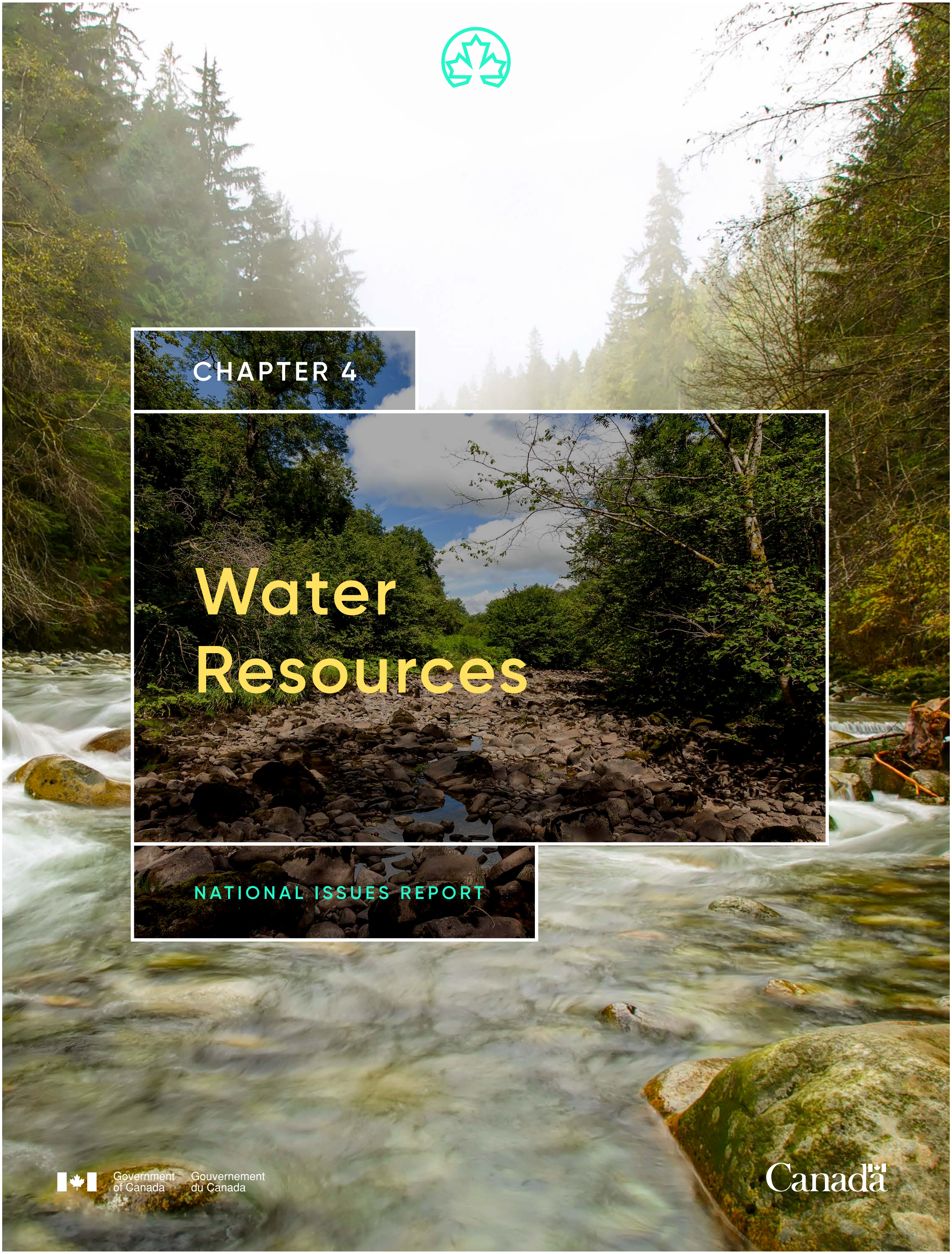

CHAPTER 4

Water Resources

NATIONAL ISSUES REPORT

Government of Canada Gouvernement du Canada

Canada

Coordinating lead authors

Hayley Carlson, Global Water Futures Program, Global Institute for Water Security, University of Saskatchewan

Alain Pietroniro, PhD, P.Eng., Department of Civil Engineering, Schulich School of Engineering, University of Calgary

Lead authors

Patricia Gober, PhD, Global Water Futures Program, Global Institute for Water Security, University of Saskatchewan

Wendy Leger, Boundary Water Issues Unit, Environment and Climate Change Canada, Government of Canada

Stephanie Merrill, Global Water Futures Program, Global Institute for Water Security, University of Saskatchewan

Contributing authors

Laila Balkhi, University of Saskatchewan

Sarah Foley, University of Saskatchewan

Bob Halliday, R. Halliday & Associates Ltd.

Lawrence Martz, PhD, University of Saskatchewan

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Key messages

Climate change creates risks for water resources (*see* Section 4.2)

Global climate change has already altered patterns of rainfall, snow, ice and permafrost melt, exacerbating existing water availability and quality issues, as well as changing the nature and timing of water-related natural hazards, such as floods and droughts.

Effective coordination across complex water systems enhances adaptation (*see* Section 4.3)

Canadian organizations and institutions are unevenly prepared to manage water-related risks associated with climate change. Partnerships and networks allow organizations at a variety of scales to access additional resources, share knowledge and risk, and enhance adaptive capacity. Transboundary and watershed organizations offer useful insights into effective coordination of water systems with diverse stakeholders that are dealing with high uncertainty.

Adaptation is advancing through innovation and adaptive management (*see* Section 4.4)

There are promising examples of coordination and innovation in the water sector across Canada. New approaches use scenarios to explore how decision-making strategies perform across a range of plausible futures, implement iterative processes for monitoring and adjusting actions, and engage stakeholders in social learning, laying the groundwork for innovation and adaptation.

It is vital to engage the public and build awareness about adaptation opportunities (*see* Section 4.5)

Successful adaptation requires public buy-in to the science of climate change and the need to implement adaptation policies. A majority of Canadians support policies to address water-related problems, but managing water resources ranks low on their list of salient problems after the economy, health care, and cost of living. Extreme events, including floods, droughts and episodes of poor water quality, can often bring the need for better water management to the forefront.

Water system vulnerability can be reduced through quality data and resilient design (*see* Section 4.6)

Reducing vulnerabilities in water systems involves identifying weak spots under current and future climate conditions, and providing access to high quality and locally relevant data. While the quality and resolution of data for monitoring change in uncertain environmental systems is variable, resilient design practices are emerging.

4.1 Introduction

Water is the vehicle that delivers many climate change impacts to society and the environment (IPCC, 2014). Water is a locally variable resource, and society's vulnerability to climate-related hazards, such as the impacts from flooding and drought, differ from one region to another. Vulnerability to hazards also stems from the ability of societal institutions to adequately prepare for and manage the new risks of climate change.

The availability of water is naturally limited, and water is not always in the right place at the right time, or of the right quality or quantity. Significant and varied water infrastructure and management systems have developed across Canada, designed primarily around the assumption that past natural variability is a reliable and robust indicator of future variability (Milly et al., 2008). With climate change, this assumption is no longer as valid, leaving practitioners and water managers often facing difficult and complex decisions (Simonovic, 2017).

Canada faces some special challenges in adapting its water systems to climate change. These include our large land mass, diverse geography, northern location and wide range of climate and hydrological regimes, coupled with a broad range of consumptive and non-consumptive uses that control the timing and supply of water resources (Statistics Canada, 2017). There are, for example, over 15,000 dams of various sizes administered by myriad jurisdictions, including federal, provincial and territorial governments, municipalities, irrigators, industries and utilities, for a wide range of purposes, including hydroelectricity, water supply, flood control, and mining and tailings management (Canadian Dam Association, 2019). The highly fragmented nature of water governance is also significant. While the constitutional responsibility for water resources management lies primarily with the provinces, the nature of the resource means that water resources are governed and managed by a complex system of stakeholders and partners, including governments at different levels, with participation from a variety of non-governmental organizations, local communities, and Indigenous and environmental organizations (Renzetti and Dupont, 2017). Effective coordination across these decision-making units enhances the capacity to share risk, learn from one another and seize opportunities to reduce vulnerability.

This chapter assesses the most up-to-date knowledge on climate and hydrological science and adaptation processes, and applies this knowledge to discuss the challenges, needs and opportunities that lie ahead for Canadian water resource managers and planners. The science presents a compelling case for action. However, equally important to assessing adaptation are the strengths and capacities of Canadian water institutions for changing business-as-usual systems of practice. In a large and diverse country like Canada, it is not surprising that the pace of adaptation is uneven, with more evidence of innovative local-scale responses, and less progress towards comprehensive national-scale strategies.

This chapter summarizes major adaptation efforts, while assessing the capacity of Canadian water institutions to respond to climate change and its associated uncertainties and complexities. It investigates the capacity of these institutions to plan for a future that may be substantially different from the past, to initiate a conversation about the kind of water future that people want and the policies needed to get there. It is still unclear whether governance systems, institutional practices and monitoring programs can change quickly enough to avert significant disruption and missed opportunities. Canada's institutional changes with respect to water resources are spotty and often bottom-up, but the case studies reviewed in this chapter demonstrate that local-level initiatives can serve as guides for more robust national action.

4.2 Climate change creates risks for water resources

Global climate change has already altered patterns of rainfall, snow, ice and permafrost melt, exacerbating existing water availability and quality issues, as well as changing the nature and timing of water-related natural hazards, such as floods and droughts.

Climate change impacts to the water cycle have already occurred, leading to damaged infrastructure, increased operating costs, disrupted operating seasons, and deteriorating water quality through excess nutrients and harmful algae blooms. Changes to overall water availability are projected to be more pronounced in the future, especially under high emissions scenarios. It is not always easy, however, to isolate climate change impacts from effects caused by human development, such as land use change. Human development can exacerbate or reduce climate-driven changes, introducing a considerable amount of uncertainty into the adaptation process.

4.2.1 Observed changes

Climate change has already affected Canada's cold-dominated water cycle, and has introduced risks to society and the environment (*see* Figure 4.1). Observed annual average temperature increases for Canada are about twice the global average, and more than three times the global average in Northern Canada (Zhang et al., 2019). *Canada's Changing Climate Report* (Bush and Lemmen, 2019) synthesizes the most recent scientific evidence of climate change impacts. Observed changes from the report that are relevant to water resources include:

- **Melting ice, thawing permafrost and shorter duration of snow cover**. Glaciers and ice fields are melting, thinning and retreating at unprecedented rates. Permafrost has warmed at many sites from the edge of the boreal forest to the tundra, and is disappearing along its southern boundaries. The portion of the year with snow cover and lake ice cover has decreased by 5% to 10% per decade since 1981 and seasonal snow accumulation has decreased in many regions (Derksen et al., 2019). These changes are particularly pronounced in Northern Canada, and present risks to the structural integrity of infrastructure (Lemmen et al., 2014) and can disrupt shipping routes and winter roads (Campbell et al., 2014; Lemmen et al., 2014). Over time, these changes may also introduce new mining and tourism opportunities in northern regions (Kovacs and Thistlethwaite, 2014; Lemmen et al., 2014), and are anticipated to increase the productivity of northern ecosystems as nutrients become more readily available (Orihel et al., 2017).
- **Increasing precipitation and a transition from snow to rain**. Precipitation has increased across all regions by an average of 20% since 1948. The greatest increases have occurred in Northern Canada and parts of Manitoba, Ontario, northern Quebec and Atlantic Canada. Precipitation is falling more often as rain rather than snow, especially in the spring and fall (Zhang et al., 2019). Increased precipitation and subsequent runoff have been linked with excess nutrients in water systems, increasing the incidence of harmful algae blooms (McCullough et al., 2012).

- **Changes in the timing of water availability**. The total volume of water flowing through a river basin[1] in an average year shows very little change, but significant shifts in timing have been observed (Bonsal et al., 2019). There is an increasing risk that less water may be available in hotter months for energy (Lemmen et al., 2014) and food production (Campbell et al., 2014), as early snowmelt contributes to lower summer flows (Bonsal et al., 2019). River and lake freeze-up now occurs later in the winter and over a shorter period of time, while ice break-up occurs earlier in the spring (Derksen et al., 2019). These shifts in timing can affect farming and industrial operations, and disrupt the natural patterns to which ecosystems have adapted (Islam et al., 2017; Campbell et al., 2014).
- **Changes in the nature of extreme events**. There are detectable changes in the nature of flood events in some areas, with more rain-on-snow events, rainfall-driven events and earlier spring flooding (Bonsal et al., 2019). For example, climate change played a role in the extreme rainfall events that contributed to the 2013 Calgary flood (Teufel et al., 2017), the 2014 Assiniboine flood (Szeto et al., 2015), and the 2017 Ottawa floods (Teufel et al., 2019). Canadian municipal planners rank extreme storm events and flooding as the two most frequently experienced climate change impacts (McMillan et al., 2019), and these events can increase contaminant loads in water systems, degrading water quality (Gooré Bi et al., 2015; Jalliffier-Verne et al., 2015). While costly, observed changes in droughts to date represent yearly variations from the normal, rather than the product of long-term trends related to climate change (Bonsal et al., 2019).

Thus far, these observed changes have resulted in varied impacts to average annual river flows and lake levels (Bonsal et al., 2019) due to the tremendous amount of variation in natural systems and increased evaporation (Bonsal et al. 2019; Bush et al., 2019). There remains considerable uncertainty, especially in terms of predicting the timing, magnitude and direction of changes in precipitation. For example, while there do not appear to be detectable trends in short-duration extreme precipitation events in Canada (Zhang et al., 2019), other studies find increasing trends in extreme precipitation events over large portions of North America (Kirchmeier-Young and Shang, 2020; Paplexiou and Montanari, 2019). Unfortunately there is no consensus in the literature, largely because rainfall is extremely difficult to simulate, especially summertime convection. Ultimately, reported changes are really a patchwork of different changes across Canada that are heavily influenced by such things as latitude, altitude and proximity to lakes, which makes a pan-Canadian assessment very local by necessity. Additionally, human management decisions related to land-use, water management and changing socioeconomic conditions (Bonsal et al., 2019; Statistics Canada, 2017), can reduce or exacerbate climate change-driven processes, and can impact the water cycle on the same order of magnitude as hydroclimatic changes (Döll et al., 2015). For example, while some climate change processes have been linked to deterioration of water quality in Canada, a number of studies have also found strong links to land-use intensification with agricultural production and urban development (Weiss et al., 2018; El-Khoury et al., 2015; Gooré Bi et al., 2015; Jalliffier-Verne et al., 2015; Taranu et al., 2015). These human management elements introduce considerable uncertainties into future projections and complexities into future decision making (*see* Case Story 4.1).

1 A river basin refers to the area of land that drains into a river, including its contributing tributaries such as streams and creeks. Watersheds represent smaller sub units of a river basin that capture precipitation and drains it towards a water source.

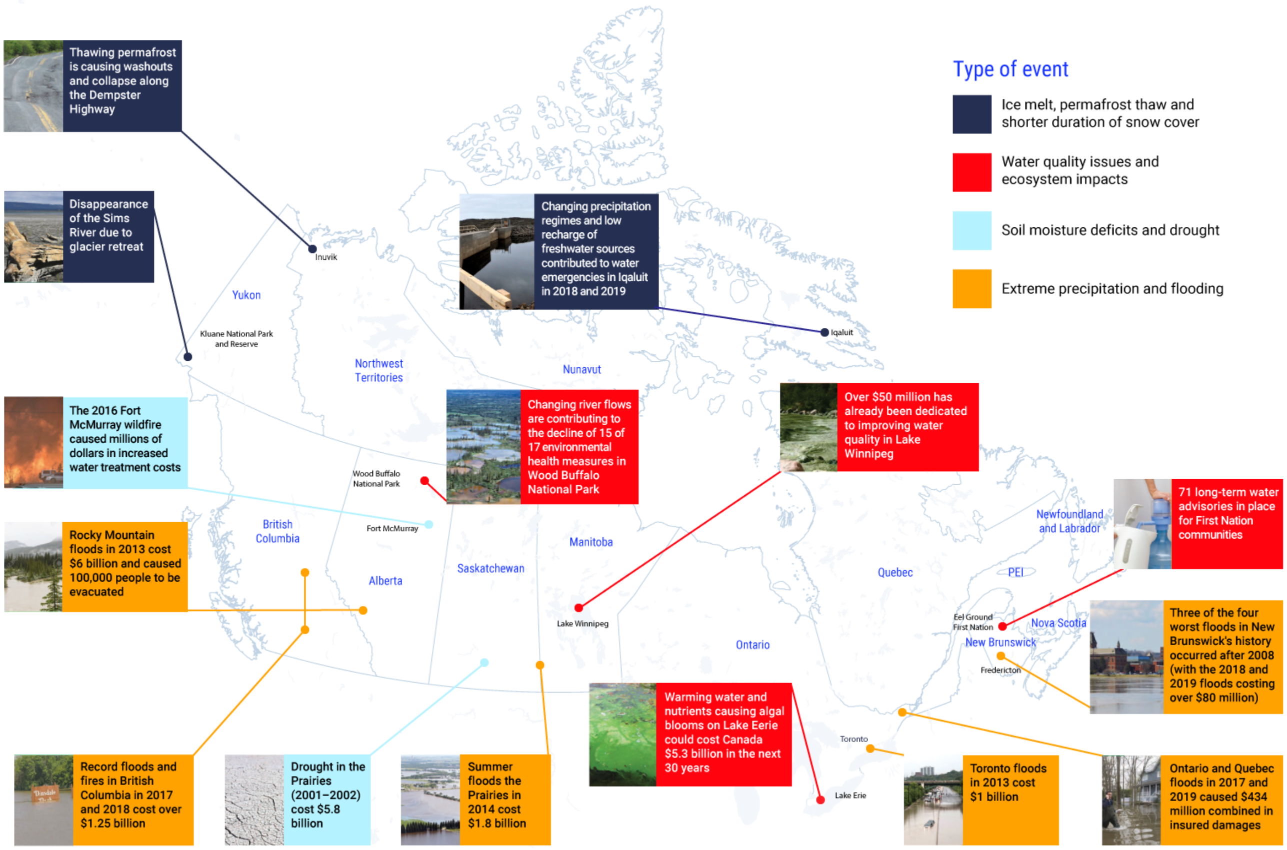

Figure 4.1: Major recent events and trends in Canada related to water resources that have had significant impacts to communities and the economy. Source: Adapted from Government of Canada, 2020a, b; Government of New Brunswick, 2019; Insurance Bureau of Canada, 2019a; McKay, 2019; Ormiston and Sheldon, 2019; Poitras, 2019; Smith et al., 2019; Wang and Strong, 2019; Abbott and Chapman, 2018; Environment and Climate Change Canada, 2018; Lindsay, 2018; Weber, 2018; Bakaic, 2017; Insurance Bureau of Canada, 2019a, 2017; Maclean, 2017; O'Neill and Burn, 2017; Phillips, 2017; Thurton, 2017; Weikle, 2017; Sills et al., 2016; Wheaton et al., 2008; Public Safety Canada, n.d.

Case Story 4.1: Extreme water level variability on the Great Lakes

The Great Lakes are the largest surface freshwater system on Earth and serve the diverse needs of 30 million people. Water levels across the Great Lakes were very high throughout 2019 and have continued to be high in 2020, approaching or exceeding seasonal or all-time record-high water levels at various times throughout the year. During 2019, Lake Superior, Lake Saint Clair, Lake Erie and Lake Ontario all met or exceeded all-time record high levels for the period of record of 1918–2018. In the case of Lake Ontario, the new record-high level set in 2019 exceeded the previous record-high level set only two years prior in 2017. Lake Michigan–Huron, which came very close to record highs in the summer of 2019, remained high through the fall, and was above seasonal records in the winter and spring of 2020. High water levels have caused flooding and erosion along the shorelines of all the Great Lakes, with enhanced local impacts during storm events generating wind-driven wave action (*see* Figure 4.2; Toronto and Region Conservation Authority, 2019; Great Lakes–St. Lawrence River Adaptive Management Committee, 2018). While it is outside of the Great Lakes basin, the Ottawa River experienced its largest spring flows on record in 2019, surpassing its previous record reached just two years before, in 2017 (Ottawa River Regulation Planning Board, 2019), which caused flooding throughout the Ottawa River basin and downstream on the St. Lawrence River. Communities battled emergency conditions, and water regulators attempted to balance upstream and downstream flooding conditions (Ottawa River Regulation Planning Board, 2019; Great Lakes–St. Lawrence River Adaptive Management Committee, 2018; International Lake Ontario–St. Lawrence River Board, 2018). Only six short years earlier, shoreline communities on the Upper Great Lakes had been adjusting to a fifteen-year period of very low water levels, with Lake Michigan–Huron at an all-time record low level in the winter of 2013 (Gronewold et al., 2016).

Figure 4.2: Record high water levels and flooding on a dock near Saint Catharines, ON (left), and a walkway near Ontario Place in Toronto, ON (right). Photos courtesy of Environment and Climate Change Canada.

While water level fluctuations are normal on the Great Lakes, these extreme shifts between record low and high water levels fit the pattern of what would be expected under a changing climate. Projections for the future are not simply that water levels in the Great Lakes will trend up or down, but rather that they will experience more frequent periods of very high or very low levels (Gronewold and Rood, 2019; Mailhot et al., 2019; Music et al., 2015; Notaro et al., 2015). Extreme water levels have occurred in the recorded past (1918–2018) (Canadian Hydrographic Service, 2019; Great Lakes Environmental Research Laboratory, National Oceanic and Atmospheric Administration, 2019), and therefore it is difficult to determine whether the record-breaking conditions in 2017 and 2019 are extraordinarily rare events for the climate in this region, or moderately rare events in a climate that is changing (Great Lakes–St. Lawrence River Adaptive Management Committee, 2018). An event attribution study by Teufel et al. (2019) shows that events such as the heavy April 2017 precipitation accumulation over the Ottawa River basin are between two and three times more likely to occur in the present-day climate than they were in the pre-industrial climate, as the current warmer atmosphere holds more moisture. The record high and low water levels across the Great Lakes are a clear reminder that these types of extreme conditions are not only plausible, but are indeed occurring, with growing evidence of linkages to climate change. Planning is difficult in this context, as shoreline communities struggle to adjust and adapt to uncertain future conditions (Gronewold and Rood, 2019; McNeil, 2019).

Adaptation planning must manage uncertainty, rather than try to avoid it (Kwakkel et al., 2016). Emerging insights from adaptive management theory and practice suggest that building resilience—the ability to withstand a wide range of scenarios—into both human and ecological systems is an effective way to cope with environmental change characterized by future uncertainty (Pahl-Wostl, 2008; Panel on Adaptive Management for Resource Stewardship, 2004). Adaptive management techniques allow planners and practitioners to move forward with decisions and actions that meet current needs and conditions, and then to respond with modifications if conditions change in an unanticipated manner (Land Trust Alliance, 2019; Wood et al., 2017). The International Joint Commission has adopted such an adaptive management approach as a means of dealing with future uncertainty on the Great Lakes (*see* Case Story 4.5 and Section 4.4.5 for examples in the Great Lakes Region).

4.2.2 Climate trends and projections

Combined changes in precipitation phase (e.g., rain or snow), earlier snowmelt, ice cover retreat and decreasing glacier mass affect Canadian river flows and lake levels. Future trends identified in *Canada's Changing Climate Report* (Bush and Lemmen, 2019) and other studies, include:

- **Less water availability in southern basins, particularly in the summer.** Precipitation will continue to increase in the short term for all seasons, but summer rainfall in southern Canada is projected to decrease in a high emissions scenario near the end of the century (Zhang et al., 2019). Along with increasing evaporation rates, early snowmelt and less ice, this trend is expected to contribute to reduced annual flows in southern interior basins and southern lake levels (Bonsal et al., 2019), potentially initiating social and ecological conflict over increasingly scarce water resources in some basins (Clark et al., 2017).
- **Increased frequency and intensity of water-related extremes.** Some conditions that increase the potential for flooding, such as extreme rainfall events, are projected to be more common in the future, escalating the potential for rain-generated local flooding, particularly in urban areas (Zhang et al., 2019). Extreme precipitation events can lead to the loss of human life and property destruction (Simonovic, 2017), and can affect mining operations, energy transmission and tourism infrastructure (Kovacs and Thistlethwaite, 2014; Lemmen et al., 2014), as well as increase soil erosion and nutrient runoff, degrading water quality (Campbell et al., 2014; Crossman et al., 2013). Extreme summer dry periods are expected to increase in frequency and will contribute to soil moisture deficits leading to drought, particularly across the southern Prairies and in the interior of British Columbia (Bonsal et al., 2019; Zhang et al., 2019).

- **Reduced water quality and more harmful algae blooms.** There is significant potential for climate change to exacerbate current water quality issues (Liu et al., 2019; Gooré Bi et al., 2015; Jalliffier-Verne et al., 2015). In particular, it is anticipated that warmer temperatures will contribute to additional occurrences of harmful algae in the future, particularly where nutrient concentrations are already elevated (Orihel et al., 2017; Paterson et al., 2017).

Climate change influences on the water cycle are already impacting Canadian food, energy and natural resource sectors, communities, and the natural environment. For example, property and casualty insurance payouts from extreme weather events have more than doubled every five to ten years since the 1980s, and the Insurance Bureau of Canada estimates that for every dollar of insured loss, home and business owners and governments spend three to four dollars for uninsured losses (Moudrak et al., 2018). Since 2009, insured losses from catastrophic severe weather events in Canada, such as flooding, have averaged $1.4 billion per year, compared to an average of $400 million per year prior to this (Insurance Bureau of Canada, 2019b).

The current reality for water practitioners in every part of Canada is that design and operational protocols for water resources management are almost exclusively based on a historical understanding of the resource. However, as we move into the Anthropocene (i.e., the era in which human activity has been the dominant influence on climate and the environment), indications are that the future will no longer resemble the past. Adapting to new changes is made more complex by the interaction of climate change with human development and by rapidly changing socioeconomic conditions. While uncertainties create challenges for adaptation, they should not be an impediment to action. Instead, they can serve as a call to address uncertainty, and to develop more robust management systems that can cope with variability. The remainder of this chapter provides a national perspective on adaptation efforts in the water resources sector, with a focus on how governments, communities and civil societies are adapting to complex and uncertain change.

4.3 Effective coordination across complex water systems enhances adaptation

Canadian organizations and institutions are unevenly prepared to manage water-related risks associated with climate change. Partnerships and networks allow organizations at a variety of scales to access additional resources, share knowledge and risk, and enhance adaptive capacity. Transboundary and watershed organizations offer useful insights into effective coordination of water systems with diverse stakeholders that are dealing with high uncertainty.

Canadian governance of water resources involves primarily the provincial and municipal/regional governments with involvement from federal and Indigenous governments, along with civic societal organizations such as watershed groups, environmental organizations, philanthropic foundations and scientific and research groups. Capacity challenges often occur in rural, northern and Indigenous communities. Coordination, sharing agreements and partnerships enhance the capacity to self-organize, share risk, and incorporate multiple *sources of knowledge (e.g., scientific, Indigenous, social, practitioner). Networks enhance institutional capacity to address the uncertainty posed by climate change, and they support local organizations, help to share risk, and incorporate new forms of knowledge. Watershed organizations, such as Ontario's Conservation Authorities, and transboundary organizations, such as the International Joint Commission, exemplify the benefits and challenges of coordination around shared water resources.*

4.3.1 Introduction

A common climate change adaptation strategy involves coordination across organizations and institutions. An organization is a group of people devoted to a particular purpose, such as research or a business aim, while an institution is a type of formal organization, and also refers to systems of practices, norms and formal laws or policies (Hulbert and Gupta, 2017). For example, the World Meteorological Organization (WMO) is an organization providing world leadership and expertise in international cooperation in the delivery and use of high-quality, authoritative weather, climate, hydrological and related environmental services by its members. The WMO facilitates an international greater good, while member countries maintain sovereignty and provide funding to the WMO to maintain this oversight role. The Global Institute for Water Security at the University of Saskatchewan and the Water Institute at the University of Waterloo are examples of institutions that function similarly to an organization. The broader definition of water institutions also refers to formal water laws and policies (e.g., the Water Sustainability Act in British Columbia), water governance arrangements (e.g., Conservation Districts in Ontario), market-based mechanisms (e.g., Alberta's water market), public opinions about water and climate change, and attitudes towards public and private ownership, among other things. Organizations are governed by rules and regulations, whereas institutions are governed by customs and values. Canadian water institutions have deeply engrained patterns of how we manage water, and they are in the process of adapting to climate-related water risks through new institutional arrangements, enhanced coordination, risk sharing and capacity building (Global Water Futures, 2020). Coordination allows institutions to respond more quickly and effectively to the challenges of an uncertain climate by defining clear roles, fostering information sharing and mobilizing additional resources (Hurlbert and Diaz, 2013; Bakker and Cook, 2011). Risk-sharing tools distribute capacity to prepare for climate change impacts (Thistlethwaite and Henstra, 2017).

In Canada, the constitutional division of power between federal, provincial, territorial and Indigenous governments, and the role of municipal and regional organizations means that adaptation in the water sector often occurs at a variety of scales (Global Water Futures, 2020; Renzetti and Dupont, 2017; Bakker and Cook, 2011; Sandford et al., 2011; Simms and de Loë, 2010). This decentralized context for governance can lead to a mix of outcomes for adaptation in the water sector. On one hand, the fragmentation of governance across multiple authorities can result in inefficiencies and redundancies (Bakker and Cook, 2011) that contribute to unsustainable water use (Renzetti and Dupont, 2017), delayed policy development (Mitchell, 2017), and uneven adaptive capacity across stakeholder groups (Hurlbert and Diaz, 2013). In other circumstances, decentralized governance is inclusive of many groups and can produce outcomes that are responsive to local needs (Bakker and Cook, 2011). Often, intermediary groups such as watershed organizations (*see* Case Story 4.2) and transboundary water organizations (*see* Case Story 4.3) can play an important coordination role across various stakeholder groups (Clancy, 2014). Municipalities, Indigenous communities and environmental organizations are also becoming more commonly included in water governance and adaptation activities, in part due to the fact that the federal role in water governance has declined over several decades (*see* Box 4.1; Renzetti and Dupont, 2017; Hurlbert et al., 2015; Bakker and Cook, 2011; Simms and de Loë, 2010; Hill et al., 2009; Ivey et al., 2004). These diverse sets of new actors often have novel ideas about water management and adaptation to risk that can transform existing institutions (Clancy, 2014).

Ideally, networks and partnerships between governance authorities and stakeholders can play a significant role in strengthening adaptation of the Canadian water sector to climate change (Bauer and Steurer, 2014). Effective coordination implies that programs are necessary, efficient, consistent and comprehensive (de Loë, 2017). Improved water governance arrangements are important for clarifying roles and coordinating policies across all orders of government (Bakker and Cook, 2011; de Loë, 2009), and in sectors beyond water, such as energy and agriculture (de Loë, 2017; Gober, 2013).

Box 4.1: Flood management in Canada

Floods are among the most costly natural disasters in Canada (Insurance Bureau of Canada, 2019b; Public Safety Canada, 2011). Seventy-five percent of annual weather event expenditures under the Federal Disaster Financial Assistance Arrangement program are flood-related (Office of the Parliamentary Budget Officer, 2016).

Historically, the federal government has played a substantial coordinating role in reducing flood risk. In 1970, Canada passed the Canada Water Act to design an enhanced national and comprehensive approach to water management (Watt, 1995). The federal–provincial/territorial Flood Damage Reduction Program (FDRP) was introduced in 1976 to identify flood hazards, map floodplains, discourage flood-vulnerable development, and encourage effective land use in flood-vulnerable areas. This initiative was a significant shift away from reactive, ad hoc flood policy and towards a proactive approach and preventative philosophy. Between 1976 and 1999, the FDRP was the main mechanism coordinating national action on flood risk reduction, including facilitating cost sharing between governments, supporting the development of flood risk maps, and assisting in the implementation of structural and non-structural methods for flood control (Scott et al., 2017; Thistlethwaite and Henstra, 2017; Watt, 1995). Ultimately, the program designated 320 flood-risk areas covering more than 900 urban communities (Natural Resources Canada, 2018).

Since the FDRP was discontinued in 1999, flood management has become highly fragmented and currently reflects uneven adaptive capacity across the country. A 2014 review of flood risk approaches across Canada found that approximately half of existing flood mapping was completed after the discontinuation of the FDRP (MMM Group, 2014), with 59% of these instances being in Ontario, 21% in Quebec, 10% in British Columbia, and the remaining 10% distributed across the rest of the country. A more recent study found that, while many Canadian municipalities have some sort of flood map, most of these maps are of poor quality and are ill-suited for communicating flood risk to the public (Henstra et al., 2019a). Institutional fragmentation appears to be a particular challenge to building resiliency. In interviews with city officials in 15 major Canadian cities, Feltmate and Moudrak (2015) found that cities have made minimal flood preparations in areas where they have limited or shared jurisdiction, such as food, electricity and petroleum supply. Similarly, Morrison et al.

(2018) interviewed experts in the Canadian Prairie provinces, and identified the lack of coordination between the various agencies responsible for flood risk management as a challenge to building resiliency, resulting in a duplication of efforts, siloed expertise and gaps in responsibilities.

The Federal Flood Mapping Guideline Series provides governments and organizations with resources, technical guidance and support for conducting risk assessments and floodplain mapping. The first document in the series, released in 2018, will facilitate a common national best practice and will increase the sharing and use of flood hazard information (Natural Resources Canada, 2018). Also, Natural Resources Canada and Public Safety Canada released the Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation in 2019, which provides technical guidance to support the development of flood hazard maps in a Canadian jurisdiction, including on different types of flooding and how to consider climate change in the flood mapping process. In recent years, all levels of governments have been investing to update flood maps across Canada, which are outdated and lack consistent standards. Although there are examples of communities and jurisdictions incorporating climate change into flood mapping (Natural Resources Canada and Public Safety Canada, 2018), there is a need for further overarching guidance on how to address the potential impacts of climate change on floodplain mapping in Canada.

4.3.2 Transboundary and watershed organizations

Canadian water organizations with mandates spanning jurisdictional boundaries and involving a variety of stakeholders have built cooperative institutional structures to promote shared understanding, trust and capacity for addressing complex and contentious water management challenges in a coordinated fashion. These groups can effectively link decision-making processes and priorities across scales and regions, and they are well-positioned to continue to drive participatory and adaptive water governance (Rouillard and Spray, 2017; Mguni, 2015; Cook et al., 2013). Transboundary organizations are expected to be particularly important in addressing potential interregional or international water conflicts that may be exacerbated by climate change (De Stefano et al., 2012). However, the ability of these organizations to continue to collaborate and respond to increasing risks posed by climate change has not been sufficiently studied (Akamani and Wilson, 2011).

A variety of regional organizations with water management mandates exist in Canada, many of them based on watershed boundaries rather than political boundaries. Examples include Alberta's Watershed Planning and Advisory Councils, Saskatchewan's Watershed Associations, Manitoba's Watershed Districts, Quebec's *organismes de bassins versants*, watershed groups in Prince Edward Island, New Brunswick and Nova Scotia, and water boards in the Yukon, Northwest Territories and Nunavut. Some of these groups have legislative authority, such as Ontario's Conservation Authorities (*see* Case Story 4.2), others are financially supported by provincial government programming, such as in Prince Edward Island and New Brunswick, while others exist as non-profit organizations or citizen-run groups, such as the Fraser Basin Council in British Columbia (Scott et al., 2017; Canadian Council of Ministers of the Environment, 2016). These groups have played key roles in coordinating action on adaptation planning across the country (Oulahen et al., 2018; Mitchell et al., 2014; Ontario Centre for Climate Impacts and Adaptation Resources, 2011; Sandford et al., 2011). The watershed approach to governance can link land use and water management activities, and enable collaboration between a variety of upstream and downstream stakeholders (Mguni, 2015).

Case Story 4.2: Ontario Conservation Authorities and climate change adaptation in the Lake Simcoe Watershed

Ontario Conservation Authorities are 36 watershed-based partnerships between municipalities and the Province with legislative authority "to undertake watershed-based programs to protect people and property from flooding, and other natural hazards, and to conserve natural resources for economic, social and environmental benefits" (Conservation Ontario, 2020; Scott et al., 2017). Conservation Authorities were originally formed to foster greater cooperation and collaboration among the various groups involved in water management (Mitchell et al., 2014), and now play a key role in building resilience to water-related risks (Ontario Centre for Climate Impacts and Adaptation Resources, 2011). For instance, the Lake Simcoe Region Conservation Authority (LSRCA; *see* Figure 4.3) was one of the partners involved in a multi-partner pilot project to develop a climate change adaptation strategy for the Lake Simcoe Watershed in Ontario. This watershed encompasses about 330,000 ha, is home to approximately 350,000 people, and generates over $200 million annually for the local economy, primarily through agriculture and recreation (Lake Simcoe Region Conservation Authority, 2016; Ontario Centre for Climate Impacts and Adaptation Resources, 2012). The climate change adaptation plan was made possible through a number of enabling legislative and policy mechanisms, including the Lake Simcoe Protection Act (the first legislation in Canada to focus on a single watershed), the Lake Simcoe Protection Plan (the first plan in Ontario to integrate climate change considerations) and Ontario's Climate Ready: Adaptation Strategy and Action Plan (2011–2014) (Lemieux et al., 2014). With other partners, the LSRCA identified current and future climate change vulnerabilities, such as the drying of wetlands and spread of aquatic invasive species, using future scenarios of climate and non-climate stressors. The team solicited adaptation ideas and prioritized them with an expert panel, organizing them into themes of engaging people (e.g., ensuring community engagement and interagency cooperation and coordination), reducing threats (e.g., encouraging and supporting water conservation), enhancing adaptive capacity (e.g., determining how well plans account for and protect important natural assets) and improving knowledge (e.g., instituting standardized monitoring of species at risk) (Lemieux et al., 2014).

Figure 4.3: Map of the Lake Simcoe Watershed in Ontario. Source: Lake Simcoe Region Conservation Authority, 2016

The LRSCA is currently engaged in updating and improving the adaptation plan for the Lake Simcoe Watershed. In the meantime, it is building resilience to climate change impacts primarily through promoting low-impact development projects such as natural infrastructure (*see* Section 4.6.3), and through implementing a new Phosphorus Offsetting Policy. Excess phosphorus from land-use activities and their consequences, such as agriculture and urban runoff, is a major threat to the current health of Lake Simcoe, degrading water quality and leading to excessive growth of aquatic plants and algae (Weiss et al., 2018; Lake Simcoe Region Conservation Authority, 2017). Climate change is exacerbating this process by contributing to more extreme rainfall events and by changing the timing of seasonal flows, affecting runoff volumes into the lake (Lake Simcoe Region Conservation Authority, 2013). The LSRCA has been working with partners to improve urban storm water management, and has introduced an offsetting policy that requires new development to control 100% of the phosphorus leaving their property (Lake Simcoe Region Conservation Authority, 2019).

There are also a variety of transboundary water organizations in Canada. The most prominent of these is the International Joint Commission (IJC), established under the Boundary Waters Treaty of 1909. The IJC is a binational institution for the resolution of water disputes and cooperation on water policy priorities across the U.S.–Canada border. There are a total of 13 transboundary water systems governed by the 1909 Boundary Waters Treaty, including the Osoyoos, Kootenay and Columbia rivers, the Saint Mary and Milk rivers, the Souris River, the Red River, the Rainy River and Lake of the Woods, the Great Lakes–St. Lawrence River (*see* Case Story 4.3), Lake Champlain and the Richelieu River, and the Saint Croix River. Many of these transboundary systems have IJC boards, studies and committees dedicated to binational water management issues. Other transboundary organizations and agreements address interjurisdictional drainage basins, such as the Prairie Provinces Water Board (the 1969 Master Agreement on Apportionment), the Ottawa River Regulation Planning Board (1983 Agreement Respecting Ottawa River Basin Regulation) and the Mackenzie River Basin Board (the Mackenzie River Basin Transboundary Waters Master Agreement).

Case Story 4.3: The International Joint Commission and the Great Lakes Region

The role of the International Joint Commission (IJC) in the Great Lakes Region demonstrates successful coordination of policy design and implementation in a decentralized context. The Great Lakes Region is home to one of the largest freshwater basins on earth, serving more than 30 million people. Regional water governance is characterized by a complex set of policies and arrangements involving two countries, more than 75 First Nations communities along the coasts, eight states and two provinces, numerous municipalities, and a variety of users and stakeholders with different roles and concerns. While outstanding policy issues remain, the United States and Canada have slowed substantial ecological damage in the basin (Renzetti and Dupont, 2017; Carmichael and Boyer, 2016), with the IJC playing a key role in coordinating engagement across stakeholder groups, and completing technical and policy work around issues such as regulating shared water uses and water quality (Johns, 2017). Notable activities and accomplishments recognized internationally (United Nations, 2015) include the following:

- Large transboundary integrated assessments, such as the Lake Ontario–St. Lawrence River Study (1990–2005) and the International Upper Great Lakes Study (2007–2012). These studies resulted in flexible management plans and operating rules to respond to climate variability and uncertainty (*see* Case Story 4.5; International Upper Great Lakes Study Board, 2012, 2009; Stakhiv et al., 2006).
- The Great Lakes Water Quality Agreement to maintain the chemical, physical and biological integrity of the Great Lakes Basin ecosystem. The Great Lakes Water Quality Protocol of 2012, enacted under the Great Lakes Water Quality Agreement, is one of the only transboundary coordinating instruments in the world to explicitly address the impacts of climate change on water quality (United Nations, 2015; Government of Canada and Government of the United States of America, 2012).
- A Climate Change Framework (2018) providing guidance for transboundary IJC boards for addressing climate change in policy and operations to maintain the resilience of Canada–U.S. water systems (IJC, 2018).

Some of the success of the IJC can be credited to its multi-disciplinary teams, meaningful engagement with stakeholders, and willingness to incorporate new ways of learning and information sharing (Straith et al., 2014).

While transboundary organizations are strong coordinating forces in the Canadian water sector, their mandates and water sharing agreements rarely take into account climate change. Vulnerabilities such as the absence of flow apportionment agreements or drought provisions in periods of low or variable flow have been noted in the Columbia River Basin (Garrick, 2017) and the Red River Basin (de Loë, 2009). The Prairie Provinces Water Board, which oversees water sharing among Alberta, Saskatchewan and Manitoba, has explicitly considered climate change and drought as key stressors in technical work, but finds it more difficult to take into account changing and uncertain socioeconomic factors, such as voluntary water sharing (Global Water Futures, 2020). The IJC considers climate change in multiple products, including in a framework to guide climate change considerations across transboundary boards (IJC, 2018), in the climate change impacts annex in the Great Lakes Water Quality Agreement (United Nations, 2015) and in the creation of the Great Lakes–St. Lawrence River Adaptive Management Committee (IJC, 2015). An adaptive management approach to transboundary management can be an effective way to respond to changing circumstances and may include the following: periodic reviews; limited terms; special provisions for meeting environmental water needs; mechanisms for dealing with extreme circumstances, such as floods and droughts; information sharing; and the creation of organizations that are empowered by the parties to make adjustments in response to changing circumstances (*see* Section 4.4; de Loë, 2009).

While transboundary water organizations strengthen Canada's ability to adapt, the existence of these organizations alone is not sufficient. A lack of leadership in coordinating action and a failure to sustain policy attention have been noted as issues impeding progress in both the Great Lakes Region (Johns, 2017) and the Mackenzie River Basin (Morris and de Loë, 2016).

4.3.3 Adaptive capacity and the changing nature of water governance

Access to adequate technical, human, social and financial capital is critical to adaptive capacity in the water sector (Hurlbert and Diaz, 2013; Ontario Centre for Climate Impacts and Adaptation Resources, 2011). Practitioners in the field point to declining technical skills and resources (ICF, 2018; Hamlet, 2011; Patino, 2010), employee turnover and burnout (Global Water Futures, 2020; Moncrieff-Gould et al., 2018; Straith et al., 2014), and a lack of stable funding (Moncrieff-Gould et al., 2018) as challenges to adaptation in the water sector (McMillan et al., 2019; Oulahen et al., 2018). Contextual, place-based knowledge, networks, and a wide range of interdisciplinary skills are all assets in enhancing a community's ability to respond, survive and adapt to climate-related situations such as extreme events (Global Water Futures, 2020; Straith et al., 2014).

Capacity challenges are often more evident in communities and organizations that are most vulnerable to water-related risks of climate change, including in rural, northern and Indigenous communities (Global Water Futures, 2020; Archer et al., 2017; Ecology North, 2017; Clancy, 2014; Willox et al., 2013; Ford and Pearce, 2010; Wall and Marzall, 2006; Ivey et al., 2004). As a result, such organizations and communities are unevenly prepared for the water-related impacts of climate change. Financial resource constraints are particularly challenging for non-governmental groups and local communities. Many non-governmental water organizations are volunteer-based, or lack streamlined, stable core-funding opportunities to engage in effective networking with each other and with the public about water-related issues (Global Water Futures, 2020; Mitchell et al., 2014; Telfer and Droitsch, 2011). Similarly, those in rural and Indigenous communities are more susceptible to disruptions to reliable income sources, such as flooding on cropland or culturally significant foraging areas (Fletcher and Knuttila, 2018; Lemmen et al., 2014; Wandel et al., 2010; Wall and Marzell, 2006). However, communities that have recently experienced water-related natural hazards, such as flooding or drought, are generally more adaptive than those lacking this experience (Di Baldassarre et al., 2015). For example, the long history of extreme climate variability experienced by rural communities in the Canadian Prairies has generally increased adaptive capacity across the region, through adaptations such as the expansion of irrigation infrastructure and crop diversification (*see* Prairie Provinces chapter; Kulshreshtha et al., 2016; Hurlbert and Diaz, 2013).

Significant progress has been made towards climate change adaptation in North America at the municipal level (Canadian Water Network, 2019; Oulahen et al., 2018). Municipalities, however, often lack capacity to raise the revenue necessary to maintain and upgrade infrastructure, despite being responsible for 60% of public infrastructure across Canada (Global Water Futures, 2020; Moncrieff-Gould et al., 2018; Thistlethwaite and Henstra, 2017; Miller, 2015). While about half of municipalities have undertaken a risk assessment of their water-related assets, fewer than 20% have formally introduced climate change adaptation strategies (Canadian Infrastructure Report Card, 2016). Others have not carried out any assessment whatsoever of their community's vulnerability to specific climate change impacts (McMillan et al., 2019). As such, communities are unevenly prepared to handle water-related extremes like floods (Feltmate and Moudrak, 2015).

Indigenous communities have displayed remarkable resilience in the face of considerable and rapid change over the past century. In northern Canada, where the temperature is warming three times faster than the global average (Bush and Lemmen, 2019), the impacts of climate change have been felt acutely by Inuit communities in changing patterns of sea ice, thawing permafrost and the loss of snow and ice cover (Inuit Tapiriit Kanatami, 2019). Communities have already had to modify behaviour to cope with these rapid changes, including hunting in boats on open water rather than from ice floes, using all-terrain vehicles instead of snowmobiles, and utilizing sea routes rather than inland routes damaged by permafrost thaw (Berkes and Armitage, 2010). High levels of adaptive capacity exist in Inuit communities, via knowledge systems that incorporate change and uncertainty, and through adaptive practices, such as diversifying the timing and type of land-based activities (Cameron et al., 2015; Ford et al., 2015; Berkes and Armitage, 2010). However, adaptive capacity may not be able to keep pace with the rapid rate of environmental change in the north. Furthermore, many traditional Inuit strategies to manage change continue to be undermined by colonial processes that have severely affected Indigenous populations in the Arctic (Ford et al., 2017; Ford et al., 2015). Indigenous communities elsewhere in Canada face similar challenges, including the effects of industrial pollution, the downstream impacts of hydropower dam operations, and on-going socioeconomic issues, such as high costs of living and limited employment opportunities, many of which stem from the continuing legacy of systemic racism and colonial policies (Global Water Futures, 2020; Archer et al., 2017; Thompson, 2015; Castleden and Skinner, 2014; Clancy, 2014; Magzul and Rojas, 2006). These compounding factors inhibit the ability of these communities to consider and undertake water resource adaptation planning. Competing priorities and limited human and technical capacity mean that communities are not always able to take advantage of financial resources to promote and implement adaptation plans, even when such resources are available (Ecology North, 2017; Ford and Pearce, 2010).

To increase adaptive capacity, organizations across Canada are creating partnerships to address the water-related risks of climate change. Partnerships exist across different scales (national, regional and local) and types of organizations (government, industry, academia, civil society), and facilitate information sharing (Straith et al., 2014), trust building and cooperation (Moore et al., 2014; Patino, 2010), as well as adding technical and human resources (Global Water Futures, 2020; Dale et al., 2019; Hamlet, 2011; Cohen et al., 2006).

National and international institutions also support local self-organization and social networking around water issues. For example, a key facilitator of adaptation at the municipal level is the International Council for Local Environmental Initiatives (ICLEI), a network of local governments and staff that provide technical capacity and networking opportunities. Working with the Federation of Canadian Municipalities, ICLEI is a key driver of municipal greenhouse gas (GHG) emissions reduction and climate change adaptation in Canada (Dale et al., 2019; Guyadeen et al., 2018). While many provinces have released guidelines or funding programs supporting adaptation at the local level, Ontario was the first province to enact regulations requiring municipalities to consider climate change in asset management planning in 2017 (Canadian Water Network, 2019). In other provinces, key water-related policies, such as the Water Modernization Act in British Columbia, the 25 Year Water Security Plan in Saskatchewan and Guides to Water Withdrawal Approvals in Nova Scotia, are instrumental in supporting social networks and self-organization. For example, policies may provide extension services through field days and meetings, piloting the application of suggested practices, supporting local advisory committees, and offering workshops in key areas such as new standards and guidelines (Bizikova et al., 2013).

Risk-sharing policy tools are another way of enhancing capacity to address water-related climate change issues. There are a variety of risk-sharing tools available to Canadian municipalities to address flood risk, including disaster assistance programs that share the cost of recovering from disasters between the federal and provincial governments (e.g., the Ontario Municipal Disaster Recovery Assistance Program, the Alberta Disaster Recovery Program, the Saskatchewan Provincial Disaster Assistance Program, etc.) (Morrison et al., 2018; Thistlethwaite and Henstra, 2017). While there is a diversity of policy approaches to flooding in Canada (Morrison et al., 2018), cities do not always take advantage of the full suite of risk-sharing tools available (Thistlethwaite and Henstra, 2017). For example, both Calgary and Toronto attach a fee to property taxes and utility bills to fund flood mitigation and adaptation infrastructure, but do not employ a risk-based charge (a charge that is roughly proportional to the property's contribution to urban flood risk), as a means of incentivizing the uptake of property-level flood protection (Thistlethwaite and Henstra, 2017). Alternatively, Edmonton, Mississauga, Kitchener and Waterloo are examples of municipalities that charge user fees for storm water management that is roughly based on how much the property contributes to runoff (EPCOR, 2019; Aquije, 2016). While there are many methods to fund storm water management, including property taxes, development charges and intergovernmental transfers, user charges can provide a good balance of stability in revenue intake and equity (Aquije, 2016).

Organizations are finding ways to maintain valuable institutional knowledge while linking to a variety of knowledge communities in order to improve understanding of water management issues and potential solutions. For example, for the Prairie Provinces Water Board, contextual knowledge of working in an interjurisdictional context is very important. To ensure that this knowledge is maintained through turnover in members, the Board has begun a process of succession planning whereby each member identifies an alternate who shares their responsibilities and can therefore act as a replacement as turnover occurs (Global Water Futures, 2020). Indigenous Knowledge is also becoming more explicitly recognized in water research, and in the mandates and practices of water organizations. For example, the Northern Voices, Northern

Waters Strategy of the Northwest Territories explicitly includes provisions for recognizing Indigenous rights and considers Indigenous Knowledge equivalent to science (Global Water Futures, 2020; Sandford et al., 2011). Similarly, the Red River Basin Commission signed a Memorandum of Understanding with the Southern Chiefs Organization in Manitoba, committing both partners to work collaboratively on issues such as deteriorating water quality and flooding (Southern Chiefs Organization, 2018). In Mittimatalik (Pond Inlet), Nunavut, youth and supporting partners use traditional knowledge from community Elders in tandem with Western scientific methods, such as water sampling, to study the increasing frequency of gastrointestinal illnesses in the community (Inuit Tapiriit Kanatami, 2019). Successful integration of Indigenous Knowledge can reveal variables previously unaccounted for (Sandford et al., 2011) and provide additional evidence about the meaning of change (Abu et al., 2019), though it can be challenging in practice (Mantyka-Pringle et al., 2017). For example, while the Mackenzie River Basin Board has a mandate to include Indigenous peoples and integrate Indigenous Knowledge, it is difficult to adequately represent the diverse interests and knowledge of the many unique Indigenous communities in the Mackenzie River Basin's work (Morris and de Loë, 2016).

Partnerships can also involve sharing power over decision making, such as in the case of the co-management arrangements that have resulted from negotiated land claim agreements with Indigenous nations across Canada (Latta, 2018; Zubrycki et al., 2016). For example, in the Northwest Territories, the Mackenzie Valley, Sahtu, Gwich'in and Wek'èezhii are four land and water boards that involve the co-management of natural resources by the territorial and federal governments of Canada, and the governments of some of the Indigenous peoples who occupy those territories (Tsatsaros et al., 2018; Canadian Council of Ministers of the Environment, 2016). These co-management arrangements have been implemented with mixed success, but, overall, it is believed that they increase access to resources, and contribute to processes of social learning and knowledge exchange—particularly the bridging between Indigenous Knowledge and scientific knowledge (*see* Section 4.4.4, Mantyka-Pringle et al., 2017; Armitage et al., 2011).

4.3.4 Conclusion

Adaptation offers opportunities to address vulnerabilities in our water resources systems. Overall, progress in coordinating adaptation efforts in the water sector is uneven across Canada. Local communities, and Indigenous and civil society organizations are becoming more involved in water governance, yet often have limited capacity to effectively address impacts from climate changes. New organizational arrangements, such as water-based networks, offer an opportunity to draw on existing capacity and coordinate effectively among the myriad participants involved in adaptation to reduce the water-related risks of climate change.

4.4 Adaptation is advancing through innovation and adaptive management

There are promising examples of coordination and innovation in the water sector across Canada. New approaches use scenarios to explore how decision-making strategies perform across a range of plausible futures, implement iterative processes for monitoring and adjusting actions, and engage stakeholders in social learning, laying the groundwork for innovation and adaptation.

While institutional barriers remain, innovations around water management and climate change adaptation have occurred across Canada. Innovation in the water sector is driven by leaders who propose new ideas and build coalitions around them, and by the creation of safe spaces for policy experimentation. Exploratory modelling and scenario exercises can build empathy and consensus between stakeholders and lead to the development of low- or no-regret adaptation strategies that perform reasonably well against a wide range of plausible futures. Adaptive management provides a systematic, iterative process of monitoring and adjusting actions to new information and changing circumstances.

4.4.1 Introduction

Managing uncertainty is a key component of adaptation planning in the water resources sector. The same hydrologic or water quality model with slightly different inputs of initial environmental conditions can yield very different results, particularly at local and regional scales where most adaptive action takes place (Gober, 2018). Adaptive management aims to anticipate a wide range of future conditions and to reduce risk exposure (Hurlbert, 2018), leading to decisions that are more robust in the face of these uncertainties.

4.4.2 Institutional barriers to innovation

Inflexible institutional governance, water system design and planning can limit the ability of the water sector to adapt to climate change impacts. Many Canadian water systems were historically designed around the needs of influential regional groups with primarily single-use interest in water, such as irrigation or hydropower (Heinmiller, 2017; Clancy 2014). As such, policy and management failures can result from fixed commitments, such as water allocation rules based on historical appropriation that does not consider ecosystem needs or equitable distribution for newer users (Sandford et al., 2011; Hamlet, 2011). Effective adaptive governance systems are dynamic, analytical, nimble and responsive to current and emerging needs (Cosens et al., 2017; Hurlbert and Diaz, 2013); however, institutional support for flexible, diverse programming to encourage proactive policy design is not always available (Global Water Futures, 2020; Sandford et al., 2011; Ivey et al., 2004). For example, the absence of a flexible regulatory framework and clear legal system around water reuse rights limits the adoption of demand-side management approaches to water conservation in Alberta (Alberta WaterSMART, 2013). Similarly, there is little in terms of water and ecosystem services market development in Canada, which impedes competition for conservation and wetland retention activities on private land (Global Water Futures, 2020). Actions to redesign or improve the institutional systems, including infrastructure upgrades (Sandford et al., 2011), and policy and administration processes (Straith et al., 2014; Patino, 2010), are sometimes accompanied by high financial and political costs that can be a barrier to action.

Despite these institutional barriers, there are pockets of innovation in the water sector across Canada. At the provincial level, the past two decades have seen many water policy reforms, with renewed focus on drinking and source water protection, and a rise in watershed-based decision-making organizations (Bakker and Cook, 2011). Some notable water management modernizations include Alberta's water markets, the Northwest Territories Northern Voices, Northern Waters strategy, which prioritizes water for nature, and Ontario's requirements for full-cost pricing and accounting for water supply infrastructure (Global Water Futures, 2020; Bakker and Cook, 2011; Sandford et al., 2011). Innovation often stems from supportive local factors and the creation of safe spaces for policy experimentation (Moore et al., 2014; Straith et al., 2014).

4.4.3 Leadership and water champions

Adaptive organizations and policies require strong leadership to foster an institutional culture of innovation (Dale et al., 2019; Burch, 2010), take necessary risks to carry out mandates (Mitchell, 2017; Morris and de Loë, 2016; Hurlbert and Diaz, 2013), and successfully implement and follow through with adaptation plans (Zubrycki et al., 2016; Simms and de Loë, 2010). Leadership can play an important role in empowering water practitioners to do their best work, especially in a fragmented policy context where there is not always clear authority for adaptation work (Oulahen et al., 2018). For example, in the City of Vancouver, leadership by elected officials and city administrators was identified as critical to advancing flood risk adaptation efforts (Oulahen et al., 2018). Burch (2010) also details the actions of a persuasive practitioner within the City's Planning Department, who noticed that cultural conflicts between staff in planning and operations were slowing progress on adaptation, and intentionally hired staff who valued inter-departmental collaboration. These actions contributed to a paradigm shift within the City that has led to systems being highly responsive to dealing with a changing climate, given the vulnerabilities of Vancouver and its surrounding municipalities.

Water "champions" propose innovation, build coalitions to support it, and appeal to the interests and concerns of those in the decision-making network (Daniell et al., 2014). These individuals can work inside or outside of an organization (Moore et al., 2014), but are usually more successful if they have implementing capacity (Daniell et al., 2014). They are change agents, highly skilled at recognizing cultural and institutional characteristics that inhibit or promote changes, and strategies that can successfully influence implementation. They usually have strong informal and formal networks, are good communicators who are willing to take necessary risks, and are humble, respectful and open to new ideas. They may also be skillful at managing and brokering relationships between different water communities and other relevant sectors (Hurlbert, 2018; Straith et al., 2014). These skills are fostered by leadership training and negotiating opportunities.

4.4.4 Stakeholder participation and social learning

Social networks and social learning are linked with innovation in water institutions. Social learning means that people learn as part of a group from observing behaviours and their consequences. Social networks connect water practitioners to different types of knowledge and resources, facilitating understanding and trust (Moore et al., 2014; Gupta et al., 2010; Folke et al., 2005). Stakeholder engagement that incorporates social learning enables participants to explore adaptation options and confront the inevitable trade-offs associated with them.

Exploration of the future often involves exploratory models and participatory exercises to investigate a range of potential future conditions (Maier et al., 2016). Scenarios are consistent stories about the future for systems that are too complex to predict (Wiek et al., 2015). They cover the range of plausible futures (Lemieux et al., 2014), including rare but potentially devastating events such as the failure of critical infrastructure or energy systems. Scenario development often involves local stakeholders who share their (often competing) views of the future to facilitate robust decision making (*see* Case Story 4.4 and Case Story 4.5; White et al., 2015). A goal of these exercises is to develop strategies that perform reasonably well against a wide range of plausible climate change and societal forces, even when confronted by surprise circumstances (Lempert et al., 2003). They provide a solid basis for consensus building and political action among stakeholders with different views of the future, because they provide a reasonable outcome no matter whose view of the future proves to be correct. They can also identify "no" or "low regret" strategies that increase climate resilience and also promote good water management broadly, often at little additional cost. Examples of these types of strategies include the following: enhancing operator training and improving coordination (Casello and Towns, 2017); upgrading monitoring networks contributing to forecasting (Canadian Council of Ministers of the Environment, 2011); and water conservation and demand management (Mguni, 2015; de Loë et al., 2001). The latter is identified as important in the municipal sector in Ontario and in the Alberta Water for Life Strategy, resulting in an improvement in water use efficiency and productivity in Alberta by 30% between 2005 and 2015 (Alberta Water Council, 2017). In addition, scenarios can help identify potentially maladaptive behaviours, such as increased consumption, that could be associated with major capital projects (de Loë et al., 2001).

Case Story 4.4: Addressing climate vulnerability and sustainable water management in the South Saskatchewan River Basin

Southern Alberta has recently experienced disastrous floods and droughts. Added pressures from a growing economy, an expanding population and changing climate have significantly challenged the management of water resources in the South Saskatchewan River Basin (SSRB), and will continue to do so. To address these challenges, the Alberta WaterSMART project worked with representatives from irrigation districts, municipalities and watershed organizations to develop a set of plausible future water supply and demand scenarios for the SSRB. The scenarios linked data from historic drought and flood years with future climate projections, and also considered potential future land use and societal changes, such as wetland restoration, a major forest disturbance in the headwaters, increased water demands and possible decreased flows from the United States of America, resulting from changing glaciers extents and precipitation patterns attributed to climate change.

Working groups were asked to develop a list of adaptation strategies to address the high- and low-flow conditions that could result from each scenario (Alberta WaterSMART, 2016). A suite of performance measures were developed to help participants evaluate the success of each strategy. Performance measures reflected a desired water outcome for the SSRB or its sub-basins, and included metrics such as the "percentage of days when instream fish needs were not met" or "maximum flow violations." The performance of each adaptation strategy was assessed using a water resources model designed for the SSRB. Participants used results from model runs to sort adaptation strategies into different levels, from strategies that could improve current conditions to those that would make the basin more resilient to climatic changes in the future. Strategies considered most promising by the group of multiple stakeholders for the SSRB included (Alberta WaterSMART, 2016):

- developing shortage-sharing frameworks by sub-basin;
- restricting greenfield development in the floodplain;
- redesigning operating policies for upstream Bow River reservoirs; and
- building net storage flow in the Bow River sub-basin.

Case Story 4.5: Lake Superior and Lake Ontario outflow regulation: Addressing uncertainty in Great Lakes water levels

Water levels of the Great Lakes are driven primarily by natural factors, including changes in precipitation and temperature (*see* Case Story 4.1), but are also partially affected by regulation of outflows from Lake Superior and Lake Ontario through dams and related control structures on the Saint Mary's River and dams at Cornwall-Massena on the St. Lawrence River. Outflows are managed using regulation plans—rules that guide how much water is released through the regulatory structures under widely varying hydrological and climatic (hydroclimate) conditions to meet the needs of various water-using interests throughout the basin. The International Joint Commission (IJC) conducted studies (International Upper Great Lakes Study Board, 2012; International Lake Ontario–St. Lawrence River Study Board, 2006) to evaluate alternative regulation scenarios to address emerging needs and to consider climate change, and also used scenario analysis to review the rules for regulating outflows in the context of climate variability and change, and to better balance the water needs of diverse interests in the region.

The IJC studies included detailed hydroclimatic analysis to inform assessment of the current state of water resources modelling in the region, the construction of a timeline of historical climate variability, and the downscaling of global climate models to understand the impact of climate change on future regional water levels. This analysis revealed considerable uncertainty around how water levels could change in the future, using different hydroclimatic scenarios to represent a wide range of plausible future conditions including:

- historical (assumed stationary) climate to anticipate the next 30–100 years;
- a large, 50,000-year sequence of stochastically-generated water supplies to each of the Great Lakes to capture a full range of climate variability (based on historical water supply conditions); and
- a changing climate leading to decreased and/or increased water levels.

At the same time, researchers worked with stakeholders to define water interests in the basin, such as hydroelectric generation, commercial navigation, shoreline properties, recreational boating, municipal and industrial water uses and ecosystems, and their potential vulnerabilities to fluctuations in water levels. Performance indicators and/or coping zones (i.e., the range of conditions that would be considered tolerable) were derived for each interest, and a relationship between these and water levels was determined. Public and expert feedback led the Study Boards to recommend that the new regulation plans should improve the health of the environment, minimize damage from water-related natural hazards, and increase or maintain the economic viability of shipping, hydropower, recreation/tourism and industry.

Study participants then tested different sets of regulation plans using a “shared vision model” (SVM), a user-friendly computer platform that allowed the collaborative development of models and operating plans to simulate impacts in the basin. Participants used the SVM to compare the performance of the current regulation plan to that of alternative plans under a range of hydroclimate scenarios, and drew upon the performance indicators and coping zones to explore trade-offs associated with alternative plans.

Through this process, the Study Boards in each study narrowed down alternative regulation plans to those that were more robust to changing conditions, continued to balance upstream and downstream impacts and benefits, and promoted more natural flows and ecosystem benefits under a range of hydroclimatic conditions. After considerable public and government consultation, the IJC implemented a new plan for regulating Lake Superior outflows (Plan 2012) at the beginning of 2015, and in January 2017, adopted Plan 2014 for regulating Lake Ontario outflows. An adaptive management strategy was developed to complement these new regulation plans as a means to review and refine the chosen regulation plans over time if conditions in the system changed. Adaptive management compares observed outcomes through on-going monitoring to the simulated results to improve the simulations over time. The on-going performance of the regulation plans can be assessed under a range of water level conditions and the regulation plans can be formulated and evaluated as more is learned and as conditions change. The final reports from these studies and the adaptive management process are available from the IJC website (ijc.org).

4.4.5 Adaptive management and water experiments

Many water planners seek adaptation measures that are robust under a wide range of possible future climate conditions. While there is no standardized paradigm for quantifying robustness in the water sector (Whateley et al., 2016), the idea of robustness generally implies acceptable performance over a wide range of future scenarios (Lempert and Groves, 2010; Groves and Lempert, 2007; Lempert and Collins, 2007). Therefore, decision makers need the ability to both assess how well decisions meet expectations and to adapt those management decisions as more information is received and conditions change. Adaptive management accepts that decisions are made with imperfect information and under high degrees of uncertainty, and provides a means for reviewing the performance of a decision through on-going monitoring of outcomes and stakeholder preferences, updating the modelling and evaluation tools used in the original decision, and recommending improvements as necessary (International Upper Great Lakes Study Board, 2012) (*see* Box 4.2). In adaptive management, adaptation actions and policies are designed to be flexible and are subject to adjustment in an iterative, social learning process (Lee, 1999).

Box 4.2: Adaptation vs. adaptive management

Adaptation actions are interventions taken to respond to new or different information obtained through monitoring and experience. Simply stated, adaptation is about taking action to change something if it is not working. In current practice, questions of how to measure vulnerability, adaptive capacity, and resilience for effective adaptive actions are a challenge for policy makers and scientists (Lesnikowski et al., 2017). Adaptation is complex across multiple sectors and disciplines, and there is no single, universal metric that fits the reality of adaptation (Ford and King, 2015). In an examination of 15 scientific studies around water resources adaptation strategies, Salerno (2017) found that a common weakness of adaptation strategies is identifying approaches to address uncertainty (Woodruff, 2016). Specifically, adaptation plans commonly fail to provide detailed implementation processes, raising concerns about whether adaptation actions will translate into reductions in vulnerability or maladaptation (Salerno, 2017).

Adaptive management is an approach to adaptation that embraces risk and uncertainty as a way of building understanding based on continuous monitoring, predictive modelling, evaluation and learning. Adaptive management provides a structured, iterative process of robust decision making in the face of uncertainty, with the aim of reducing uncertainty over time via system monitoring (Williams and Brown, 2014). Adaptive management recognizes that:

- no matter how much we know, there is always more to learn;
- conditions are always changing, sometimes in ways that cannot even be imagined, let alone predicted; and
- decisions are made based on the best, albeit imperfect, evidence available and may not always be effective.

The concept of adaptive management is to challenge decisions (such as adaptive actions) if outcomes are not as expected and to make necessary adjustments as more is learned and/or as conditions change. Simply put, adaptive management goes further than adaptation by following up on actions to ensure that they are working as intended and, if not, to make adjustments (*see* Figure 4.4). Adaptive management requires good planning, collaboration and quantitative predictive modelling. A successful adaptive management strategy aims to develop and apply multi-objective, flexible and sustainable solutions through collaborative efforts that include (International Great Lakes–St. Lawrence River Adaptive Management Task Team, 2013):

- monitoring and modelling for improved understanding of:
  - why and how conditions are changing;
  - existing and potential risks and complexities of problems; and
  - performance metrics for understanding the success of options;
- tools for developing and evaluating adaptive options;
- transparent, accessible information readily available to users;
- on-going assessment and evaluation of solutions maintained with feedback to decision-making processes; and
- stakeholders that are fully engaged with mechanisms to inform the decision-making process.

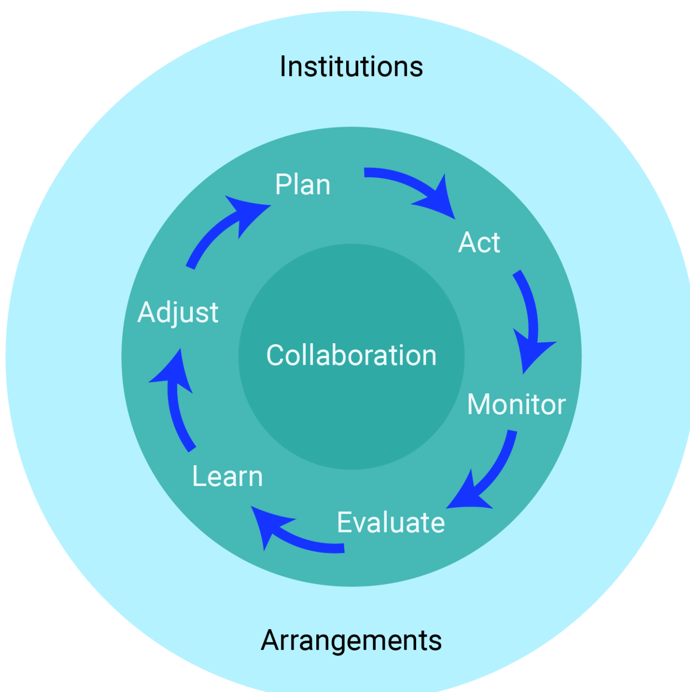

Figure 4.4: Diagram illustrating the adaptive management cycle. Source: Adapted from International Great Lakes–St. Lawrence River Adaptive Management Task Team, 2013.

Evidence suggests Canadian water management frameworks vary in their ability to respond to unanticipated events. Bizikova et al. (2013) examined water-related policies in British Columbia, Saskatchewan, Manitoba and Nova Scotia to assess the elements representing adaptability, such as multi-stakeholder deliberation, automatic policy adjustment, and integrated and forward-looking analysis. They found that these policies do not always include explicit monitoring and review processes (Bizikova et al., 2013). In some cases, formal reviews were completely absent (Roy, 2013), whereas in other instances, reviews were spontaneous or only done once, not feeding back into formal policy reviews and adjustments (Bizikova and Vodicka, 2013). In about half of the policies examined, a formal review was required, but no public report of this review was available, and no information on subsequent policy adjustment was required (Bizikova et al., 2013). Ultimately, the team examined 27 policies from the water sector, as well as the agriculture and forestry sectors, and scored them using the ADAPTool method, which assesses the adaptability of policies or programs in relation to any defined stressor or external change, such as climate. Despite the wide range of policies making it difficult to compare across jurisdictions, the team found a wide range of adaptability in the policies present (*see* Figure 4.5). High-scoring policies (in the green zone) were generally not vulnerable themselves to climate change, played a role in building adaptive capacity of groups, and were designed to use multi-stakeholder processes and/or foresight methods such as scenario analysis (Bizikova et al., 2013).

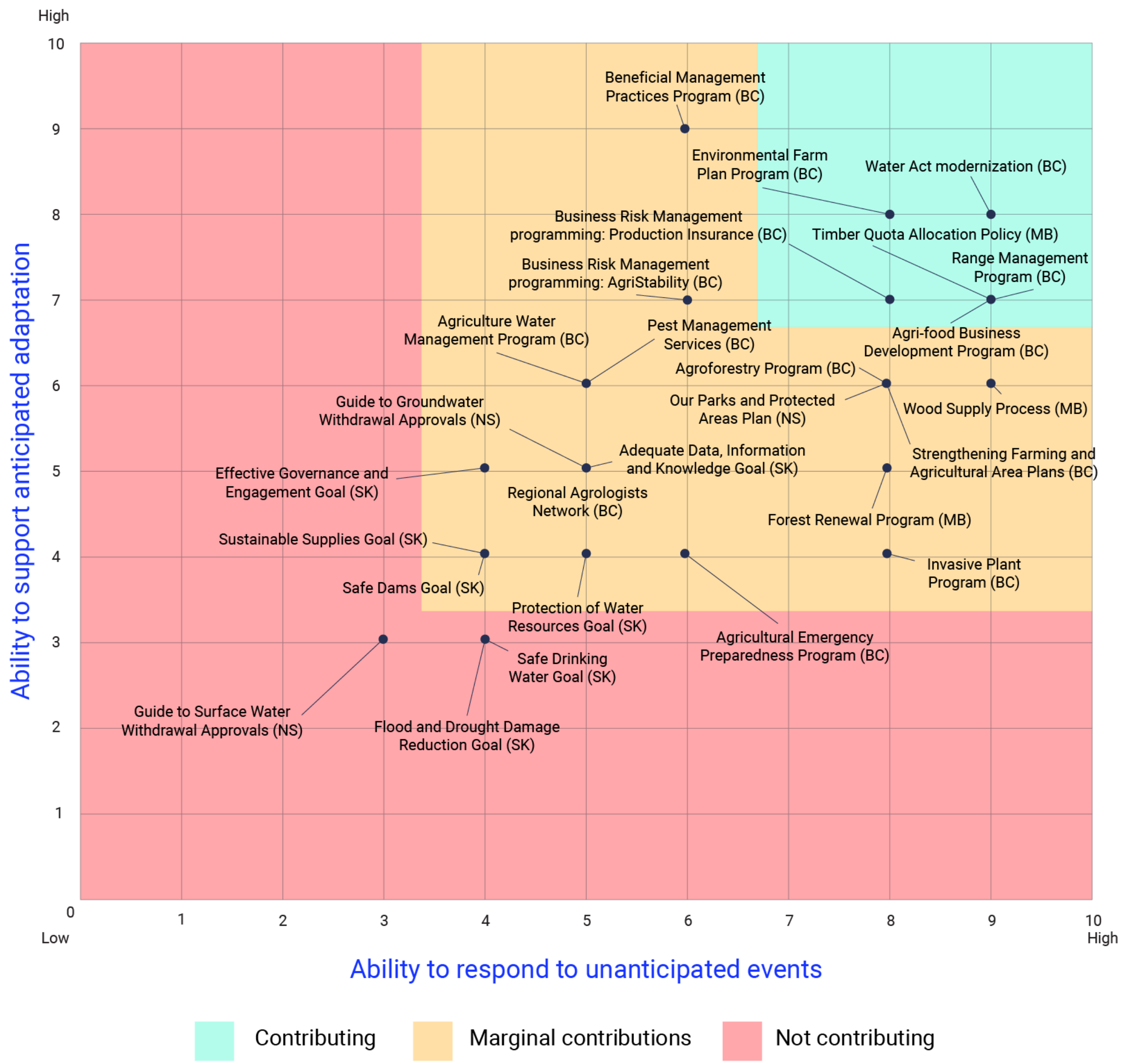

Figure 4.5: An overview of the ADAPTool Scoring Results (from 1 to 10) for 27 policies examined in British Columbia, Saskatchewan, Manitoba and Nova Scotia. ADAPTool is structured as a series of Excel spreadsheets that take analysts through a standardized step-by-step process to assess the ability of existing policies or programs to support adaptation measures and the general adaptability of the policies or programs themselves. Source: Adapted from Bizikova et al., 2013.

Adaptive management requires long-term commitments, collaboration (Global Water Futures, 2020) and funding, and an effective linkage of science-based monitoring to decision-making processes (Murphy and Weiland, 2014). While effective adaptive management is difficult to achieve, examples of this are reported in natural resource management broadly (Williams and Brown, 2014) and in the management of water resources in Canada (Failing et al., 2013). The 2012 Great Lakes Water Quality Agreement between the United States and Canada includes adaptive management as a guiding principle in order to systematically assess the effectiveness of actions and adjust future actions to achieve the ecological integrity and water goals for the basin (IJC, 2017). An even more structured adaptive management effort was initiated for the Great Lakes in 2015 by the IJC with the establishment of the Great Lakes–St. Lawrence River Adaptive Management (GLAM) Committee to provide on-going review and evaluation of newly implemented regulation plans of outflows from Lake Superior and Lake Ontario (IJC, 2015) (*see* Case Story 4.5). This initiative provides a structured approach to adaptive management to respond to climate changes and links the evaluation of plan performance directly to the IJC as the decision makers (Clamen and MacFarlane, 2018; Great Lakes–St. Lawrence River Adaptive Management Committee, 2018).

4.5 It is vital to engage the public and build awareness about adaptation opportunities

Successful adaptation requires public buy-in to the science of climate change and the need to implement adaptation policies. A majority of Canadians support policies to address water-related problems, but managing water resources ranks low on their list of salient problems after the economy, health care and cost of living. Extreme events, including floods, droughts and episodes of poor water quality, can often bring the need for better water management to the forefront.

Canadians are concerned about water and want governments to play a strong role in instituting practices that protect water resources and prepare for water-related hazards. Lack of issue salience, misperceptions about how water systems function, and financial and technical barriers can impede the buy-in for climate change adaptation. Water practitioners are fostering public support by emphasizing financial and health-related co-benefits, addressing barriers to action, and taking advantage of highly publicized water-related events. The discourse around options for adaptation in the water sector is expanding to include a wider variety of policy tools to address water issues.

4.5.1 Introduction

Water in Canada is generally perceived to be of high quality, abundant (Renzetti and Dupont, 2017; Royal Bank of Canada, 2017) and our most important resource (Royal Bank of Canada, 2017). However, Canadians make large per capita water withdrawals compared to those in other countries—which include consumptive and non-consumptive uses (Conference Board of Canada, 2013)—and water policy issues are ranked among the lowest in public opinion surveys—regarded as much lower in importance compared to the economy, healthcare and the rising cost of living (*see* Figure 4.6; Royal Bank of Canada , 2017; Clancy, 2014). These perceptions ultimately influence policy development (Heinmiller, 2017; Yates et al., 2017; Clancy, 2014) and can challenge efforts to implement adaptation strategies (Dale et al., 2019).

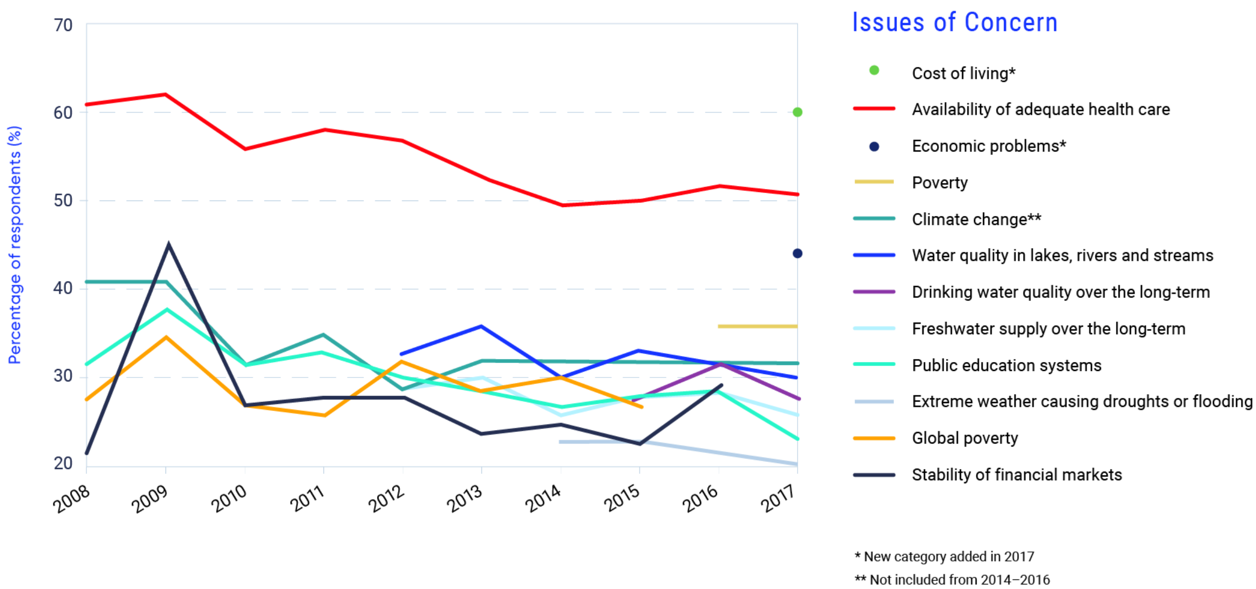

Figure 4.6: The annual RBC Canadian Water Attitudes Study, which asks respondents to indicate their degree of concern related to a range of issues, found that Canadians are concerned about water issues and climate change, but to a lesser degree than issues such as the cost of living, availability of healthcare and poverty. Source: Adapted from Royal Bank of Canada, 2017.

Practitioners in the water sector are working to influence perceptions in favour of proactive adaptation in the water resources sector (Global Water Futures, 2020). While improved scientific understanding can highlight trends, vulnerabilities and potential solutions to technical water management issues, decision makers must satisfy multiple, and often conflicting, needs and objectives (Bakker and Cook, 2011), and require processes that are responsive to public attitudes. Political turnover and the short time scales available for planning exacerbate this challenge (Dale et al., 2019; Hurlbert and Diaz, 2013; Hamlet, 2011).

4.5.2 Perceptions of water and climate

Perceptions about policy issues are important because they influence judgments around the acceptability or appropriateness of proposed solutions (Stone, 2002). According to surveys, most Canadians believe that climate change is occurring (Mildenberger et al., 2016; Lachapelle et al., 2014), and that climate change will have a negative impact on Canada's supply and quality of fresh water (Royal Bank of Canada, 2017). They expect more frequent and intense extreme storms, flooding of rivers and coastal areas, and lengthy droughts (Akerlof et al., 2010). Despite these concerns, Canadians' level of preparedness for water-related extremes has remained low for a number of years. In a survey by Royal Bank of Canada (2017) of over 2,000 Canadians, only 35% reported that they are prepared to deal with floods and drought. In another survey, almost all of the 2,300 Canadians surveyed believed that homeowners are primarily responsible for flood protection, but less than 30% pursue protective measures and only 6% know whether they live in a designated flood-risk area (Henstra et al., 2019b; Thistlethwaite et al., 2017).

Despite some skepticism, there is widespread support for climate policy and government action to protect water resources as an alternative to “doing nothing” (Comeau, 2017; Mildenberger et al., 2016). Canadians want governments to play a strong role in managing water resources and in preparing for natural hazards (*see* Figure 4.7; Henstra et al., 2019b; Royal Bank of Canada , 2017), to enforce stricter regulations, and to require commercial and industrial users to pay full water supply costs (Real Estate Foundation of British Columbia, 2018; Royal Bank of Canada, 2017). This support can diminish, however, due to issue fatigue and politicization of the climate change issue (Groulx et al., 2014; Pidgeon, 2012).

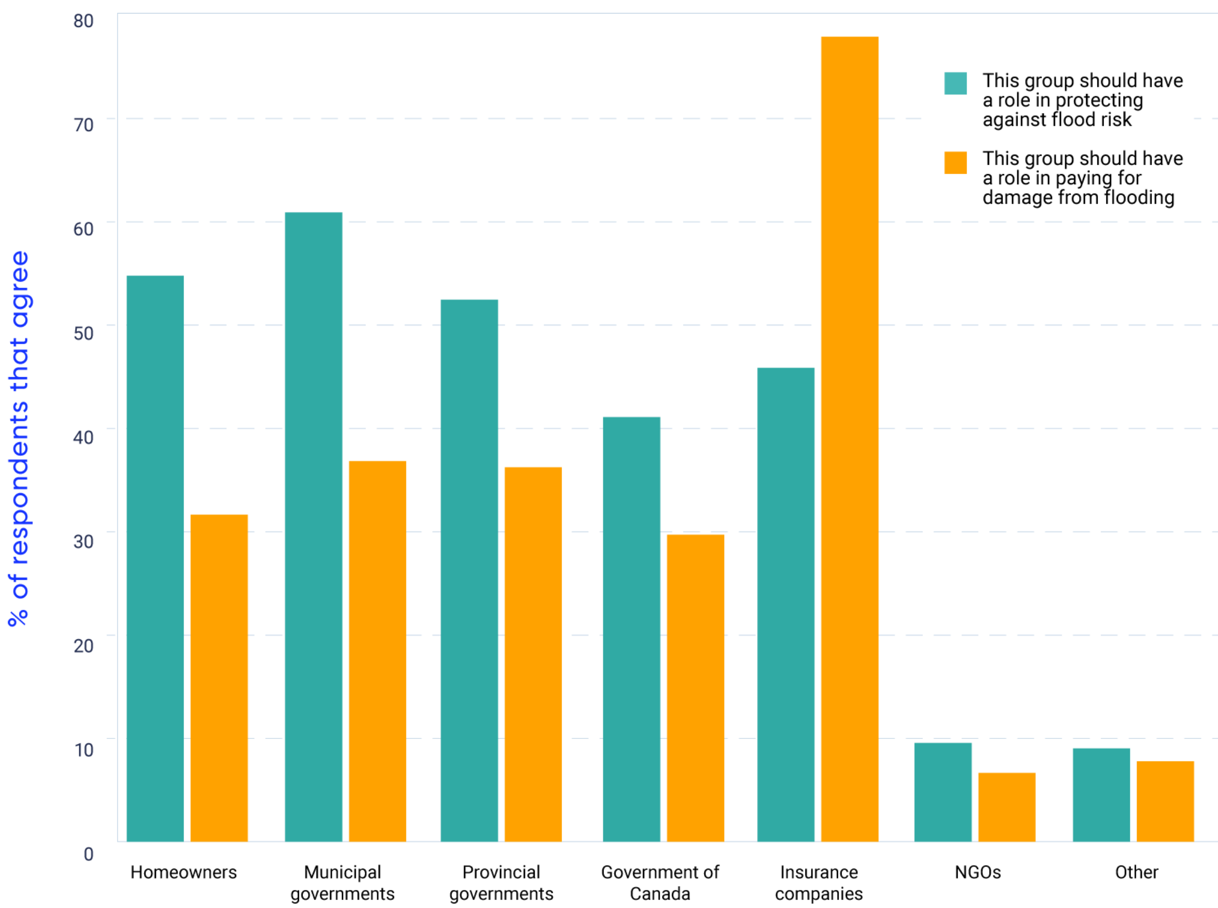

Figure 4.7: A 2016 national survey of Canadians living in “flood risk areas” (as defined by Government of Canada, 2013), developed by researchers at the University of Waterloo, evaluated perceptions about how the responsibility associated with protecting their property and paying for costs related to flood damage should be shared between different organizations. Source: Adapted from Thistlethwaite et al., 2017.

4.5.3 Building public support for adaptation

The inconveniences of maintenance and the "invisible" nature of water services are additional challenges to garnering public support for adaptation in the face of a changing climate (Canadian Water and Wastewater Association, 2015). Quite literally, most water-related water infrastructure is "out of sight, out of mind." Most water managers and regulators view ageing infrastructure as the most prominent future risk to the Canadian water sector (Global Water Futures, 2020; Moncrieff-Gould et al., 2018), yet only one in five Canadians believe that major investments in water-related infrastructure are required (Royal Bank of Canada, 2017). Building public support through emphasizing health, economic and environmental benefits of investments in water systems may increase the likelihood that decision makers will set water systems as a priority for action (Canadian Water and Wastewater Association, 2015). This process can involve framing water-related climate information in positive terms paired with consistent and constructive solutions (Global Water Futures, 2020; Canadian Water and Wastewater Association, 2015; Patino, 2010), mainstreaming climate solutions within other policy areas such as urban development (Dale et al., 2019) and engaging stakeholders early and substantively in adaptation processes (Lemieux et al., 2014).

Canadians want information about water-related risks to be relevant to the issues that they care about, and want to know what to do with that information (Jones-Bitton et al., 2016; Henrich et al., 2015; Groulx et al., 2014). A recent survey of 2,300 Canadian households found that 92% of respondents want publicly available flood risk maps with flood mitigation information, and want access to this information when they are considering home ownership (Thistlethwaite et al., 2017). The climate change dimension may not matter if the benefits of the adaptation actions align with important values held by the target audience and lead to co-benefits. For example, despite the benefits for climate resilience, improved water quality is the main motivator for farmers restoring wetlands in Nova Scotia (Sherren and Verstraten, 2013). Other studies have found that framing water management policies in terms of personal benefits, such as a lower cost of living, sustainable economic development, and lower incidence of disease, have more appeal to a wider range of people (Henrich et al., 2015; Groulx et al., 2014; Semenza et al., 2011; Akerlof et al., 2010). With the necessary information, individuals who feel personally at risk tend to be more prepared (Semenza et al., 2011).

Financial and time constraints are also issues that can prevent or slow adaptive behaviour (Groulx et al., 2014; Semenza et al., 2011). Efforts to reduce these barriers and promote behavioural change through the formation and dissemination of social norms, self-perception and memory prompts have been effective across Canada (Lieske et al., 2014; Lo, 2013; McKenzie-Mohr, 2000). For example, after identifying financial constraints as a major barrier to the adoption of water conservation behaviours, the City of Barrie, Ontario, introduced a rebate program and an interest-free pay-back scheme for water-efficient appliances and their installation, ultimately deferring millions of dollars in water infrastructure spending (Reily, 2004).

Extreme water-related events, such as floods, droughts and water quality crises, provide a window of opportunity for political and policy action that can enhance long-term climate resilience (Dale et al., 2019; Oulahen et al., 2018). Many successful adaptations in the water sector have been driven by institutional responses to a public crisis (Clancy, 2014). This occurred after floods and freeze-thaw events that caused significant road damages initiated a major adaptation process in Prince George, British Columbia (Dale et al., 2019), and when source water protection was strengthened after water contamination incidents in Walkerton, Ontario (in 2000) and North Battleford, Saskatchewan (in 2001) (Hurlbert et al., 2015; Bakker and Cook, 2011;

de Loë and Plummer, 2010). Similarly, significant flooding in 2011 and 2014 to downstream communities in Manitoba brought renewed attention to the flood control benefits of wetland retention, whereas previous attempts focusing on biodiversity protection failed to motivate political action (Global Water Futures, 2020). As a result, the Sustainable Watersheds Act was passed into law in 2018, employing a combination of economic incentives and disincentives, and regulation to promote a "no net loss of wetlands" policy in the province (Stevenson, 2018).

Water practitioners across Canada employ a number of strategies to increase issue saliency around the water-related risks of climate change. They will be required to draw on these strategies and innovate even more as water systems become increasingly complex and uncertain, and the stakes to win over public perceptions become more critical.

4.5.4 Diversifying policy tools

Traditional approaches to water resource issues have been regulatory in nature (Simms and de Loë, 2010), but researchers and practitioners are increasingly recognizing that acting with conventional policy tools will not be enough to adapt to the growing complexity in water systems (Simms and de Loë, 2010; Hurlbert et al., 2010; Okanagan River Basin Board, 2010). Innovations and variation in policy design and implementation can reduce risks, increase the chances of reaching desired outcomes, and meet diverse stakeholder needs (Bizikova et al., 2018; Thistlethwaite and Henstra, 2017). Conversations around policy options and adaptation strategies are expanding at all levels (*see* Case Story 4.6), and there now exists a diverse mix of regulatory, expenditure, institutional and economic instruments in water policies across Canada (Bizikova et al., 2018).

Case Story 4.6: The changing policy discourse for solutions to water-related hazards in the Canadian Prairies

Much of the population in the Prairie provinces of Alberta, Saskatchewan and Manitoba obtains its water from the Nelson-Churchill River Basin, the third largest watershed in North America (*see* Figure 4.8; International Institute for Sustainable Development, 2016).

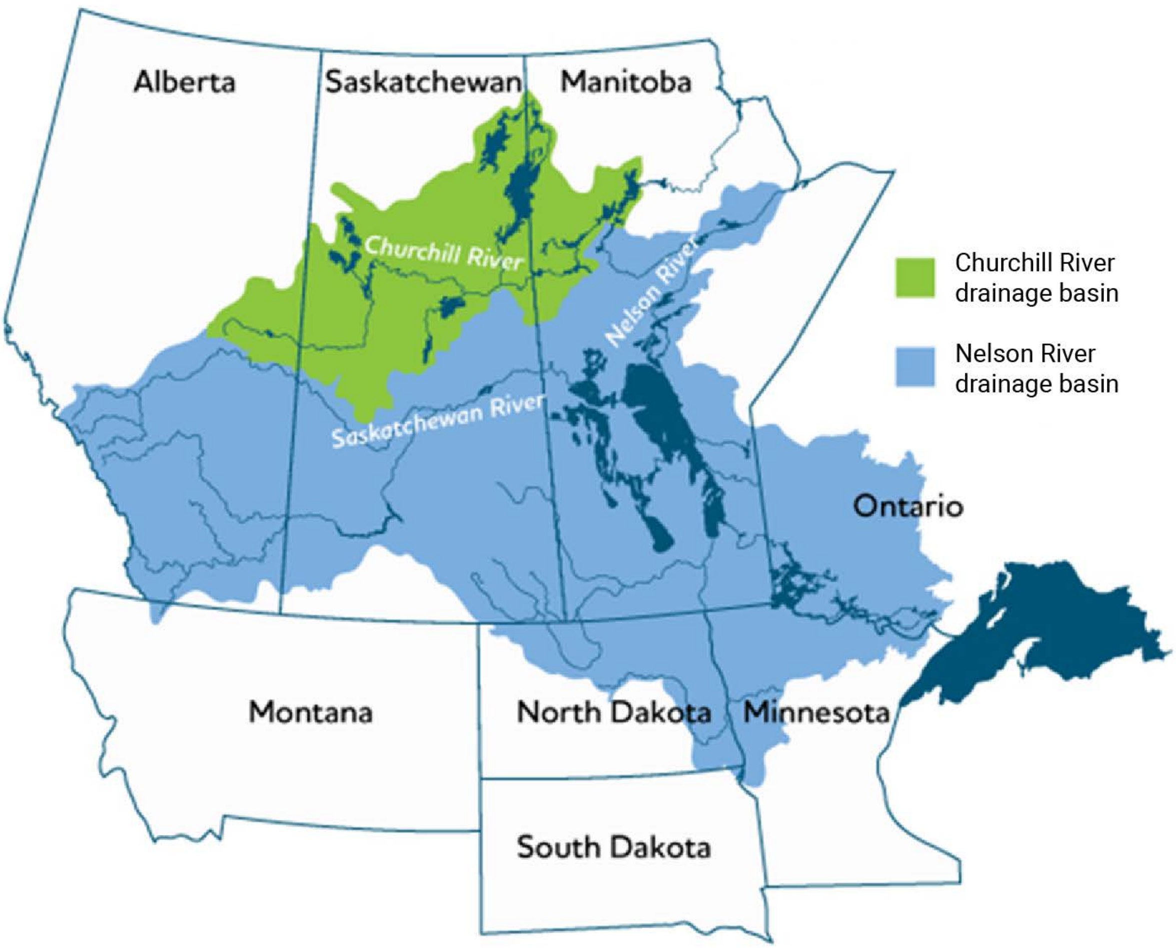

Figure 4.8: The drainage basins of the Nelson and Churchill Rivers. Source: Manitoba Hydropower, n.d.

In this basin, numerous organizations advocate for diverse approaches to address current water management that will likely be exacerbated by climate change (Global Water Futures, 2020). A wide range of policy approaches is discussed (*see* Figure 4.9). In policy and planning documents authored by different organizations operating within the basin, infrastructure solutions are the most discussed approach to address floods and droughts across the drainage basin. While built infrastructure approaches are most frequently referenced, natural infrastructure approaches are also mentioned and sometimes preferred, such as in the case of improving water quality (*see* Table 4.1).

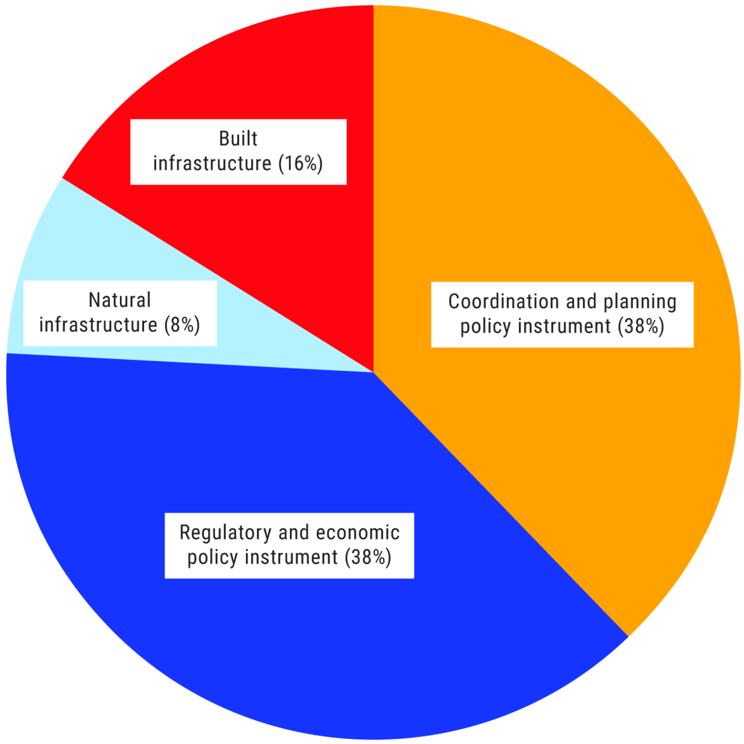

Figure 4.9: Percentage of dialogue in policy and planning documents across the Nelson–Churchill basin related to four policy instruments for addressing water issues. See Table 4.1 for specific examples.

Table 4.1: Examples of policy instruments and options to address water-related hazards in the Nelson–Churchill River Basin

BUILT INFRASTRUCTURE	NATURAL INFRASTRUCTURE	COORDINATION AND PLANNING	REGULATORY AND ECONOMIC
• Dyke and floodway construction • Installing tile drainage • Upgrading spillways and dams to new design standards for extremes	• Retaining and restoring wetlands • Increasing soil organic matter on agricultural lands	• Emergency response planning • Cooperative agreements • Coordinated drought and flood plans	• Mandated water rationing • Legislated penalties for drainage • Compensating flood victims • Tax credits for riparian (land along the banks of rivers and streams) management • Water pricing or surcharges

Source: Global Water Futures, 2020.

Improving coordination and organizational policies across the basin is widely discussed as a means to enhance capacity to respond effectively to water-related hazards. This involves proactive planning (e.g., coordinated strategies for drought, wetlands and drainage, and invasive species), increasing financial and human resource capacity (e.g., reliably funding water resource groups, providing technical support to communities, increasing funding opportunities), and developing operating rules and procedures to enhance resilience to cope with new extremes. An example of the latter is the five-year agreement between TransAlta and the Government of Alberta that allows Alberta Environment and Parks to modify the levels of TransAlta-owned reservoirs on the Bow River for the purposes of enhancing flows during dry years and providing additional storage during wet periods (Government of Alberta, 2018).

There are differences in strategies and advocacy approaches across organizations with different roles in water governance (Global Water Futures, 2020). For example, environmental and non-profit groups tend to favour information provision and community engagement work, and prefer a regulatory-based approach to water management, whereas agricultural and industry organizations preferentially discuss market-based solutions to water management challenges, such as funding infrastructure upgrades to improve efficiencies, subsidizing best management practices and establishing insurance schemes.

4.5.5 Conclusion

Adapting to climate change in the water sector involves strengthening water planning and management capacities and mobilizing public support for investments, and institutional and behavioural change. Multi-sector engagement and enhanced opportunities for social learning amongst scientists, water professionals, civil society organizations and the general public are essential to building a social infrastructure that promotes adaptive decision making in the water sector. Shared learning about the need for action and the consequences of inaction would increase public support for policy action.

4.6 Water system vulnerability can be reduced through quality data and resilient design

Reducing vulnerabilities in water systems involves identifying weak spots under current and future climate conditions, and providing access to high quality and locally relevant data. While the quality and resolution of data for monitoring change in uncertain environmental systems is variable, resilient design practices are emerging.

Since there are limited resources to address the broad range of complex and widespread water challenges, it is important to identify areas and sectors that are particularly vulnerable to climate change and require specific management attention. To address vulnerabilities, practitioners require access to high quality and locally relevant data. While there are many information sources, at various scales, about water systems and future climate change impacts available across Canada, there is considerable variation in quality, and in temporal and spatial resolution of the available data. Infrastructure design and management is often based on historical information that no longer has the same relevance in a climate change context. Requirements around design, building and operations are changing to address these vulnerabilities. The Public Infrastructure Engineering Vulnerability Committee (PIEVC) Protocol (Engineers Canada, n.d.) and the use of natural infrastructure have emerged as key tools for addressing the climate change-related vulnerability of water-resource infrastructure in Canada.

4.6.1 Introduction

Climate and water-related vulnerability and risk assessments have been carried out extensively across the country at different scales and for different issues. For example, assessments have been conducted in the Atlantic region for coastal areas and water resources (e.g., AMEC Environment & Infrastructure, 2012; Cochran et al., 2012; Ferguson and Beebe, 2012; Government of Newfoundland and Labrador, 2012); in Quebec for water quality and water use (e.g., Jalliffier-Verne et al., 2017; Tremblay, 2016; Carrière et al., 2010); in the Great Lakes Region for wetlands and aquatic ecosystems (e.g., Tu et al., 2017; Chu, 2015; Lemieux et al., 2014; Mortsch et al., 2006); in the Prairies for drought and flooding (e.g., Wittrock et al., 2018; KGS Group, 2016; Thomson Agri-Environmental, 2011a, b; Magzul and Rojas, 2006); in British Columbia for hydroelectricity and coastal flooding (e.g., Associated Engineering (B.C.) Ltd., 2018; Northwest Hydraulic Consultants Ltd., 2014; Jost and Weber, 2013); and in Northern Canada for thawing permafrost and vulnerable water supplies (e.g., BGC Engineering, 2011; Goulding, 2011; Nesbitt, 2010).

Syntheses of these assessments emphasize the diversity in methodologies and organizations (e.g., watershed organizations, academia, governments) involved (Perdeaux et al., 2018), as well as the technical challenges in identifying a range of climate change impacts and hazards on water resource systems (Nodelcorp Consulting, 2014). This is especially true for organizations with limited financial and technical capacity (Lemieux et al., 2014; Plummer et al., 2012).

4.6.2 Water information systems

Effective monitoring is a key element of successful adaptation (Hall et al., 2014). Water practitioners require access to high quality and locally relevant data because many fundamental water decisions are local in scale (Global Water Futures, 2020), and good information is necessary to assess vulnerabilities to climate change risks (Canadian Water Network, 2019). Unfortunately, high quality, systematic, regularized data collection is not the norm in many parts of Canada (Nodelcorp Consulting, 2014), and climate change impact data is not always available or linked into decision-making processes (Canadian Water Network, 2019). Key datasets for water practitioners are administered by a variety of federal departments, while provincial and territorial agencies provide information such as snow depth, stream flows and lake levels (*see* Table 4.2). Non-governmental organizations, such as B.C.'s Pacific Climate Impacts Consortium, the Prairie Climate Centre, the Ontario Climate Consortium and Ouranos, provide additional resources such as climate change and hydrologic scenarios. However, capacity to provide this information is uneven across organizations and governments, and data varies significantly in its quality, and temporal and spatial resolution (Koshida et al., 2015; Dunn and Bakker, 2011).

Table 4.2: A collection of national and regional water and climate change datasets, resources and tools

ORGANIZATION	RESOURCE DESCRIPTION	DATA TYPE	SCALE	LINK
Government of Canada	The National Hydro Network (NHN) Geobase Series provides geospatial data and geometric attributes of Canada's inland surface waters.	Shapefiles	Pan-Canada	<https://open.canada.ca/data/en/dataset/a4b190fe-e090-4e6d-881e-b87956c07977>
	The Canadian Tides and Water Levels Data Archive contains historical observations from Canadian and global monitoring sites.	Datasets	Pan-Canada (observations for up to 50 years, dating back to 1848)	<https://open.canada.ca/data/en/dataset/87b08750-4180-4d31-9414-a9470eba9b42>
	The Meteorological Service of Canada 50 North Atlantic Wave Hindcast provides hourly wind and wave time series data from climate hindcast models.	Datasets	Canadian East Coast for the period 1954–2018	<https://open.canada.ca/data/en/dataset/f3f0312d-d28b-400c-b14a-28f51ff7f08a>
Agriculture and Agri-Food Canada (AAFC)	The Drought Watch website provides information on drought conditions, soil moisture, and other climate variables.	Datasets and online mapping tools	Pan-Canada	<https://www.agr.gc.ca/eng/agriculture-and-the-environment/drought-watch/?id=1461263317515>

ORGANIZATION	RESOURCE DESCRIPTION	DATA TYPE	SCALE	LINK
Agriculture and Agri-Food Canada (AAFC) (continued)	The AAFC Watershed project (2013) provides watershed related datasets for the Prairie provinces. Data includes drainage information, area of drainage, information on gauging stations, etc.	Datasets	Alberta, Saskatchewan, Manitoba, and some portions of British Columbia, Northwest Territories, Nunavut, and Ontario.	<https://open.canada.ca/data/en/dataset/c20d97e7-60d8-4df8-8611-4d499a796493>
Canadian Center for Climate Services (CCCS)	The CCCS provides access to a variety of climate datasets.	Datasets and online mapping tools	Pan-Canada	<https://www.canada.ca/en/environment-climate-change/services/climate-change/canadian-centre-climate-services/display-download.html>
Environment and Climate Change Canada	The Water Survey of Canada shows real time and historical hydrometric data collected from stations across Canada.	Datasets and online graphing tools	Pan-Canada	<https://wateroffice.ec.gc.ca/index_e.html>
Fisheries and Oceans Canada	The Canadian Extreme Water Level Adaptation Tool supports the adaptation of coastal infrastructure to water-related extremes.	Online application	Coastline of Canada	<http://www.bio.gc.ca/science/data-donnees/can-ewlat/index-en.php>

ORGANIZATION	RESOURCE DESCRIPTION	DATA TYPE	SCALE	LINK
Natural Resources Canada	Canada's Climate Change Adaptation Platform provides links to various resources to support adaptation planning.	Collaborative forum with resources available for decision makers	Pan-Canada	<https://www.nrcan.gc.ca/climate-change/impacts-adaptations/adapting-our-changing-climate/10027>
	The Federal Flood Mapping Guidelines Series guide flood-mapping activities across the country (part of Canada's Platform for Disaster Risk Reduction).	Documents	Pan-Canada	<https://www.publicsafety.gc.ca/cnt/mrgnc-mngmnt/dsstr-prvntn-mtgtn/ndmp/fldpln-mppng-en.aspx>
Public Safety Canada	The Canadian Disaster Database provides information on Canadian and international disasters since 1900.	Datasets	Pan-Canada (1900–present)	<https://www.publicsafety.gc.ca/cnt/rsrcs/cndn-dsstr-dtbs/index-en.aspx>
Global Institute for Water Security	The Changing Cold Regions Network provides online access to water-related data and outputs from models and observatories.	Datasets	Pan-Canada	<http://www.ccrnetwork.ca/>

ORGANIZATION	RESOURCE DESCRIPTION	DATA TYPE	SCALE	LINK
The Gordon Foundation	DataStream is an open access online data platform for sharing data across diverse data collection programs—from community groups to academic organizations. Datastreams exist for the Mackenzie, Lake Winnipeg and Atlantic Canada watersheds.	Datasets	Mackenzie, Lake Winnipeg and Atlantic Canada watersheds	<https://gordonfoundation.ca/initiatives/datastream/>
Government of Yukon	The Water Data Catalogue is an interactive map information on near real-time and historical water-related variables.	Interactive map with accessible data sources	Yukon	<http://yukon.maps.arcgis.com/apps/webappviewer/index.html?id=2365a4c0b8744f34be7f1451a38493d2>
Government of Northwest Territories	The NWT Discovery Portal allows users to browse, share and link a wide range of information, including water-related variables.	Variable	Northwest Territories	<http://nwtdiscoveryportal.enr.gov.nt.ca/geoportal/catalog/main/home.page>
	The Inventory of Landscape Change platform is an interactive map showing a variety of water variables.	Spatial data	Northwest Territories	<https://www.enr.gov.nt.ca/en/services/cumulative-impact-monitoring-program-nwt-cimp/inventory-landscape-change-webviewer>
Government of Nunavut	The Nunavut Water Board provides data on water licences and projects across the territory.	Interactive map and data	Nunavut	<https://www.nwb-oen.ca/nwb-license-map>

ORGANIZATION	RESOURCE DESCRIPTION	DATA TYPE	SCALE	LINK
Government of British Columbia	The BC Water Resources Atlas displays various detailed water-related data.	Dataset and online mapping tool	British Columbia	<http://maps.gov.bc.ca/ess/hm/wrbc/>
	Change in Timing and Volume of River Flow in BC is a long-term hydrological dataset from 1912 to 2012.	Datasets, graphs and associated R code	British Columbia	<http://www.env.gov.bc.ca/soe/indicators/climate-change/rivers.html>
	The GeoWeb Water Portal displays historical and current water and climate data for stations across the province.	Interactive map and downloadable datasets	Northern British Columbia	<http://waterportal.geoweb.bcogc.ca/#12/54.3891/-126.7240>
	BC Water Tool displays watershed reporting, streamflow data, and groundwater and surface water quality data.	Interactive online map and downloadable datasets	Southern and coastal British Columbia	<http://kwt.bcwatertool.ca/streamflow>

ORGANIZATION	RESOURCE DESCRIPTION	DATA TYPE	SCALE	LINK
Government of British Columbia (continued)	The Provincial Groundwater Observation Well Network displays data from 190 provincial monitoring stations.	Interactive online map and downloadable dataset	British Columbia	<https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/groundwater-wells-aquifers/groundwater-observation-well-network>
	Real-time Water Data for snow, groundwater, and hydrometric stations displayed on interactive map.	Interactive map and downloadable datasets	British Columbia	<https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-science-data/water-data-tools/real-time-water-data-reporting>
	Change in Sea Level in BC (1910–2014) displays summary trends of sea level observations from four long-term monitoring stations.	Dataset	British Columbia	<https://www.env.gov.bc.ca/soe/indicators/climate-change/sea-level.html#:~:text=Average%20sea%20level%20has%20risen,centimetres%20per%20century%20at%20Vancouver>
Pacific Climate Impacts Consortium	Station Hydrologic Model Output provides simulated streamflow data for locations throughout BC.	Interactive map with downloadable datasets	British Columbia	<https://www.pacificclimate.org/data/station-hydrologic-model-output>
	Gridded Hydrologic Model Output provides gridded hydrologic projections for four watersheds in the province.	Interactive map with downloadable datasets	British Columbia (Four watersheds)	<https://www.pacificclimate.org/data/gridded-hydrologic-model-output>

ORGANIZATION	RESOURCE DESCRIPTION	DATA TYPE	SCALE	LINK
Pacific Climate Impacts Consortium (continued)	PCIC's Climate Explorer visualizes future projections of climate conditions in the Pacific and Yukon regions based on GCM CMIP5 10-km-resolution downscaled data with a daily time resolution.	Interactive map, graphs, downloadable datasets	Pacific and Yukon regions (1961–2099)	<https://pacificclimate.org/analysis-tools/pcic-climate-explorer>
Fraser Basin Council	The Retooling for Climate Change website supports local governments in preparing for climate change adaptation.	Guidebooks, synthesis reports, and other informational material	British Columbia	<https://www.retooling.ca/>
University of British Columbia	Future Delta 2.0 is a serious videogame enabling real-time exploration of local climate change scenarios in local settings.	Educational videogame	British Columbia	<https://futuredelta2.ca/>
Government of Alberta	Surface Water Quality Data users can view and download water quality variables in lakes and rivers across the province.	Datasets and interactive map	Alberta	<https://www.alberta.ca/surface-water-quality-data.aspx>
	The Alberta River Basins Application is an interactive map showing a variety of near real-time water-related data.	Interactive map and downloadable datasets	Alberta	<https://rivers.alberta.ca/>

ORGANIZATION	RESOURCE DESCRIPTION	DATA TYPE	SCALE	LINK
Government of Alberta (continue)	The Alberta Water Licence Viewer is an interactive web application that allows users to search for existing water licences.	Interactive map	Alberta	<http://waterlicences.alberta.ca/>
Saskatchewan Water Security Agency	The Lakes and Rivers website section provides near real-time stream flow, water levels and ten-day forecasts.	Hydrographs and streamflow data	Saskatchewan	<https://www.wsask.ca/Lakes-and-Rivers/>
	The Water Wells GIS Web application provides information on Water Wells in Saskatchewan, including information on local lithology, completion date, and well depth.	Interactive map with downloadable datasets	Saskatchewan	<https://gis.wsask.ca/Html5Viewer/index.html?viewer=WaterWells.WellsViewer/>
Government of Manitoba	The Manitoba Drought Monitor website provides hydrologic forecasts, reports, flood alerts and drought information.	Interactive map and downloadable datasets	Manitoba	<https://www.gov.mb.ca/water/drought_condition/>
	The Hydrologic Forecast Centre provides timely hydrologic forecasts, maps and information for lakes and rivers.	Data and interactive map	Manitoba	<https://gov.mb.ca/mit/floodinfo/>

ORGANIZATION	RESOURCE DESCRIPTION	DATA TYPE	SCALE	LINK
Government of Ontario	Far North Major River Systems Maps provide stream and climate monitoring information.	Interactive map and downloadable datasets	Ontario	<https://geohub.lio.gov.on.ca/datasets/major-river-systems-in-the-far-north>
	Provincial (Stream) Water Quality Monitoring Network online map provides water chemistry data from sampling sites.	Interactive map and downloadable datasets	Ontario	<https://www.ontario.ca/environment-and-energy/map-provincial-stream-water-quality-monitoring-network>
	Baseline Hydrology Statistics provide data on streamflow regimes for Southwestern Hudson Bay and Nelson River watershed systems. Data includes frequency, timing, duration and discharge at Water Survey Canada gauge locations.	Datasets	Ontario, Southwestern Hudson Bay and Nelson River Watershed	<https://www.ontario.ca/data/baseline-hydrology-statistics>
	The Intensity-Duration-Frequency (IDF) Curve Lookup is a web-based application for retrieving rainfall IDF curves.	Datasets and online graphing	Ontario	<http://www.mto.gov.on.ca/IDF_Curves/terms.shtml>
Ontario Climate Consortium (OCC)	The OCC website provides high-quality and regionally specific climate information for decision makers.	Reports and other publications	Ontario	<https://climateconnections.ca/programs/>

ORGANIZATION	RESOURCE DESCRIPTION	DATA TYPE	SCALE	LINK
International Institute for Sustainable Development (IISD)	IISD Experimental Lakes Area provides long-term ecosystem and atmospheric datasets—available by request. The metadata includes hydrology, physical limnology, zooplankton, fish, algae ecology, chemistry and meteorology research data.	Metadata	Northwestern Ontario (58 small lakes and their watersheds) (1968–present)	<https://www.iisd.org/ela/science-data/our-data/metadata/>
Government of Quebec	*Ministère de l'Environnement et de la Lutte contre les changements climatiques* provides hydrological and hydroclimatological forecasts, and historical data.	Datasets	Quebec	<https://www.cehq.gouv.qc.ca/prevision/index.asp>
	The Hydroclimatic Atlas of Southern Quebec describes the current and future water regime of southern Quebec.	Interactive map and datasets	Quebec	<https://www.cehq.gouv.qc.ca/hydrometrie/index.htm>
Government of New Brunswick	The River Watch and Flood Forecast tool provides 5-day flood forecasts and historical water level information.	Datasets	New Brunswick	<https://www2.gnb.ca/content/gnb/en/news/public_alerts/river_watch.html>

ORGANIZATION	RESOURCE DESCRIPTION	DATA TYPE	SCALE	LINK
Government of New Brunswick (continued)	Coastal Erosion Data displays trends of coastal erosion and shoreline displacement based on specific measurement sites.	Datasets	New Brunswick	<http://www.snb.ca/geonb1/e/apps/apps-E.asp>
Government of Nova Scotia	The Flood Event Database contains historical records of flood events in Nova Scotia since 1992.	Interactive map	Nova Scotia (1992–Feb. 2015)	<https://mathstat.dal.ca/~ameliay/flood/>
	The DNR Coastal Flood Risk Map provides static coastal flood risk maps, and emergency coastal flooding decision-support systems for different regions of the province.	Interactive map	Nova Scotia	<https://agrgims.cogs.nscc.ca/CoastalFlooding/lidar-mapping>
	The Potential Impact of Drought to Private Wells gridded interactive map shows potential water shortages and drought risk.	Interactive map	Nova Scotia	<https://fletcher.novascotia.ca/DNRViewer/?viewer=DroughtIndex>
Nova Scotia Community College	The Applied Geomatics Research Group Coastal Storm Surge Interactive Map is a Decision Support System for flood risk from storm surges and sea-level rise.	Interactive map and data	Nova Scotia	<http://agrgims.cogs.nscc.ca/CoastalFlooding/Map/>

ORGANIZATION	RESOURCE DESCRIPTION	DATA TYPE	SCALE	LINK
Government of Prince Edward Island	The Surface Water Quality Database provides information about sampling locations, downloadable data and visualizations.	Datasets and visualization tools	Prince Edward Island	<https://www.princeedwardisland.ca/en/service/view-surface-water-quality>
Government of Newfoundland and Labrador	The interactive Geoscience Atlas allows users to select and view layers that include coastal monitoring variables.	Datasets and mapping tools	Newfoundland and Labrador	<https://gis.geosurv.gov.nl.ca/>
Atlantic Climate Adaptation Solutions Association	The Coastal Community Adaptation Tool supports decision making around coastal flooding and erosion.	Reports and case studies	Atlantic Canada	<https://atlanticadaptation.ca/en/content/guidance-coastal-flooding-and-erosion-adaptation>
U.S. National Snow and Ice Data Center	The Ice Climatology dataset contains long-term information on ice conditions over specific geographic regions.	Datasets	Arctic/Antarctic	<https://nsidc.org/data/sipn/data-sets.html>

This list is not exhaustive and URLs may change over time.

To help address this issue and enhance collaboration around information sharing at the national level, the Canadian Centre for Climate Services (CCCS) was established by Environment and Climate Change Canada in 2018. The goal of the CCCS is to provide authoritative, relevant and timely climate change information and assistance interpreting this information. The Centre indirectly plays an important role in centralizing resources related to climate change and water resources spread across many organizations. It complements work undertaken by others, such as Canada's Regional Adaptation Collaboratives (RACs), which produced a variety of vulnerability assessments, guidebooks and technical studies, and significantly increased awareness of climate-related issues, resulting in a number of outputs to address the water-related risks of climate change (Eyzaguirre, 2015).

Despite these efforts, there are key gaps in Canadian water information systems, and these present challenges to adaptation in the water sector, including:

- Fewer weather and hydrometric monitoring stations in northern regions and watersheds (Koshida et al., 2015);
- Limited data availability for groundwater, water quality, evapotranspiration, return flows, glaciers, future trends and actual water use (Bakker and Cook, 2011; Corkal et al., 2011; Sandford et al., 2011; National Round Table on the Environment and the Economy, 2010; Stratton, 2005; Langsdale et al., 2004), ecological health (World Wildlife Fund, 2017), and water-related infrastructure (Canadian Council of Professional Engineers, 2008);
- Uneven regional research on hydrological trends. Current research is focused on northern regions, British Columbia and the Prairie region, with fewer studies in Eastern Canada. Drought analysis and climatological trend research is primarily focused on the Prairie region (Mortsch et al., 2015);
- Limited understanding of spatial and temporal variability in climate change impacts on water resources (Shrestha, et al., 2012);
- Uncertainty associated with hydrologic modelling tools, data inputs and methodologies for generating future projections (Milner et al., 2018; Cohen et al., 2015; Brown and Wilby, 2012; Poulin et al., 2011);
- Little standardization, centralization and consistency in data collection, indicators and methodologies for risk assessments (Moody and Brown, 2012) and water availability studies (Koshida et al., 2015; Dunn and Bakker, 2011); and
- Stakeholder uncertainty about what data exists, how it can be accessed and integrated into planning, and who is responsible for collecting and assembling data (Canadian Water Network, 2019; Ontario Centre for Climate Impacts and Adaptation Resources, 2011; Telfer and Droitsch, 2011; Diaz et al., 2009).

These limitations result in uneven information system capacity to build resilient and adaptive institutions and infrastructure.

4.6.3 Water-related infrastructure

Infrastructure provides critical services for Canadians. For example, dams provide flood control, water supply, and hydroelectric production; wastewater infrastructure removes harmful nutrients and toxins from effluent to meet health and environmental standards; and pumping stations deliver water to industries, communities and households. There is also a growing understanding that natural infrastructure, such as wetlands, forests and soils, provides outcomes similar to built infrastructure at a lower cost and more efficiently (Moudrak et. al, 2018), largely resulting from reduced maintenance and life-cycle management costs.

Water-related climate change impacts constitute some of the main hazards to all infrastructure in Canada (Public Safety Canada, 2018) and can manifest as physical damage, service disruptions, and increased maintenance and operational costs (Boyle et al., 2013). Ageing infrastructure is particularly vulnerable to climate change impacts (Public Safety Canada, 2018).

Three assessments provide a general overview of water-related climate change hazards, infrastructure vulnerabilities and adaptive actions across Canada (Andrey et al., 2014; Boyle et al., 2013; Canadian Council of Professional Engineers, 2008). While extensive vulnerability assessments have been undertaken at the local and regional levels, there is much less information available at the provincial and national scales (Boyle et al., 2013). Insufficient information is the main factor limiting a systematic pan-Canadian assessment of water infrastructure (Andrey et al., 2014); however, key hazards and risks to water infrastructure are identified in the assessments listed above and are summarized in Figure 4.10.

A key tool for assessing the vulnerability of water resource infrastructure in Canada is the Public Infrastructure Engineering Vulnerability Committee (PIEVC) Protocol (*see* Box 4.3).

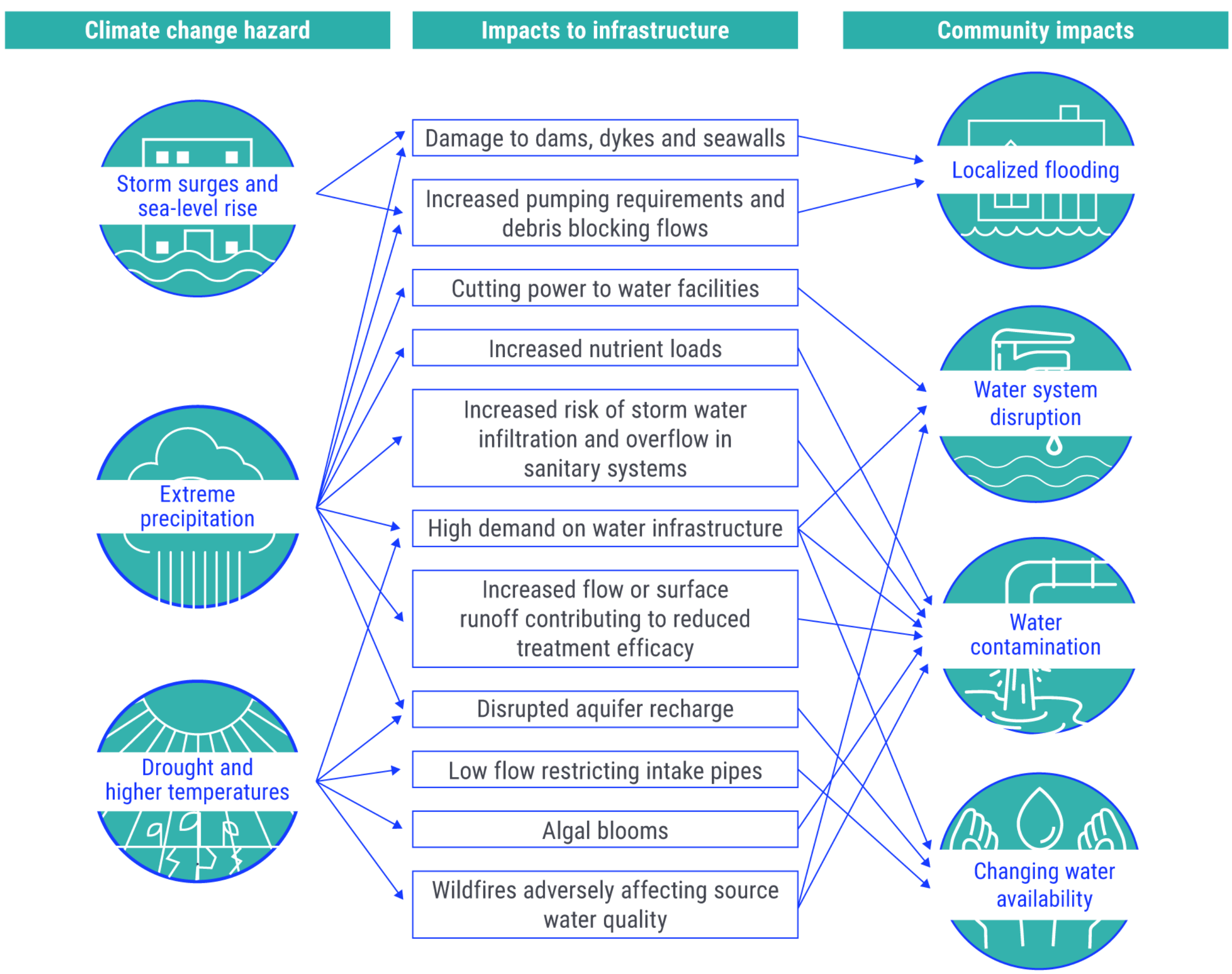

Figure 4.10: Key climate change hazards and risks to water infrastructure.

Box 4.3: Assessing infrastructure vulnerability

The Public Infrastructure Engineering Vulnerability Committee (PIEVC) Protocol is a five-step procedure to systematically assess engineering vulnerability and risk from current and future climate impacts; this procedure can be applied to any type of infrastructure. The five steps include 1) project definition, 2) data gathering, 3) vulnerability assessment (*see* Figure 4.11), 4) vulnerability indicator analysis, and 5) recommendations for building in resilience.

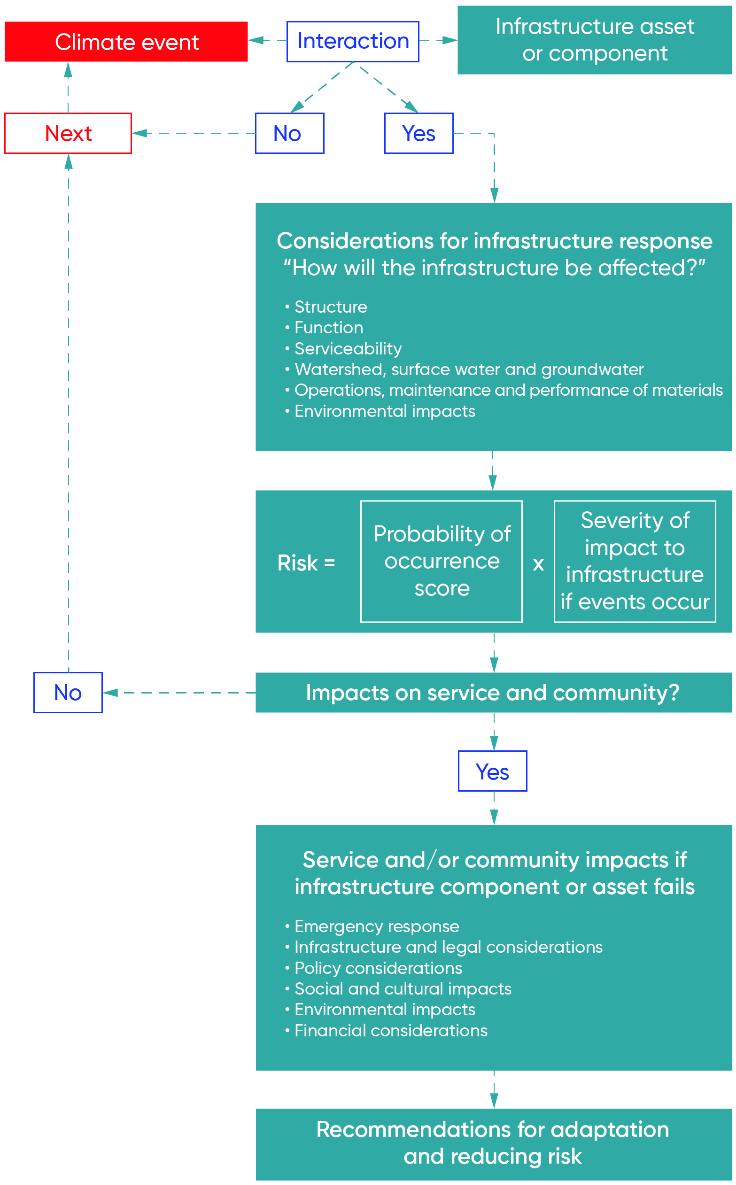

Figure 4.11: Flow chart illustrating step 3 of the Public Infrastructure Engineering Vulnerability Committee (PIEVC) protocol. Step 3 includes a vulnerability assessment to identify the relationships between climate change and impacts to infrastructure. Source: Adapted from Félio, 2017.

The PIEVC protocol has been applied in dozens of local water infrastructure assessments, leading to a wide range of conclusions and recommendations. For example, the City of Calgary concluded that its water supply infrastructure is generally resilient to climate change impacts (Associated Engineering, 2011), while the City of Nelson found that storm water infrastructure required additional investment to alleviate flooding concerns (*see* Case Story 4.7; Paré, 2014). In general, case study findings point to best practices for resilient water infrastructure design and operation, including:

- good maintenance and management; older and/or poorly maintained and managed infrastructure is more at risk to climate impacts;
- building redundancies into water systems (e.g., multiple intake points and delivery mechanisms);
- for new infrastructure, considering climate change impacts during project design to avoid difficult and costly retrofits or facility upgrades once built; and
- ensuring infrastructure-related codes, standards and related instruments (CSRI) reflect reliable and up-to-date information and/or factor in climate change projections.

These assessments also call attention to three major vulnerabilities in existing water infrastructure systems. Firstly, these systems usually assume that conditions of the past will apply in the future, with design and operating rules based on empirical records from the past rather than anticipated future conditions (Sauchyn et al., 2016; Mguni, 2015; Boyle et al., 2013; Hamlet, 2011; de Loë and Plummer, 2010; Minville et al., 2010). As it is not always clear what climate information was used to develop codes, standards or related instruments, developing future standards is not always as simple as updating past climate data (Andrey et al., 2014). Secondly, there is a tendency to not account for low-probability climate events that have highly adverse impacts (Sauchyn et al., 2016). Case studies highlight the importance of robust emergency planning and preparedness, as well as back-up power and communications systems, to support infrastructure design and maintenance (Félio, 2015; Nodelcorp Consulting, 2014). Thirdly, there are significant costs associated with infrastructure maintenance, redundancies, upgrades and increasingly stringent regulations (de Loë and Plummer, 2010). The most recent Canadian Infrastructure Report Cards (2019, 2016) indicate that while the majority of potable water, wastewater and storm water systems are rated "good," reinvestment rates in these systems remain below the rates required to maintain or improve them (Canadian Infrastructure Report Card, 2019, 2016).

Requirements around design, building and operations are changing to address these vulnerabilities. For example, Infrastructure Canada introduced a "climate lens" assessment requirement for several of its funding initiatives in 2018. The assessment requires proponents to consider risk management approaches to adapt to climate change-related impacts during the lifecycle of the proposed infrastructure and potential upstream and downstream impacts (e.g., reduction of downstream flooding due to engineered wetland construction) (Infrastructure Canada, 2018).

Case Story 4.7: Climate change impacts on water and wastewater infrastructure at Akwesasne

In 2015, Engineers Canada initiated discussions with the Ontario First Nations Technical Services Corporation about the impacts of climate change on infrastructure in Indigenous communities. The intent was to incorporate climate considerations into First Nations asset management planning.

Engineers Canada's PIEVC Protocol was considered the best approach to assess climate risks for infrastructure, and work progressed in the Mohawk territory of Akwesasne. Akwesasne is a community of approximately 12,300 people distributed across three districts: Kawehno:ke (Cornwall Island, Ontario), Kana:takon (Saint Regis, Quebec) and Tsi:Snaihne (Snye, Quebec). The Akwesasne territory spans portions of Ontario, Quebec and New York, and is governed by the Mohawk Council of Akwesasne and the Saint Regis Mohawk Tribe.

The first phase of the study (Félio, 2017) employed the PIEVC protocol to evaluate the vulnerability to climate change impacts in potable water and wastewater collection and treatment systems for Cornwall Island, Saint Regis and Snye. Risks were ranked based on occurrence probability and severity, but included special cases such as low probability–high impact events. The team analyzed climate–infrastructure interactions that would impact infrastructure design, functionality, serviceability and community impacts, such as social and cultural effects and emergency response.

The risks assessed differed between the locations and systems evaluated, but largely included water-related climate change impacts such as ice storms, hail, snowfall and rain events, as well as tornadoes and strong winds. Of these, the hazard–infrastructure interactions considered to pose "high" and "extreme" risks are projected to increase in the future (by the 2050s).

The study found that the water and wastewater infrastructure of Akwesasne appears to be in good condition to withstand some increases in frequency and intensity of the climate events predicted, with the caveat that deteriorating infrastructure will present a greater risk (Félio, 2017). Recommended adaptive and risk mitigation measures include maintaining high levels of operations staff, competencies and infrastructure conditions; reviewing land-use policies to avoid building in high-risk areas of the community; and emergency planning, such as implementing a weather alert system with public outreach (Félio, 2017).

The second phase of this study led to the development of a PIEVC Protocol tailored to First Nations communities. This version of the protocol provides guidance on how to integrate traditional ecological knowledge (TEK); it is adapted to unique circumstances that impact Indigenous communities (e.g., smaller communities, remote locations, etc.) (Engineers Canada, 2018).

There is also greater awareness of the potential of nature-based solutions or natural infrastructure to reduce the water-related impacts of climate change (Stanley et al., 2019; Moudrak et al., 2018). Natural infrastructure is defined as "a strategically planned and managed network of natural lands, such as forests and wetlands, working landscapes, and other open spaces that conserves or enhances ecosystem values and functions, and that provides associated benefits to human populations" (Benedict and McMahon, 2006). This infrastructure can be fully natural (e.g., conserved natural wetland) or engineered (e.g., restored wetland with an engineered outlet), and can complement existing built infrastructure (Moudrak et al., 2018). In water resource management, natural infrastructure tends to be more flexible than built infrastructure and provides important co-benefits, such as carbon sequestration and improved water quality and ecosystem health (*see* Ecosystem Services chapter; Goldstein et al., 2019; Stanley et al., 2019; Moudrak et al., 2018). Widespread implementation of natural infrastructure solutions has been hindered by a lack of knowledge and expertise, and policy and regulatory processes that favour built infrastructure (ICF, 2018). However, a number of recent examples across Canada have illustrated natural infrastructure success stories for reducing the water-related impacts of climate change (*see* Box 4.4).

Box 4.4: Nature-based options for adaptation

Floodplain preservation, wetland restoration, flood setbacks, two-stage channels (for high and low flows), relief channels (for high flows) and adding in-stream structures and bank vegetation are all nature-based strategies that reduce the risks from riverine flooding (ICF, 2018). These solutions are effective methods of enhancing the capacity of water systems to absorb the impacts of excess water. For example, a study demonstrated that naturally occurring wetlands in Ontario reduced flood damage costs to buildings by $3.5 million at a rural site and by $51.1 million at an urban site, while another study found a restored and engineered wetland in Manitoba provided flood reduction, water quality and other benefits valued at $3.7 million (Moudrak et al., 2018). In urban centres, runoff from rainfall can contribute to urban flooding and increase contaminant loads to receiving waters. Nature-based adaptation options such as green roofs, bioswales (sloped, vegetated surfaces), bioretention ponds, rain gardens, urban trees and vegetative swales are effectively reducing the risks from storm water runoff in many sites across Canada (*see* Cities and Towns chapter; ICF, 2018). For example, Toronto's Green Roof Program contributes to an estimated reduction of just over 12,000 m^3 (435,000 ft^3) of storm water annually, and enabled the creation of over 100 jobs related to the design, manufacturing, installation and maintenance of the infrastructure (ICF, 2018). Similarly, naturally occurring ponds in Gibsons, B.C., provide approximately $4 million of storm water storage services annually (Moudrak et al., 2018).

The vulnerability assessment process has helped water resource managers across Canada envision how climate change interacts with current systems to exacerbate existing risks or produce new ones. This process, in turn, is helping to identify adaptation actions, and ultimately guide planning and resource allocation in the face of uncertainty.

4.7 Moving forward

4.7.1 Knowledge gaps and research needs

This chapter highlights some key knowledge and information exchange gaps that present challenges for adaptive water resources management efforts in Canada. These include:

- **Access to data:** While there is a plethora of water and climate information and research actively produced at many scales and locations across Canada, there is considerable variation between this data, with little centralization or standardization (Dunn and Bakker, 2011). This contributes to uncertainty around what data exists, and how it can be accessed and interpreted or applied (Telfer and Droitsch, 2011; Diaz et al., 2009).
- **Guidance for decision making:** There is a critical need for translating scientific and technical knowledge into practical guidance for decision makers, managers, practitioners and stakeholders. This includes guidance for considering climate change in engineering design, codes and standards for built and natural infrastructure, and in policy and institutional mandates (IJC, 2018; de Loë, 2017; Andrey et al., 2014; Nodelcorp Consulting, 2014; Canadian Council of Professional Engineers, 2008).
- **Engagement for shared understanding:** Stakeholder engagement is critical to advancing adaptation in the Canadian water sector. The development of strategies to build consensus or compromise around solutions between the conflicting needs and objectives of water stakeholder groups is an emerging field of practice and study in the Canadian water sector. There is a need for practical and effective methods to assist decision makers in navigating stakeholder interactions, negotiating conflicts, accounting for changing social dynamics, and reconciling trade-offs between competing water uses (Global Water Futures, 2020; Clark et al., 2016; Hurlbert and Diaz, 2013; Hamlet, 2011; Ivey et al., 2004).
- **Knowledge mobilization between knowledge producers and users:** Effective knowledge mobilization is required to bridge the gap between knowledge generated by the research community and water organizations, and knowledge held by water practitioners and stakeholders across Canada. Knowledge mobilization is a reciprocal exchange and uptake of knowledge between organizations and individuals dedicated to making research useful to society (Research Impact Canada, 2018). Social factors play a significant role in the uptake of new knowledge, and it is important to develop strong, trusting, meaningful relationships between researchers and knowledge user communities (Crona and Parker, 2011).

Addressing the following additional research needs and knowledge gaps would help to better understand the effectiveness of adaptation efforts and advance adaptive management processes:

- **Monitoring and data collection:** There is limited monitoring capacity, particularly in northern regions, and a need for additional observational data for groundwater, water quality, evapotranspiration, return flows, glaciers and actual water use (Koshida et al., 2015; Bakker and Cook, 2011; Corkal et al., 2011; Sandford et al., 2011; National Round Table on the Environment and the Economy, 2010; Stratton, 2005; Langsdale et al., 2004).

- **Modelling, forecasting and prediction:** Detailed model inter-comparison studies would provide insights about shortcomings in specific models and multi-model analyses (Milner et al., 2018; Cohen et al., 2015; Brown and Wilby, 2012; Poulin et al., 2011). Such studies would allow world-class hydrology and water quality prediction models to be deployed nationally for short-term forecasting and long-term prediction of changes to water availability and quality. Practical methods to clarify, reduce or prioritize key areas of model uncertainty need to be developed with the practitioner community and effectively mobilized in the Canadian water sector (Clark et al., 2016; Razavi and Gupta, 2016; Brown and Wilby, 2012).
- **Understanding of institutional barriers:** Institutional barriers to adaptation are under-studied, and not always comprehensively understood, despite their recognition as a real issue by Canadian water practitioners (Global Water Futures, 2020; Straith et al., 2014). There is an on-going need to look beyond the science and technology of climate change to drive governance change that will enhance the climate resilience of Canadian water systems (Gober, 2013; de Loë and Plummer, 2010). While the importance to adaptive governance is broadly recognized, indicators of institutional resilience are rarely reflected in vulnerability tools, and there is a limited understanding of how to adequately capture and measure these concepts (Plummer et al., 2012).
- **Documentation of successes and failures:** Evaluation of adaptive management processes is critical; however, it often lacks rigorous documentation in academic literature. Evaluation is necessary at local, regional and national scales, including monitoring of short-term and longer-term outcomes from adaptation measures. Identifying and sharing failures, while often avoided, is sometimes more useful for informing adaptation efforts and social learning.

4.8 Conclusion

Water is central to economic growth, environmental health and social stability in Canada. This chapter has shown that water systems are in the throes of rapid transformation as a result of climate change and human action. Global climate change has already affected Canada's cold-dominated water cycle, melting ice and snow, altering the precipitation phase, and changing the nature and timing of water-related natural hazards. Future changes are uncertain, but include the following: risks of reduced water availability and more frequent drought, particularly in the southern Prairies and interior of British Columbia; extreme rainfall contributing to floods; and additional occurrences of harmful algae blooms.

There is much to be done to prepare Canada for an uncertain water future. Uncertainty is not an invitation to inaction; it does, however, change the way in which we must prepare. Canadian water institutions have historically been organized to deal with predictable future conditions where we can extrapolate a future based on the past. Climatic uncertainty has changed that. Water organizations are beginning to embrace exploratory modelling, scenario exercises and adaptive management as a way of planning under uncertainty and of adjusting plans to meet changing circumstances.

Responsibility for adaptation in the water resources sector is also spread across a complex array of governments and organizations involved in water stewardship activities. Effective coordination between these groups plays an important role in strengthening adaptation in the water resources sector, and is exemplified by transboundary water organizations in Canada. Case studies also emphasize that adaptation is a local, place-based process. While access to technical skills, resources and contextual, place-based knowledge are assets to adaptation, capacity challenges are often concentrated in rural, northern and Indigenous communities. These communities are often the most vulnerable to the water-related risks of climate change, and bear a disproportionate burden of the costs of adaptation.

Canadians experience climate change impacts in their own communities, and climate-related impacts vary significantly across Canada. Water practitioners benefit from access to high quality, locally relevant climate data to reduce vulnerabilities in systems and infrastructure, and Canadians are more likely to support adaptation efforts when they understand co-benefits and are armed with information to act decisively. One-size-fits-all national adaptation strategies are unlikely to meet the challenge of climate change or the values of Canadians across regions.

Still, adaptation efforts lag behind what will be required to meet the challenges of climatic change. They are for the most part one-off experiments at local levels rather than part of institutionalized processes for environmental management and societal change. Water-related risks have not yet reached critical urgency in the minds of Canadians to trigger support for widespread, immediate action.

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