. 18, pp. 165-179.
5. **Smit, B. and Wandel, J.** Adaptation, adaptive capacity and vulnerability. *Global Environmental Change.* 2006, Vol. 16, pp. 282-292.
6. **Burton, I., Malone, E. and Huq, S.** *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures.* [ed.] B. Lim and E. Spanger-Siegfried. Cambridge : Cambridge University Press, 2004. p. 263. United Nations Development Programme. ISBN 0 521 61760 X paperback.
7. **National Research Council.** Adaptive Management Theories, Frameworks, and Practices. [book auth.] Committee to Assess the U.S. Army Corps of Engineers Methods of Analysis and Peer Review for Water Resources Project Planning, National Research Council Panel on Adaptive Management for Resource Stewardship. *Adaptive Management for Water Resources Project Planning.* Washington : The National Acadamies Press, 2004, 2, pp. 52-82.
8. **Elemental Sustainability Consulting Ltd.** The Municipal Climate Change Plan Assistant: Learning from Others.
9. **Gleeson, J., *et al.*** A Practitioner's Guide to Climate Change Adaptation in Ontario's Ecosystems. [Online] 2011. http://www.climateontario.ca/doc/Tools/A%20Practitioners%20Guide%20to%20ClimateChange%20Adaptation%20in%20Ontario's%20Ecosystems%20Ver%201%202011.pdf . ISBN 978-1-4435-7304-7 (PDF).
10. **Halifax Regional Municipality.** Climate change developer's risk management guide. [Online] 2007. http://ccap.org/docs/resources/394/DevelopersGuidetoRiskManagment.pdf.
11. **Service Nova Scotia and Municipal Relations and Canada-Nova Scotia Infrastructure Secretariat.** Municipal Climate Change Action Plan Guidebook: Canada-Nova Scotia Agreement on the Transfer of Federal Gas. [Online] 2011. https://fcm.ca/Documents/tools/PCP/municipal_climate_change_action_plan_guidebook_EN.pdf.
12. **Alberta Sustainable Resource Development.** Climate Change Adaptation Framework Manual. [Online] 2010. http://aep.alberta.ca/forms-maps-services/publications/climate-change-adaptation-framework.aspx
13. **Australian Government.** Climate Change and Risk Management: A Guide for Business and Government. [Online] 2006. http://www.climatechange.gov.au/community/~/media/publications/local-govt/risk-management.ashx.
14. **ICLEI Oceania.** Local Government Climate Change Adaptation Toolkit. Cities for Climate Protection Australia Adaptation Initiative. [Online] 2008. http://www.iclei.org/
15. **Williamson, T. B., *et al.*** A framework for assessing vulnerability of forest-based communities to climate change. [Online] 2007. http://cfs.nrcan.gc.ca/pubwarehouse/pdfs/27507.pdf.
16. **Lalonde, R., *et al*.** Climate Change Vulnerability Assessment and Adaptation Options for Ontario's Clay Belt: A Case Study. [Online] 2012. http://www.mnr.gov.on.ca/stdprodconsume/groups/lr/@mnr/@climatechange/documents/document/stdprod_100191.pdf. . ISBN 978-1-4606-0195-2.
17. **Douglas, A., *et al.*** Adapting to Climate Change: Tools and Techniques for an Adaptive Approach to Managing for Climate Change. [Online] 2011. http://www.climateontario.ca/doc/workshop/2011LakeSimcoe/Lake%20Simcoe%20Adaptation%20Options%20Final%20Report%20June%20%202011.pdf.
18. **Gray, Clifford and Larson, Erik.** *Project Management: the managerial process.* 4th. Boston : McGraw-Hill Irwin, 2008. p. 589. ISBN-13: 978-0-07-352515-0.
19. **Columbia Basin Trust.** Six Step Planning Process. *Columbia Basin Trust: Adaptation Resources.* [Online] 2010. http://adaptationresourcekit.squarespace.com/six-step-planning-process/.
20. **England's Highway Agency.** Climate Change Adaptation Strategy and Framework. [Online] 2009. http://assets.highways.gov.uk/about-us/climate-change/CCAF_Strategy_and_Vol_1_Rev_B_Nov.pdf.
21. **Ranger, N., *et al*.** Adaptation in the UK: a decision-making process. [Online] 2010. http://personal.lse.ac.uk/RANGERN/PB-adaptationUK-rangeretal.pdf.

22. **Ebi, Kristie L., Lim, Bo and Aguilar, Yvette.** Scoping and Designing an Adaptation Project. [book auth.] Ian Burton, Elizabeth Malone and Saleemul Huq. [ed.] Bo Lim and Erika Spanger-Siegfried. *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures.* New York : Cambridge University Press, 2004, 1, pp. 33-46.
23. **Barry, L. and Weigeldt, N.** *Having the Climate Conversation: Strategies for Local Governments.* s.l. : ICLEI-Local Governments for Sustainability (Management) Inc., 2012. p. 112.
24. **ICLEI Local Governments for Sustainability.** Changing Climate, Changing Communities: Guide and Workbook for Municipal Climate Adaptation. [Online] http://www.iclei.org/.
25. **Ouranos.** *Élaborer un plan d'adaptation aux changements climatiques. Guide destiné au milieu municipal québécois.* 2010. p. 48.
26. **Canadian Institute of Planners.** Climate Change Adaptation Planning: A Handbook for Small Canadian Communities. [Online] 2011. http://fcm.ca/Documents/tools/PCP/climate_change_adaptation_planning_handbook_for_small_canadian_communities_EN.pdf.
27. **Tusz-King, M.** Local Government, Sustainability and Climate Change: A Resource for Elected Municipal Officials in New Brunswick, 2012. [Online] 2012. http://atlanticadaptation.ca/sites/discoveryspace.upei.ca.acasa/files/Municiple_Guidebook_English_Sept_2012.pdf
28. **Black, R., Bruce, J. and Egener, M.** *Adapting to Climate Change: A Risk Management Guide for Local Governments in British Columbia - Volume 1.* 2010.
29. **Collaborative for Advanced Landscape Planning (CALP).** Local Climate Change Visioning and Landscape Visualization: Guidance Manual. [Online] 2010. http://calp.forestry.ubc.ca/?s=Local+Climate+Change+Visioning+and+Landscape+Visualization%3A+Guidance+Manual.
30. **Government of Australia.** Prospering in a Changing Climate: A Climate Change Adaptation Framework for South Australia. [Online] 2012. http://www.sa.gov.au/
31. **CCME.** *Selected Tools to Evaluate Water Monitoring Networks for Climate Change Adaptation.* s.l. : Canadian Council of Ministers of the Environment, 2011.
32. **Conde, Cecilia and Lonsdale, Kate.** Engaging Stakeholders in the Adaptation Process. [ed.] Bo Lim and Erika Spanger-Siegfried. *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures.* New York : Cambridge University Press, 2004, pp. 47-66.
33. **Black, R., Bruce, J. and Egener, M.** *Adapting to Climate Change: A Risk Management Guide for Ontario Municipalities.* 2012.
34. **United Nations.** *Manual for the Design and Implementation of Recordkeeping Systems.* s.l. : United Nations, Archives and Records Management Section (ARMS), June 2006.
35. **Bizikova, L. T., Neale, T. and Burton, I.** Canadian Communities' Guidebook for Adaptation to Climate Change. Including an approach to generate mitigation co-benefits in the context of sustainable development. [Online] 2008. http://fcm.ca/Documents/tools/PCP/canadian_communities_guidebook_for_adaptation_to_climate_change_EN.pdf.
36. **Gray, P. A., *et al.*** A Model Process Developing Adaptation Options for Natural Heritage Areas in an Era of Rapid Climate Change. *The George Wright Forum.* 2011, Vol. 28, 3, pp. 314-328.
37. **Centre for Indigenous Environmental Resources.** Climate Change Planning Tools for First Nations. Guidebook 5: Taking Adaptive Action. [Online] 2006. http://ppw.ca/WorkArea/showcontent.aspx?id=638.
38. **MacRitchie, Scott and Stainsby, Eleanor.** *Lake Simcoe Watershed Climate Change Vulnerability Assessment - Water Quality and Quantity.* 2011.
39. **Mortsch, Linda and Hebb, Andrea J.** Assessing Vulnerability to Climate Change and Flooding in the City of London, Upper Thames River Basin, Ontario. *Plan.* Spring 2008, pp. 41-44.
40. **CCME.** *Tools for Climate Change Vulnerability Assessments for Watersheds.* s.l. : Canadian Council of Ministers of the Environment, Water Monitoring and Climate Change Project Team, Water Management Committee, 2013. p. 137.
42. **Smit, B, *et al*.** Adaptation to climate change in the context of sustainable development and equity. [ed.] James J. McCarthy, *et al*. *Climate Change 2001: Impacts, Adaptation, and Vulnerability.* Cambridge : Cambridge University Press, for the Intergovernmental Panel on Climate Change, 2001, pp. 877-912.

43. **Fussel, Hans-Martin and Klein, Richard J.** Climate change vulnerability assessments: an evolution of conceptual thinking. *Climatic Change.* 2006, Vol. 75, pp. 301-329.
44. **IPCC.** *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* [ed.] M. L. Parry, *et al*. s.l. : Cambridge University Press, Cambridge, UK, 2007. p. 976. ISBN 978 0521 70597-4.
45. **Downing, Thomas E. and Patwardhan, Anand.** Assessing Vulnerability for Climate Adaptation. [ed.] Bo Lim and Erika Spangler-Siegfried. *Adaptation Policy Framework for Climate Change: Developing Strategies, Policies and Measures.* New York : Cambridge University Press, 2004, pp. 67-91.
46. **Pittman, J.** *Institutional Adaptations to Climate Change Project: Report on the Community Vulnerability Assessment of Outlook, Saskatchewan.* s.l. : Prairie Adaptation Research Collaborative, 2008. p. 35.
47. **Chu, C. and Fischer, F.** *Climate Change Vulnerability Assessment for Aquatic Ecosystems in the Clay Belt Ecodistrict (3E-1) of Northeastern Ontario.* s.l. : Ontario Ministry of Natural Resources, CCRR-30, 2012.
48. **Parker, W. C., Colombo, S. J. and Sharma, M.** *An Assessment of the Vulnerability of Forest Vegetation of Ontario's Clay Belt (Ecodistrict 3E-1) to Climate Change.* Sault Ste. Marie, Ontario : Ontario Ministry of Natural Resources, CCRR - 32, 2012. p. 47.
49. **Bowman, J. and Sadowski, C.** *Vulnerability of Furbearers in Ontario's Clay Belt to Climate Change.* Peterborough, Ontario : Ontario Ministry of Natural Resources, Wildlife Research and Development Section, CCRR - 25, 2012. p. 24.
50. **IPCC.** *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change.* [ed.] C. B. Field, *et al*. Cambridge, UK, and New York, NY, USA : s.n., 2012. p. 582. ISBN 978-1-107-02506-6.
51. **Lemieux, C. J. and Scott, D. J.** Changing Climate, Challenging Choices: Identifying and Evaluating Climate Change Adaptation Options for Protected Areas Management in Ontario, Canada. *Environmental Management.* 2011, Vol. 48, pp. 645-690.
52. **Sullivan, M and Nasmith, K.** *Climate Change Adaptation Plan - Hamlet of Arviat, Nunavut: Building capacity in Community Planning.* 2010.
53. **Major, D. C. and O'Grady, M.** Adaptation Assessment Guidebook. Appendix B. New York City Panel on Climate Change. *Annals of the New York Academy of Sciences.* May 18, 2010, Vol. 1196, 1, pp. 229-292.
54. **Cross, M. S., *et al*.** The Adaptation for Conservation Targets (ACT) Framework: A Tool for Incorporating Climate Change into Natural Resource Management. *Environmental Management.* 2012, Vol. 50, 3, pp. 341-351.
55. **Carlson, D.** *Preparing for Climate Change: An Implementation Guide for Local Governments in British Columbia.* British Columbia : West Coast Environmental Law, 2012. 978-0-919365-31-5.
56. **National Oceanic and Atmospheric Administration (NOAA).** Adapting to Climate Change: A Planning Guide for State Coastal Managers. [Online] 2010. http://coastalmanagement.noaa.gov/climate/docs/adaptationguide.pdf.
57. **Region of Peel.** *Peel Climate Change Strategy Background Report - A strategic plan for climate change for the geographic Region of Peel.* Mississauga : s.n., 2011.
58. **Yukon Environment.** Climate Change in Yukon: Physical Impacts. *Government of Yukon, Department of the Environment, Impacts of Climate Change.* [Online]
59. **Government of British Columbia.** *Preparing for Climate Change: British Columbia's Adaptation Strategy.* s.l. : Ministry of the Environment, Government of British Columbia, 2010. p. 8.
60. **ICLR.** *Telling the Weather Story.* Institute of Catastrophic Loss Reduction for Insurance Bureau of Canada. Ottawa : Insurance Bureau of Canada, 2012. p. 67

APPENDIX A

Glossary

The following definitions are from IPCC Fourth Assessment Report Climate Change 2007: Working Group II: Impacts, Adaptation and Vulnerability (44) unless otherwise noted.

Adaptation - Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory, autonomous and planned adaptation:
Anticipatory adaptation - Adaptation that takes place before impacts of climate change are observed. Also referred to as proactive adaptation.
Autonomous adaptation - Adaptation that does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems. Also referred to as spontaneous adaptation.
Planned adaptation - Adaptation that is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state.

Adaptive Capacity - in relation to climate change impacts, the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

Baseline - baseline (or reference) is the state against which change is measured. It might be a 'current baseline', in which case it represents observable, present-day conditions. It might also be a 'future baseline', which is a projected future set of conditions excluding the driving factor of interest. Alternative interpretations of the reference conditions can give rise to multiple baselines.

Climate Change - refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), which defines 'climate change' as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'. See also climate variability.

Climate projection - The calculated response of the climate system to emissions or concentration scenarios of greenhouse gases and aerosols, or radiative forcing scenarios, often based on simulations by climate models. Climate projections are distinguished from climate predictions, in that the former critically depend on the emissions/concentration/radiative forcing scenario used, and therefore on highly uncertain assumptions of future socio-economic and technological development.

Climate variability - refers to variations in the mean state and other statistics (such as standard deviations, statistics of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability). See also climate change.

Exposure - The presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected (IPCC, SREX report) (50).

Extreme weather event - An event that is rare within its statistical reference distribution at a particular place. Definitions of 'rare' vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile. By definition, the characteristics of what is called 'extreme weather' may vary from place to place. Extreme weather events may typically include floods and droughts.

Sector - A distinct part, especially of society or of a nation's economy.

Sensitivity - Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea-level rise).

Uncertainty - An expression of the degree to which a value (e.g., the future state of the climate system) 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 the data to ambiguously defined concepts or terminology, or uncertain projections of human behaviour. Uncertainty can therefore be represented by quantitative measures (e.g., a range of values calculated by various models) or by qualitative statements (e.g., reflecting the judgement of a team of experts).

Vulnerability - is 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, its sensitivity, and its adaptive capacity.

APPENDIX B

Indicator Number	Parameter Category	Indicator	Hydrologic Parameters Needed	Non-hydrologic Parameters Needed	Calculation	Known Users of Indicator	Reference
1	Ice	Change in glacier terminus	Position of glacier terminus	Not applicable	Difference between reference terminus position and new position	Used by the BC Ministry of the Environment	BC Ministry of the Environment, 2002. (http://www.env.gov.bc.ca/air/climate/indicat/glacier_id1.html)
2	Ice	Change in freezing/melting dates	First date of permanent ice/date of complete freezing/maximum thickness/date of first melt/ice-free date	Not applicable	Not applicable	Used by the BC Ministry of the Environment	BC Ministry of the Environment, 2002. (http://www.env.gov.bc.ca/air/climate/indicat/freez_id1.html)
3	Precipitation	Average 30-year precipitation	Total precipitation	Not applicable	Average annual precipitation during the last 30 years (mm/year)	Component of the AWRVI developed for Arctic communities	Alessa *et al*., 2008.
4	Precipitation	5-year moving average precipitation	Total precipitation	Not applicable	The 5-year moving average annual or seasonal precipitation is calculated for each station.	Used by the Clean Annapolis River Project	Mehlman, 2003.
5	Precipitation	Change in average precipitation	Total precipitation	Not applicable	For each season and each ecozone (minimum of three stations per ecozone), the total precipitation is subtracted from the 1960-1990 average	Used by the BC Ministry of the Environment	BC Ministry of the Environment, 2002. (http://www.env.gov.bc.ca/air/climate/indicat/precip_id1.html)
6	Precipitation	Aridity	Total precipitation and annual potential evapotranspiration	Not applicable	Ratio of total annual precipitation to annual potential evapotranspiration	Used by the Council for Scientific and Industrial Research	Beekman, Saayman, and Hughes, 2003.
7	Precipitation	Precipitation surplus-deficit	Total precipitation and annual potential evapotranspiration	Not applicable	Subtracting the potential evapotranspiration (using Penman PE calculations) from total precipitation	Used by the International Institute for Sustainable Development	Grosshans, Venema and Barg, 2005.
8	Precipitation	Precipitation variability	Total precipitation (GIS layer)	Not applicable	Maps showing total precipitation used to calculate and construct a precipitation variability map. Coefficients of variability for each pixel area are calculated.	Used by the International Institute for Sustainable Development	Grosshans, Venema and Barg, 2005.
9	Precipitation	Variance in annual precipitation	Total precipitation	Not applicable	Variance in annual precipitation over recent 30-year period (σ/x)	Component of the AWRVI developed for Arctic communities	Alessa *et al*., 2008.
10	Precipitation	Dry periods	Rain precipitation	Not applicable	The cumulative monthly rainfall deficit during the last five years calculated by comparing the monthly total rainfall with the 30-year average. All months with more than 20% lower rainfall than the average are included in the calculation	Developed by the South Pacific Applied Geoscience Commission (SOPAC), the UN Environment Programme (UNEP) and their partners	http://www.sopac.org/index.php/environmental-vulnerability-index
11	Precipitation	Wet periods	Rain precipitation	Not applicable	The cumulative monthly rainfall surplus during the last five years calculated by comparing the monthly total rainfall with the 30-year average. All months with more than 20% higher rainfall than the average are included in the calculation	Developed by the South Pacific Applied Geoscience Commission (SOPAC), the UN Environment Programme (UNEP) and their partners	http://www.sopac.org/index.php/environmental-vulnerability-index
12	Precipitation	Precipitation anomalies	Total precipitation	Not applicable	For each ecozone, 1961-1990 average mean monthly precipitation totals are subtracted from the mean monthly precipitation to generate anomalies in mm for each month. These anomalies are added for each year to generate an annual precipitation anomaly.	Used by the US EPA	U.S. EPA, 2008.
13	Precipitation	Number of Days with High, Low, and No Precipitation	Total Precipitation	Not applicable	Number of days per year with no (<0.25 mm), low (between 0.25 and 2.5 mm) and high (>2.5 mm) precipitation	Used by the Clean Annapolis River Project	Mehlman, 2003.

Indicator Number	Parameter Category	Indicator	Hydrologic Parameters Needed	Non-hydrologic Parameters Needed	Calculation	Known Users of Indicator	Reference
14	Precipitation	Annual moisture index	Total precipitation	Number of degree days above 5°C	Ratio of the number of degree-days above 5°C and the mean annual precipitation	Used by the Alberta Climate Change Adaptation Team (ACCAT)	Sauchyn *et al*., 2008.
15	Precipitation	Summer moisture index	Total precipitation	Number of degree days above 5°C	Number of degree-days >5°C divided by mean growing season precipitation	Used by the Alberta Climate Change Adaptation Team (ACCAT)	Sauchyn *et al*., 2008.
16	Precipitation	Prcp1	Total precipitation	Not applicable	Number of days per year with more than 1 mm of precipitation (%)	Used by the Climate Change Action Fund of Environment Canada	Gachon *et al*., 2005.
17	Precipitation	SDII	Total precipitation	Not applicable	Total precipitation during all wet days (days where precipitation was greater than 1 mm) divided by number of wet days in a year (mm/day)	Used by the Climate Change Action Fund of Environment Canada	Gachon *et al*., 2005.
18	Precipitation	CDD	Total precipitation	Not applicable	Maximum number of consecutive dry days in a year (defined as days where precipitation is less than 1 mm) (days)	Used by the Climate Change Action Fund of Environment Canada	Gachon *et al*., 2005.
19	Precipitation	R3D	Total precipitation	Not applicable	Maximum amount of precipitation received during three consecutive days (mm)	Used by the Climate Change Action Fund of Environment Canada	Gachon *et al*., 2005.
20	Precipitation	Prec90pc	Total precipitation	Not applicable	The daily precipitation during wet days (days where precipitation is greater than 1 mm) is listed in increased order and the 90th percentile value is noted (using the Cunnane formula: (0.9 * (W + 0.2)) + 0.4 where W is the number of wet days	Used by the Climate Change Action Fund of Environment Canada	Gachon *et al*., 2005.
21	Precipitation	Extreme precipitation events	Total Precipitation	Not applicable	Number of precipitation events consisting of more than 50 mm of rain (or snow water equivalent) during a 48-hour period is counted for each year and for all meteorological stations	Used by the Gulf of Maine Council on the Marine Environment	Wake *et al*., 2006.
22	Precipitation	Palmer Drought Severity Index (PDSI)	Total Precipitation	Air temperature, available water content of the soil	The PDSI is the most prominent index of drought used in Canada and measures the cumulative deficit (relative to local mean conditions) in surface land moisture by incorporating previous precipitation and estimates of moisture drawn into the atmosphere (based on atmospheric temperatures) into a hydrological accounting system. Typically ranges from -4 (extreme drought) to 4 (extremely wet). Note: Several other major drought indices are listed below	Used by the Intergovernmental Panel on Climate Change; Agriculture and Agri-Food Canada	IPCC, 2008.
23	Precipitation	Drought Frequency per the Palmer Drought Severity Index (PDSI)	Total Precipitation	Air temperature, available water content of the soil	Frequency of continuous time periods where the PDSI is less than the 20th percentile of the PDSI distribution over the period of available years	Used by the Intergovernmental Panel on Climate Change	IPCC, 2008.
24	Precipitation	Mean Drought Duration per the Palmer Drought Severity Index (PDSI)	Total Precipitation	Air temperature, available water content of the soil	Mean duration of continuous time periods where the PDSI is less than the 20th percentile of the PDSI distribution over the period of available years	Used by the Intergovernmental Panel on Climate Change	IPCC, 2008.
25	Precipitation	Proportion of land surface in drought per the Palmer Drought Severity Index (PDSI)	Total Precipitation	Air temperature, available water content of the soil, total land area	Proportion of land surface at any given time experiencing continuous time periods where the PDSI is less than the 20th percentile of the PDSI distribution over the period of available years	Used by the Intergovernmental Panel on Climate Change	IPCC, 2008.
26	Precipitation	Crop Moisture Index (Drought Index)	Total Precipitation	Air temperature, available water content of the soil	The Crop Moisture Index is derived from the PDSI, but while the PDSI monitors long-term wet and dry spells, the CMI was designed to evaluate shorter-term moisture conditions	Used by the United States Department of Agriculture	NDMC, 2006.
27	Precipitation	Surface Water Supply Index (Drought Index)	Total Precipitation, aerial extent of snowpack, depth of snowpack, river flow rate, reservoir storage	Not applicable	A region-specific index designed to resemble the PDSI, but take into account snow accumulation and large topographic variations across a region. Differs from the Surface Water Supply Index in that it includes duration and a temperature-based demand compo	Used by the Colorado Division of Water Resources	NDMC, 2006.

Indicator Number	Parameter Category	Indicator	Hydrologic Parameters Needed	Non-hydrologic Parameters Needed	Calculation	Known Users of Indicator	Reference
28	Precipitation	Reclamation Drought Index	Total Precipitation, aerial extent of snowpack, depth of snowpack, river flow rate, reservoir storage	Air temperature	A region-specific index designed to resemble the PDSI, but take into account snow accumulation and large topographic variations across a region. Differs from the Surface Water Supply Index in that it includes duration and a temperature-based demand component	Used by the Oklahoma Water Resources Board	NDMC, 2006.
29	Precipitation	Percent of Normal (Drought Index)	Total Precipitation	Not applicable	The current precipitation as percent of the 30-year mean precipitation	Used by the National Climatic Data Center (U.S.)	NDMC, 2006.
30	Precipitation	Standardized Precipitation Index (Drought Index)	Total Precipitation	Not applicable	The Standardized Precipitation Index was designed to quantify the precipitation deficit for multiple time scales. It is calculated as difference of precipitation from the mean for a time scale ranging from 1-24 months, divided by the standard deviation	Used by the National Drought Mitigation Center (U.S.)	NDMC, 2006.
31	Precipitation	Deciles (Drought Index)	Total Precipitation	Not applicable	Groups monthly precipitation occurrences into deciles so that "much lower than normal" weather cannot occur more often than 20% of the time	Used by the Australian Drought Watch System	NDMC, 2006.
32	Precipitation and Flows	Dryness ratio	Total precipitation and river flowrate	Not applicable	Share of total average annual precipitation that is lost through evapotranspiration. Calculate as the ratio of annual precipitation minus unregulated mean annual streamflow to the annual precipitation	Developed by 14 US Water Resources Experts	Hurd *et al*., 1999.
33	Snow	Snow cover season	Areal extent of snowpack	Not applicable	Ratio of the number of days with snow cover and 365 days	Used by the Alberta Climate Change Adaptation Team (ACCAT)	Sauchyn *et al*., 2008.
34	Snow	Number of days with snow on the ground	Areal extent of snowpack	Not applicable	For each year, a summation of number of days with snow on the ground is performed	Used by the Gulf of Maine Council on the Marine Environment	Wake *et al*., 2006.
35	Snow	Mean snow cover	Areal extent of snowpack	Not applicable	Mean snow cover over a specified period of time	Used by National Resources Canada	Furgal *et al*., 2008.
36	Snow	SCD1	Depth of snowpack	Not applicable	The number of days in the first half of the snow cover year (August to January) with daily snow depth greater than or equal to 2 cm	Used by State of the Canadian Cryosphere	SOCC, 2003.
37	Snow	SCD2	Depth of snowpack	Not applicable	The number of days in the second half of the snow cover year (January to July) with daily snow depth greater than or equal to 2 cm	Used by State of the Canadian Cryosphere	SOCC, 2003.
38	Snow	SCD Total	Depth of snowpack	Not applicable	The number of days in the snow cover year (August to July) with daily snow depth greater than or equal to 2 cm	Used by State of the Canadian Cryosphere	SOCC, 2003.
39	Snow	Maximum, mean, median and standard deviation of snow depth	Depth of snowpack	Not applicable	Maximum, mean, median and standard deviation of daily snow depth during period of continuous snow cover	Used by State of the Canadian Cryosphere	SOCC, 2003.
40	Snow	Date of maximum snow depth	Depth of snowpack	Not applicable	Date of maximum daily snow depth during period of continuous snow cover	Used by State of the Canadian Cryosphere	SOCC, 2003.
41	Snow	First date of continuous snow cover	Depth of snowpack	Not applicable	The first date where there were 14 consecutive days with daily snow depth greater than or equal to 4 cm	Used by State of the Canadian Cryosphere	SOCC, 2003.
42	Snow	Last date of continuous snow cover	Depth of snowpack	Not applicable	The first date where there were 14 consecutive days with daily snow depth less than 4 cm	Used by State of the Canadian Cryosphere	SOCC, 2003.
43	Snow	% of Normal	Depth of snowpack	Not applicable	The current value as percent of the current date's normal	Used by United States Department of Agriculture	USDA, 2009.
44	Snow	% of Normal Peak	Depth of snowpack	Not applicable	The current value as percent of the normal seasonal peak for the year	Used by United States Department of Agriculture	USDA, 2009.
45	Snow	Percentile	Depth of snowpack	Not applicable	Ranking with respect to data on the same day of the year for other years in the period of ranking. Equal to the fraction of available years whose data is less than the current year's value (i.e. 100% means that all other years are less than the present value)	Used by United States Department of Agriculture	USDA, 2009.

Indicator Number	Parameter Category	Indicator	Hydrologic Parameters Needed	Non-hydrologic Parameters Needed	Calculation	Known Users of Indicator	Reference
46	Flows	Average 30-year annual river runoff	Runoff Quantity	Not applicable	Average annual watershed runoff during the last 30 years ($m^3/s \cdot km^2$/year)	Component of the AWRVI developed for Arctic communities	Alessa *et al*., 2008.
47	Flows	Variance in river runoff	Runoff Quantity	Not applicable	Variance in annual river runoff over recent 30-year period (σ/x)	Component of the AWRVI developed for Arctic communities	Alessa *et al*., 2008.
48	Flows	Change in the 1/3-volume and 1/2-volume cumulative annual discharge dates	River flowrate	Not applicable	Record date when cumulative flow at a certain point in a river equals 33.3% and 50.0% of annual flow	Used by the BC Ministry of the Environment	BC Ministry of the Environment, 2002. (http://www.env.gov.bc.ca/air/climate/indicat/timevol_id1.html)
49	Flows	Change in the peak annual discharge date	River flowrate	Not applicable	Record date of peak annual discharge	Used by the BC Ministry of the Environment	BC Ministry of the Environment, 2002. (http://www.env.gov.bc.ca/air/climate/indicat/timevol_id1.html)
50	Flows	Level of Development	River flowrate	Total annual surface and groundwater withdrawal	Ratio of total annual surface and groundwater withdrawal to unregulated mean annual streamflow	Developed by 14 US Water Resources Experts	Hurd *et al*., 1999.
51	Flows	Natural streamflow variability	River flowrate	Not applicable	Coefficient of variation (CV) of unregulated streamflow, computed as the ratio of the standard deviation of unregulated annual streamflow to the unregulated mean annual streamflow	Developed by 14 US Water Resources Experts	Hurd *et al*., 1999.
52	Flows	Groundwater depletion	Groundwater baseflow	Average groundwater withdrawal in a year	Ratio of average groundwater withdrawals in a year to annual average baseflow, reflecting the extent that groundwater use rates may be exceeding recharge.	Developed by 14 US Water Resources Experts	Hurd *et al*., 1999.
53	Flows	High streamflow	River flowrate	Not applicable	For each site, the annual three-day high flow volume is calculated for five consecutive years and the median value is compared to the 1941-1960 median average three-day high flow volume baseline.	Used by the US EPA	U.S. EPA, 2008.
54	Flows	Low streamflow	River flowrate	Not applicable	For each site, the annual seven-day low flow volume is calculated for five consecutive years and the median value is compared to the 1941-1960 median average seven-day low flow volume baseline.	Used by the US EPA	U.S. EPA, 2008.
55	Flows	Streamflow variability	River flowrate	Not applicable	Difference between the 1st and 99th percentile 1-day flow volumes in a given year, divided by the median 1-day flow	Used by the US EPA	U.S. EPA, 2008.
56	Flows	Dry season flow by river basin	Runoff quantity	Population in the river basin	Ratio of runoff volume during the four consecutive months with the lowest cumulative runoff to the population	Developed by the World Resources Institute	Unknown, 2004.
57	Flows	Variability of flow	Runoff quantity	Not applicable	Ratio of 95th percentile surface runoff to the 5th percentile surface runoff.	Developed for assessment of climate change vulnerability of US watersheds	Unknown, 2004.
58	Flows	Seasonal variation in monthly river discharge	River flowrate	Not applicable	The minimum monthly river streamflow is subtracted from the maximum monthly river streamflow and divided by the average monthly streamflow	Component of the AWRVI developed for Arctic communities	Alessa *et al*., 2008.
59	Temperature	Permafrost distribution	Ground Temperature	Area of continuous permafrost, discontinuous permafrost and permafrost-free land	Percentage of the land comprised of continuous, discontinuous and permafrost-free areas.	Component of the AWRVI developed for Arctic communities	Alessa *et al*., 2008.

Indicator Number	Parameter Category	Indicator	Hydrologic Parameters Needed	Non-hydrologic Parameters Needed	Calculation	Known Users of Indicator	Reference
60	Temperature	Sea temperatures	Sea temperature	Not applicable	The 30-year mean annual sea surface temperature is subtracted from the average annual sea surface temperature during the last five years	Developed by the South Pacific Applied Geoscience Commission (SOPAC), the UN Environment Programme (UNEP) and their partners	http://www.sopac.org/index.php/environmental-vulnerability-index
61	Temperature	Sea surface temperature anomalies	Sea temperature	Not applicable	1880-2006 average annual sea surface temperature is subtracted from the average annual temperature to generate anomalies in °F for each year.	Used by the US EPA	U.S. EPA, 2008.
62	Temperature	Trends in sea-surface temperature	Sea temperature	Not applicable	For each month and each ecozone, the daily temperature readings are averaged for the entire monitoring period to establish the "normal" sea temperature. Then for each month of the recording period, the "normal" monthly temperature is subtracted from the average monthly temperatures. These anomalies are averaged for each year to observe trends.	Used by the BC Ministry of the Environment	BC Ministry of the Environment, 2002. (http://www.env.gov.bc.ca/air/climate/indicat/pdf/seasurftemp_tdoc2.pdf)
63	Temperature	Change in sea surface temperature	Sea temperature	Not applicable	Percent change in sea surface temperature compared to baseline	Used by the Australian Government Department of Climate Change	Hobday *et al*., 2006.
64	Temperature	Change in sea temperature at 500 m depth	Sea temperature	Not applicable	Percent change in sea temperature at 500 m depth compared to baseline	Used by the Australian Government Department of Climate Change	Hobday *et al*., 2006.
65	Temperature	Water Temperature	Surface water temperature	Not applicable	7-day moving average of the highest daily temperature (°C)	Used by the Oregon Coastal Watershed Health Indicators Project	Bauer *et al*., 2008.
66	Soil Moisture	Maximum, minimum, mean, median and standard deviation of soil moisture	Soil moisture content	Not applicable	Maximum, minimum, mean, median and standard deviation of soil moisture over a specified period of time	Used by the National Institute of Water & Atmospheric Research Ltd. (New Zealand)	Tait *et al*., 2007.
67	Soil Moisture	Soil Moisture Percentile	Soil moisture content	Not applicable	Current soil moisture conditions in percentile with respect to historical conditions	Used by the University of Washington Experimental Surface Water Monitor for the Continental U.S.	Wood *et al*., 2008.
68	Soil Moisture	Change in Soil Moisture Percentile	Soil moisture content	Not applicable	Change in soil moisture percentile for the month leading up to the current day	Used by the University of Washington Experimental Surface Water Monitor for the Continental U.S.	Wood *et al*., 2008.
69	Soil Moisture	Relative Soil Moisture Index (RSMI)	Soil moisture content	Soil moisture content at wilting point and at field capacity	Dryness relative to wilting point, calculated as $RSMI = [(\theta_t – \theta_{wp}) / (\theta_{fc} – \theta_{wp})] \times 100\%$ where θ_t - actual soil moisture content; θ_{wp} - soil moisture content at wilting point; and θ_{fc} - soil moisture content at field capacity	Used by the Walloon Agricultural Research Centre	Buffet *et al*., 2005.
70	Soil Moisture	Soil Moisture Deficit Ratio (SMD)	Soil moisture content	Not applicable	Dryness during a given month, calculated as $SMD = [(SM_i – SM_i^{mean}) / (SM_i^{max} – SM_i^{min})] \times 100\%$ where SM_i^{mean} - long-term mean soil moisture for month i; SM_i^{max} - long-term maximum soil moisture for month i; SM_i^{min} - long-term minimum soil moisture for month i; SM_i - actual soil moisture during month i in any year (where i = 1…..12)	Used by the Texas Water Development Board	Srinivasan *et al*., 2002.
71	Soil Moisture	Soil Moisture Index	Soil moisture content	Not applicable	The culmulative SMD, calculated as $X_i = X_{i-1} + (SMD_i / 36.51) – 0.32X_{i-1}$ where X_i = soil moisture index during month I; X_{i-1} = soil moisture index during the previous month (i-1); and SMD_i = soil moisture deficit ratio for month i	Used by the Texas Water Development Board	Srinivasan *et al*., 2002.

Indicator Number	Parameter Category	Indicator	Hydrologic Parameters Needed	Non-hydrologic Parameters Needed	Calculation	Known Users of Indicator	Reference
72	Soil Moisture	Risk of soil erosion by wind (E_{wind})	Soil moisture content	Surface roughness and aggregation factor, soil resistance to movement by wind factor, drag velocity, variable related to the soil moisture content when erosion begins, erosion reduction factor	Agricultural area subject to wind erosion, that is the area for which there is a risk of degradation by wind erosion above a certain reference level. Calculate as $E_{wind} = KC (V^2 - \rho W^2)^{1.5} (1 - R)$ where K = Surface roughness and aggregation factor; C = soil resistance to movement by wind factor; V = drag velocity; ρ = variable related to the soil moisture content when erosion begins; W = surface soil moisture content; and R = erosion reduction factor, e.g. crop type. See reference for details	Used by the Organization for Economic Co-operation and Development	OECD, 2001.
73	Groundwater and Surface Water Quality	Water Quality Index	Water quality parameters	Not applicable	$WQI = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right)$ where F1 = scope, F2 = frequency and F3 = amplitude. See link for details	Developed by the CCME	Canadian Council of Ministers of the Environment, 2001.
74	Groundwater Quality	Naturally-occurring groundwater quality problems index	Groundwater quality parameters	Studied aquifer area	Percentage of areas in the aquifer in which the concentration of the indicator parameter exceeds the maximum level specified in the WHO drinking water guidelines (or equivalent)	Developed by the United Nations Educational, Scientific and Cultural Organization	Groundwater Indicators Working Group, 2007.
75	Groundwater Quality	Groundwater under human stress quality problems index	Groundwater quality parameters	Studied aquifer area	Percentage of areas in the aquifer where an increase in concentration of a specific variable was detected during the observation period	Developed by the United Nations Educational, Scientific and Cultural Organization	Groundwater Indicators Working Group, 2007.
76	Groundwater Quality	GALDIT index	Salt concentration	Groundwater occurrence, aquifer hydraulic conductivity, depth to groundwater level above the sea, distance from the shore, thickness of the aquifer	An index for the assessment of aquifer vulnerability to saltwater intrusion in coastal aquifers based on several indicators of varying weights (with respect to the other indicators, W) and importance ratings (based on range of indicator results, R). Calculate as GALDIT Index = $\Sigma W_i R_i / \Sigma W_i$ where the indicators are Groundwater occurrence; Aquifer hydraulic conductivity; depth to groundwater Level above the sea; Distance from the shore; Impact of existing status of sea water intrusion in the area; and Thickness of the aquifer. See link for details	Developed by Euro - India International Cooperation with Developing Nations	Chachadi *et al*., 2005.
77	Groundwater Quality	Position of saline front	Total Dissolved Solids (TDS), salt concentration	Not applicable	The extent of saltwater intrusion. No standard practice exists for defining the transition zone; however, the USGS typically characterizes the transition zone as having TDS concentrations between 1,000 and 35,000 mg/L and chloride concentrations between 250 and 19,000 mg/L (where lower limits are World Health Organization recommended guidelines and upper limits are average concentrations of TDS and chloride in seawater)	Used by the U.S. Geological Survey	In-Situ Inc., 2008
78	Ocean Dynamics	Change in sea surface currents	Current strength	Not applicable	Percent change in average sea surface currents compared to baseline	Used by the Australian Government Department of Climate Change	Hobday *et al*., 2006.
79	Water Level	Changes in water temperature	Ground/groundwater/sea/surface water	Not applicable	Record temperature measured at the same time each day	Used by the BC Ministry of the Environment	BC Ministry of the Environment, 2002. (http://www.env.gov.bc.ca/air/climate/indicat/rivtemp_id1.html)

Indicator Number	Parameter Category	Indicator	Hydrologic Parameters Needed	Non-hydrologic Parameters Needed	Calculation	Known Users of Indicator	Reference
80	Water Level	Rise in sea level	Sea water level	Not applicable	One-minute average sea level is measured every minute and referenced to the nautical chart datum	Used by the BC Ministry of the Environment	BC Ministry of the Environment, 2002. (http://www.env.gov.bc.ca/air/climate/indicat/sealevel_id1.html)
81	Water Level	Surface water resources	Total surface water area	Total land area	Ratio of total surface water area divided by total land area	Developed by Agriculture and Agri-food Canada	Swanson, Hiley and Venema, 2007.
82	Water Level	Percent surface water storage in watershed	Total surface water area	Watershed area	The percentage land area of a watershed that is of a land-cover type representing lakes, ponds, rivers, wetlands and other water bodies.	Component of the AWRVI developed for Arctic communities	Alessa *et al.*, 2008.
83	Water Level	Variability in surface water	Total surface water area	Not applicable	The coefficient of variation of percentage of surface water area of the watershed over a 30-year period	Component of the AWRVI developed for Arctic communities	Alessa *et al.*, 2008.
84	Water Level	Absolute and relative change in sea level	Sea water level	Not applicable	The 1993-1997 absolute and relative mean annual sea level at monitoring stations are subtracted from the absolute and relative annual sea level	Used by the US EPA	U.S. EPA, 2008.
85	Water Level	Sea Level Rise Risk (for islands)	Sea water level	Total island land area and area of land less than 5 m above the sea level	Percentage of the land less than 5 m above the sea level and divided by 10.	Used by UNEP Islands	http://islands.unep.ch/indicat.htm
86	Water Level	Groundwater recharge and population	Groundwater level	Population	Ratio of groundwater recharge to population	Used by UNEP/GRID-Geneva	Brooksa, Adgera and Kelly, 2005.
87	NA	Water flow per area	NA	Municipal, industrial, commercial and private well water use and area	Ratio of total human water flow (m^3) to area (km^2)	Used by the International Institute for Sustainable Development	Grosshans, Venema and Barg, 2005.
88	NA	Water Exploitation Index	Precipitation, evapotranspiration and streamflow	Public, agriculture, industrial and energy sector water consumption	For each sector, calculate the ratio between the mean total annual quantity of consumed water and the long-term average of available water. The long-term average of available water is precipitation minus evapotranspiration plus inflow into the country	Used by the European Environment Agency	http://nfp-si.eionet.europa.eu/Dokumenti/pdf/2003en/4-vode_en.pdf