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Strengthening the Resilience of the Canadian Water Sector

Final Report

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STRENGTHENING THE RESILIENCE OF THE CANADIAN WATER SECTOR: Final Report

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Strengthening the Resilience of the Canadian Water Sector (2016–2018)

1. Water Security – Canada – Management. 2. Water Supply – Cyber-security.
3. Water Supply – Terrorism.

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STRENGTHENING THE RESILIENCE OF THE CANADIAN WATER SECTOR: About

ABOUT THE MacEACHEN INSTITUTE:

The MacEachen Institute for Public Policy and Governance is a nationally focused, non-partisan, interdisciplinary institute at Dalhousie University. It is designed to engage with the community – public sector, private sector, not-for-profit, students, and academics – bringing people together to work on the big policy problems of our time and providing sensible, empirically based research. The Institute's four research themes include, Civic Engagement, Atlantic Canada and the World, Health Systems and Governance and Smart Infrastructure.

This project falls under the MacEachen Institute's Smart Infrastructure theme.

ABOUT THE CRITICAL INFRASTRUCTURE PROTECTION (CIP) INITIATIVE:

The CIP Initiative is a hub located at Dalhousie University for citizens, industry, NGOs and governments to engage with questions and ideas about the management of Canada's critical assets.

This project acknowledges shared ownership and responsibility of Canada's critical infrastructure and seeks to enhance collaboration between citizens, industry, NGOs, academe, government at all levels and international partners on questions concerning its management. We aim to enrich discussion about the complexity of infrastructure and the holistic approaches necessary to make it more secure and resilient.

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List of Acronyms and Abbreviations

AMWA	Association of Metropolitan Water Agencies
ASCE	American Society of Civil Engineers
AWWA	American Water and Wastewater Association
BOD	Biochemical Oxygen Demand
CCME	Canadian Council of Ministers of the Environment
CDC	Centres for Disease Control and Prevention
CSIC	Cambridge Centre for Smart Infrastructure and Construction
CSSP	Canadian Safety and Security Program
CWS	Contamination Warning System
CWWA	Canadian Water and Wastewater Association
CWN	Canadian Water Network
DRDC	Defence Research and Development Canada
DHS	Department of Homeland Security
EPA	Environmental Protection Agency
EU	European Union
GCM	General Circulation Models
GIWS	Global Institute for Water Security
GWRC	Global Water Research Coalition
ICS	Incident Command System
IISD	International Institute for Sustainable Development
IRGC	International Risk Governance Council
ISAC	Information Sharing and Analysis Centre
IWRM	Integrated Water Resource Management
MCHM	4-Methylcyclohexanemethanol
NWRI	National Water Research Institute
OCWA	Ontario Clean Water Agency

OR	Operations Research
PDWA	Precautionary Drinking Water Advisory
PPB	Parts per Billion
PUC	Public Utilities Commission
PSC	Public Safety Canada
PWS	Public Water System
RBA	Rights-Based Approach
RRAP	Regional Risk Assessment Program
SCADA	Supervisory Control and Data Acquisition
SDWA	Safe Drinking Water Act
SIWI	Stockholm International Water Institute
SWSA	Saskatchewan Water Security Agency
TEVA	Threat Ensemble Vulnerability Assessment
TK	Traditional Knowledge
TOC	Total Organic Carbon
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UNDP	United Nations Development Programme
US	United States
WaterISAC	Water Information Sharing and Analysis Centre
WERF	Water Environment Research Foundation
WFD	Water Framework Directive
WGF	Water Governance Facility
WHO	World Health Organization
WRF	Water Research Foundation
WSA	Water Security Agency
WSAA	Water Infrastructure Resiliency and Sustainability Act
WSI	Water Security Initiative

WSRA	Water Security Risk Assessment
WSSI	Water Security Status Indicator
WUCA	Water Utility Climate Alliance

1. Executive Summary

Purpose and Scope

- This report will contribute to a risk profile for the water sector.
- This report was completed as the final task of "Strengthening the Resilience of the Canadian Water Sector," a CSSP Water Project, CSSP-2015-CP-2095.
- This report does not address issues relating to Indigenous water security or safety, particularly access to drinking water and wastewater sanitation on First Nations reserves.

Emerging Trends, Practices and Theories

- This section of the report examines threats to water security in Canada and discusses emerging trends, practices, and theories that guide water security management in Canada.
- Water security practices have evolved over time from a focus on natural hazards, to human-made hazards, and now to an all-hazards approach.
- The review uncovered many emerging theories regarding water security. While these theories have yet to be codified as concrete practices, they indicate areas in which water security and management need to be improved.

Legislative Review

- The legislative review summarizes existing federal, provincial, and territorial (F/P/T) legislation regarding water security, including emergency management practices.
- Walkerton was a seminal moment for water security legislation, but the approaches that each province and territory took in their responses varied greatly.
- There is no national standard for emergency planning requirements.

Interviews

- In-person and over-the phone interviews were conducted from February 2017 to April 2017 and included responses from 24 participants, providing us with 134 pages of transcripts.
- Responses covered topics that include:
    - Standards, rules or regulations,
    - Staff, operators, and training
    - Aging infrastructure
    - Flooding
    - Cyber security
- Responses to all of these topics were largely negative, ranging from a sense of frustration with increasingly complex rules and regulations to an inability to adequately prepare for the increased costs associated with aging infrastructure.
- Risks associated with aging infrastructure were identified as the most severe risk, followed by risks associated with source-water contamination. Both types were seen to be largely outside respondents' control because they did not have the resources or jurisdiction to address them.

- Interview subjects also noted risks associated with:
    - Climate change
    - Lack of trained or qualified staff, or lack of ability to retain these staff
    - Funding (either declining revenues or too few grants)
    - Public perception of drinking water safety
    - Contamination or spills
    - Supply chain disruptions (including other utilities, e.g., electricity)
    - Infrastructure design (flaws)

Survey

- The survey was hosted on an online platform. Responses were received from 352 individuals representing 139 different water utilities across all 10 Canadian provinces and two of the territories.
- Analysis of the survey findings suggests that there are 'Five Perceived Risks to Water Security'. These risks are infrastructure-related, water supply, cyber-related, physical access, and 'other' uncertain risks (which included earthquakes, tornadoes, visitors and suppliers). Infrastructure-related risk and water supply risk yielded the highest risk scores.
- Analyses suggest that employees from water utilities that serve large populations perceive more risk for physical access, cyber-related, and other uncertain risks than do employees from water utilities that serve small populations

Sector Specific Work Plan

- The sector specific work plan draws on previous studies of existing literature and policy, as well as our interviews with operators from the water sector and our online survey conducted with members of the CWWA.
- Recommendations include:
    - Create a constructive learning environment within the water sector.
    - Develop codified risk practices.
    - Increase transparency and public education.

2. Overview of Project

2.1. Background

In 2009, Public Safety Canada (PSC) announced the *National Strategy for Critical Infrastructure* (the *Strategy*), which aims to make Canada's critical infrastructure (CI) more resilient [1]. The *Strategy* recognizes that "critical infrastructure owners and operators have the expertise and information that governments need to develop comprehensive emergency management plans" [2]. The *Strategy* is supported by the *Action Plan for Critical Infrastructure* (the *Action Plan*), which aims to address the strategic objectives outlined in the *Strategy*, namely to: 1) build partnerships, 2) share and protect information, and 3) implement an all-hazards risk approach [2].

As a corollary to the *Action Plan*, PSC is developing a *National Risk Profile of Critical Infrastructure* to address one of the key objectives of the *Strategy* implementing an all-hazards risk management approach. PSC has defined 10 CI sectors for Canada, one of which is water [3]. In keeping with the *Strategy*, the Canadian Water and Wastewater Association (CWWA) will contribute to a risk profile for the water sector, a profile that describes key risks, interdependencies between the water sector and other CI sectors, and emerging trends.

This report was completed as the final task of "Strengthening the Resilience of the Canadian Water Sector," a CSSP Water Project, CSSP-2015-CP-2095. The report brings together all previous research and recommendations completed as a part of this project.

The report does not address issues relating to Indigenous water security or safety, particularly access to drinking water and wastewater sanitation on First Nations reserves. Further study on Indigenous water governance would be required to produce recommendations similar to those contained in this report.

2.2. Emerging Trends and Practices

The section of the report entitled Emerging Trends and Practices examines physical threats to water security in Canada and discusses emerging trends, practices, and theories that guide water security management in Canada and the US. It also draws on selective international examples from countries other than the US to provide further context, as necessary.

Key Practices

In the context of water security, key practices comprise the ideas, beliefs, and methods (as opposed to theories) that govern water security management. It has become increasingly apparent that water security management needs to develop in new directions to address emerging threats. Several management approaches are currently shaping water security practices, including ecosystem-based management, integrated management, and adaptive management. A variety of regulatory frameworks also influence – or, at least, are meant to influence – water security practices, including the ISO Risk Management Principles and Guidelines, the Water Security Risk Assessment Framework, and the Water Security Status Indicator Framework. Water security practices have evolved over time from a focus on natural hazards, to man-made hazards, and now to an all-hazards approach. One of the most notable trends in water security

management is the emergence of water Information Sharing and Analysis Centers (ISACs) for communicating risks and sharing best practices.

Emerging Standards

In the context of water security, key standards include systems that measure water quality and establish norms within water security management. Though not necessarily followed in practice, standards provide a benchmark against which water system owners and operators can measure their performance. In Canada, the federal government has worked with provincial and territorial governments to create the *Guidelines for Canadian Drinking Water Quality*, which have been formally adopted in various regions across the country. Saskatchewan's Water Security Agency (SWSA) has established standards for public confidence in the drinking water system, and regularly measures customers' faith in the security of their water.

Emerging Theories

The review uncovered many emerging theories regarding water security. While these theories have yet to be codified as concrete practices, they may indicate areas in which water security and management need to be improved. Knowledge commons, normal accidents, and insider threats are all examples of theories, frameworks, or concepts of control and risk management that may apply to the management of the water supply. Emerging theories in water security in this report indicate a general shift away from "guns and gates" and towards broader understanding of water security as interdependent on various sectors, as well as economic, ecological, social, and political factors.

2.3. Legislative Review

The literature review summarizes existing federal, provincial, and territorial (F/P/T) legislation regarding water security, including emergency management practices. This review has adopted a social science definition of water security, one that incorporates both physical and cyber safety as well as water sustainability and the continued availability of water sources. For the purposes of this review, water security is defined as "sustainable access on a watershed basis to adequate quantities of water, of acceptable quality, to ensure human and ecosystem health" [1], with a particular emphasis on emergency preparations and responses. The review provides an overview of existing legislative requirements for water supply operators across the country.

Research for the review took place from December 2015 through June 2016. The report was further researched and written between June and September 2016, using search terms related to water security and emergency management on F/P/T government websites. As such, the review only includes publicly available information, whether it be existing legislation, published policies and regulations, audits and auditors' reports, or annual reports from water-related agencies and ministries. Provinces and territories (P/Ts) may have enacted policies that are not publicly disclosed, and their water security requirements may be more stringent than this literature review was able to discover.

The scope of the report is also limited to examining F/P/T policies and legislation. Municipalities, however, are frequently involved in water security planning, and larger municipalities in particular may have extensive water security practices and policies in place.

The review further focuses on legislated requirements for water supply operators – those who provide potable water to consumers – rather than on environmental regulations meant to safeguard entire watersheds. Finally, the review did not examine rates of compliance with existing legislation across the country, in part because of a lack of accessible data on enforcement and compliance rates. The existence of comprehensive water security legislation in a province may not translate to improved practices on the ground, or across all individual water suppliers.

Water security legislation was reformed across the country after the Walkerton contamination, which left as many as 2,000 people ill and seven dead [4]. The initial inquiry into the contamination blamed the lack of water testing regulations in the province as well as the manager of the water treatment plant for the outbreak [4]. Though there has not been a biological contamination of a similar size since, the water sector continues to face emerging challenges from a variety of sources, including chemical spills, contamination from industrial activity, and aging infrastructure. Climate change, natural disasters, and increased water needs of growing populations have also been identified as potential threats to water security by the National Water Research Institute [5], impacting both the availability of water for human use and the capacity of water suppliers to treat and deliver water to consumers.

Though Walkerton was a seminal moment for water security legislation, the approaches that provinces and territories took in their responses varied greatly. Table 1 (below) provides a summary of provincial and territorial regulations covering water testing, including testing standards and public access to testing data, and demonstrates the variation in water security approaches throughout the country.

Institutional arrangements vary across the country. Both Saskatchewan and Ontario have established provincial water agencies, which centralize water regulation and provide training and support to water system operators. Saskatchewan's Water Security Agency (WSA) and Walkerton Clean Water Centre (WCWC) are examples of centralized arrangements in Canada, aiding water system operators in accessing the resources they need for water security planning. SaskWater, a crown corporation, also provides wholesale water services to corporations and municipalities, as does the Ontario Clean Water Agency (OCWA), ensuring access to a stable source of potable water. Some provinces, like British Columbia, have adopted decentralized models for water testing, leaving five regional health authorities responsible for testing water and enforcing regulations while the provincial government develops policy. Others, like Prince Edward Island, rely on their equivalent of the Department of Health (responsible for water testing in many provinces) to supervise the relatively low number of public water supplies in the province [6].

Dependence on municipal water systems varies across provinces. The Maritimes has the lowest rates of municipal water system usage of Canadian provinces; 66% of the population of New Brunswick uses a municipal water system, while 74% of Nova Scotia does the same, versus a high of 98% in Saskatchewan [8]. Data for Prince Edward Island are unavailable, though the province is 100% dependent on groundwater sources [10], and only half of the population is connected to a municipal water utility that uses high-capacity wells [6]. Residents using private

water systems like personal wells are not subject to the same level of regulation or testing requirements as public water systems.

All of the P/Ts have adopted a variety of water testing and quality standards, with some using the *Guidelines for Canadian Drinking Water Quality*, and others, like Saskatchewan, creating their own standards to suit their respective needs. In addition to variation across individual provinces, there are differing requirements depending on the size of the water supplier; water systems serving a single resident are regularly exempt from all testing, while a hospital or restaurant may face regular inspections of its drinking water. A recent survey of major Canadian cities found that only one, Ottawa, tested for all of the potential contaminants listed in the federal guidelines, further highlighting the complexity of water regulations across the country [12].

Though water is regulated at the provincial and municipal levels, the Government of Canada (in partnership with provincial and territorial governments) has established the *National Strategy* and *Action Plan for Critical Infrastructure* to enhance the resilience of CI across the country [1] [2]. The current *Action Plan* seeks to implement an all-hazards approach across CI sectors, encouraging provinces, territories, and critical infrastructure owners to work with the federal government to identify and prevent or mitigate potential threats [2]. As every provincial and territorial government has its own standards, the *Strategy* aims to respect local legislation while improving resilience across the country [1].

There is no national standard for emergency planning requirements, but seven provinces and one territory require that their water supply operators provide emergency or contingency plans. While some provinces have formally adopted the Incident Command System (ICS), a site command and control system that manages emergency responses by coordinating networks of organizations [16], most did not have public information about their emergency response system available. Alberta alone has both physical and cyber-security requirements in place [18].

2.4. Interviews

In-person and over-the-phone interviews were conducted from February 2017 to April 2017. These interviews formed the first stage of primary research and data collection. In total, we conducted 14 interviews (including two regulators) and received one written response.

Questions were broad and open ended, designed to allow respondents to raise issues that concerned them the most. Questions encouraged respondents to discuss where they gained information about risks, how they managed risks, and which risks they perceived to be most pressing for their organization. This report provides a summary of the responses to each question, taking regional or size-based trends into consideration.

Though some differences in perceptions and attitudes towards risk did emerge, respondents generally had a common understanding of the risks that faced their own and other water organizations. Common risks, outlined in Appendix F, were raised independently by respondents throughout the interviews, as were topics not included in the chart such as financial stress, employee retention and training, and government relations.

Respondents were asked to use a number to convey their impression of the potential severity or likelihood of a given risk. These ratings do not represent a statistically significant measurement.

Methods and Overview

We conducted 14 interviews by phone and received one written submission. Interviewees were operators of water systems or utilities, suppliers, or regulators from a provincial regulation agency. Interviewees worked in communities across seven P/Ts, all in Canada. While most interviews were conducted one-on-one over the phone, some respondents elected to have multiple employees attend and respond to the interview questions. In total, we received responses from 24 participants, providing us with 134 pages of transcripts.

Respondents were selected based on both their geographic location and the size of community their organization served. In total, we received responses from 13 communities and two regulators. See Table 1 for a breakdown of respondents by size.

Analysis was conducted using Nvivo interview analysis software. Nvivo was used to code transcripts, determine positive or negative connotations with set key words or themes, and determine word frequency. The software was also used to establish trends in interview responses, including by size of utility.

- Standards, rules or regulations – 459 individual references
- Staff, operators, and training – 197 individual references
- Aging infrastructure – 165 individual references
- Flooding – 123 individual references
- Cyber-security – 119 individual references

Responses to all of these topics were largely negative, ranging from a sense of frustration with increasingly complex rules and regulations to an inability to adequately prepare for the increased costs associated with aging infrastructure.

Table 1: Breakdown of interview respondents by population

Number of Interviewees	Size of Community Served (population)
4	100 000+
4	10,000 – 99,999
5	1 – 9,999

Summary by Question

Below is a summary of responses given for each question. Questions that were not asked of regulators are noted as such, as are responses that came specifically from regulators.

How is the water sector changing? What opportunities and threats do these changes pose?

Increased demands on water suppliers' services were frequently cited in responses. Respondents from communities of all sizes, as well as regulators, noted that the level and stringency of regulations and requirements from F/P/T governments had increased dramatically in the

preceding years. Interviewees also occasionally noted that customers' expectations for their water had increased, including its quality, appearance, and level of service provided, as well as downtime, maintenance, and amount of information available. All of these factors increased the financial burden placed on respondents and the amount of work required to successfully deliver water.

Most interviewees saw these increased demands on their services and time as a threat; several felt overwhelmed or unable to keep up, while others noted that they had difficulty understanding some of the new regulations, or were unable to communicate effectively with their regulators or other levels of government. The increased financial burden, when combined with the effects of aging infrastructure, was also a significant threat raised in interviews.

Many of the interviewees who raised increased regulations and expectations as a threat also acknowledged the opportunity they provided. They noted that increased regulations and expectations usually led to a safer water supply, as well as an increased understanding of water usage and the role of utilities in local communities. While financial burden was a concern, respondents did not generally give the impression that they wanted fewer or looser regulations, but rather they needed more support to follow them.

Some interviewees saw lower revenues caused by declining water usage (through efficiencies) as a threat. This was primarily a concern for smaller utilities.

What does your organization do well when it comes to managing risk? What could it do better?

Smaller and medium-sized organizations were generally more hesitant to answer this question than their larger counterparts; several had never considered the question before, while others had attempted reviews of risk-related policies, but did not have the time, funding, or other resources to conduct these reviews regularly or comprehensively. Generally, those that identified a lack of formal policies or reviews as a problem in managing risk agreed that this was one area in which they could do better.

Larger organizations, as well as some in Northern Canada, usually had a list of activities they could point to as proactive and effective measures for managing risk. These included annual simulations, policy reviews, and participating in learning events like conferences. Larger organizations in particular usually highlighted one or two risks they had been particularly pro-active in managing, including risks from local geography, climate, or financial situation. These interviewees seemed equally likely to note that they could dedicate more time or resources to their existing strategies, or to risks they had recently identified and had yet to address.

Which risks cause you the greatest anxiety, and why?

Responses varied widely depending on region and size of organization. Below is a non-exhaustive list of risks provided by respondents, chosen generally because they would cause temporary or permanent disruption to the water supply. Risks are listed in no particular order, and have been occasionally extrapolated from site-specific concerns.

- Climate change
- Lack of trained or qualified staff, or lack of ability to retain these staff

- Funding (either declining revenues or too few grants)
- Aging infrastructure
- Public perception of drinking water safety
- Contamination or spills
- Supply chain disruptions (including other utilities, e.g., electricity)
- Contamination of source water
- Infrastructure design (flaws)

Where do you get information about risks?

Examples of responses to this question are listed below. Smaller utilities were more likely to respond with word of mouth, personal experience, or actual disaster events, while larger organizations were more likely to cite publications, advisories, or journals, giving them a broader range of sources of information. Nearly all respondents agreed that conferences and meetings were a source of information about risks.

- Conferences (e.g., CWWA conferences, regional meetings)
- Operator feedback/experience
- Disaster events
- Other utilities (informally, word of mouth)
- Research publications and journals
- Advisories from organizations (e.g., CWWA, AWWA)
- Regulations

What arrangements (e.g., processes, committees, policies) do you have in place for managing risk? How well do they work?

Respondents generally answered this question in the same way, speaking to internal policies, regulations, procedures, and informal practices they were aware of within their organizations. Larger organizations were typically able to list more arrangements from memory, and were more likely to indicate that their arrangements or policies had some sort of a formal review process. While smaller organizations either had fewer or less formal arrangements, few if any respondents indicated that they were totally dissatisfied with their processes or committees. Some indicated a lack of knowledge about them, or noted that they would invest more time in updating and reviewing policies if possible; none listed specific examples of policy or process failures, even when speaking about disaster events that had impacted the community.

Can you list examples of previous learning opportunities about risk within your organization? What did you learn? How did you learn?

Responses to this question varied between respondents, without any clear link to size or geographic location. Some interviewees restated their responses to the question “Where do you get your information about risk?” while some provided examples of previous simulations or disaster events in their communities. Few were able to provide concrete outcomes from their learning opportunity (e.g., revising an emergency plan after a flood), though most indicated that they had developed better knowledge of their organization’s shortcomings. Few, if any

respondents clearly indicated how they had learned, though examples given were generally hands-on learning opportunities where operators had direct exposure to real or simulated emergency events.

Responses to this question focused almost exclusively on disaster or emergency events. Some interviewees spoke at length about non-emergency risks (e.g., lack of staff training, lack of funding), but none brought up learning opportunities about these types of risks.

To what extent do you depend on external organizations to fulfill your organizational mandate? What systems do you have in place for managing external relationships?

All respondents were in general agreement that they were at least partially dependent on external organizations. Most noted that external suppliers (e.g., chemical suppliers, power utilities) were crucial to their organizations, and that backup supplies of materials or resources may mitigate but not prevent potential impacts on water delivery or service in case of a shortage. In this question, respondents were more likely to state that they were dependent on external organizations that provide a physical good or resource. While some acknowledged that they work with governments and regulators, the general impression was that these external bodies were not necessary to fulfill an organizational mandate.

A small number of interviewees noted that they had stringent contracts in place with suppliers to prevent disruptions in service, while others said that they had staff or a department dedicated to procurement and managing relationships with external suppliers. At least one respondent noted that they were not sure if there was a contract with their suppliers; rather, they relied on personal communication to ensure timely and accurate deliveries.

What standards (e.g., rules and policies) do you follow in managing risks? How effective are they?
Follow up; can you list the strengths and weaknesses of each set of standards and behaviours? Do these include laws, business continuity plans, supply chain management, public reporting, and training standards?

This question provided respondents with another opportunity to discuss interactions with provincial and federal governments, as well as regulators.

While most respondents listed provincial and federal environmental and health regulations as the main standards they follow, ISO, the *Canadian Drinking Water Guidelines*, engineering standards, and standards developed by the CWWA and AWWA were also brought up.

Respondents were generally apprehensive about the complexity and cost of government-mandated standards, even if they acknowledged that they did make water supplies safer. Interviewees noted that it was difficult to establish contacts in governments, that governments were unwilling or unable to explain how or why a standard was being applied to a specific organization, or that there was a lack of information about how to implement specific standards. Some respondents also noted that standards were unevenly or illogically applied, particularly those that were written into permits or licenses.

Respondents who had a positive view of the standards they followed generally did not have specific examples of their strengths. Attitudes towards regulations seemed to vary based on individual respondents, rather than on size or location of their organizations.

I am going to list a series of risks. Score each on a scale of 1 to 10:

10 means that you have a very robust plan, you are confident you have limited exposure, and if exposed, the consequences would be limited. 1 means that you do not have a plan, risk is high, and consequences would be serious. The rating is not an exact science, but rather an impression; it is a way to communicate your overall impressions of the risk management plans and practices in place. Once you have rated the risk exposure, take a minute to explain your rationale.

1. Aging infrastructure
2. Flooding
3. Cyber
4. Insider threat
5. Environmental protesters
6. Source-water protection

Aggregate responses to this question are summarized in Appendix F.

Perception of risk varied among respondents, and did not seem to correlate strongly with the size or location of the organization. Some rated all risks as very likely, while others identified two or three risks with extremely high ratings, and others rated all risks towards the middle of the spectrum.

Aging infrastructure was, on average, rated as the most severe risk, followed by source-water protection. Both risks were seen to be largely outside respondents' control because they did not have the resources or jurisdiction to address them. Some respondents indicated that they felt similarly helpless with regards to insider threats; while several organizations indicated that they had taken proactive steps (like providing mental health services) to keep employees happy, others acknowledged that things like labour disputes, sudden employee unhappiness, or former employees seeking revenge was beyond their control.

Environmental protesters had a uniformly high ranking and several organizations had taken steps to engage with the public as a means of deterring protests. These steps include communication strategies, facility tours, directly responding to individual citizens, and liaising with public officials, including politicians.

Some organizations and regulators declined to provide ratings for all of the risks listed. This was because interviewees felt they had insufficient information to provide a fair rating; the risk was generally managed by different staff or a different department, or was too complex to be rated across a large region (in the regulators' case).

What would you do with an extra day a month if you had to spend it on improving risk management?

All respondents were able to identify an area in their organization that they had the desire, skills, or knowledge to improve. Many said they would update their organization's policies, particularly around emergency management, while some would use the time to learn more about emerging risks and emergency management issues. Some organizations detailed how, precisely, they would use the day, citing specific risks they would work to address. Generally, respondents wished that they did have an extra day (occasionally with extra funding) to work on any of the issues facing their organization, indicating that they were working at capacity but had a clear idea of what could be done better.

What would you like to see come out of this report?

All respondents were curious to see if other organizations had given similar responses, and to see what trends and patterns were emerging across the country. Many of the interviewees reiterated that they often learned about risks from other organizations in the preceding questions, and noted that this report was another opportunity for them to learn from their colleagues in the sector. A few respondents indicated here or throughout the interview that they would like to see policy or regulatory changes enacted, usually simplification of existing rules.

Regulators

The regulators interviewed shared many of the same concerns as the water and wastewater operators. They answered similar questions to those posed to water operators, though their responses sometimes focused on their relationships with regulatory committees (like the F/P/T Drinking Water Guidelines Committee) or other levels of government, rather than other regulators or water suppliers. While they did not see themselves as directly responsible for the security of the water supply, they did acknowledge all of the risks listed as tangible threats, and often had in-depth knowledge of how those risks were likely to affect the organizations they regulated.

Like the water operators, the regulators interviewed highlighted that a lack of funding was hindering their work, particularly planned updates to their regulations and policies.

2.5. Survey Methods and Analysis

The survey was developed through an iterative process between the authors and a steering group composed of CWWA members and representatives from PSC. Special attention was paid to ensuring the content and face validity of the survey during the development process.

The survey was hosted on an online platform and a link to the survey was distributed by the CWWA to its members and to non-members. The link to the online survey was active for 32 days for the purposes of data collection. Responses were received from 352 individuals representing 139 different water utilities across all 10 Canadian provinces and two of the three territories.

Analysis of the survey findings suggests that there are 'Five Perceived Risks to Water Security'. These risks are infrastructure-related, water supply, cyber-related, physical access, and other uncertain risks. Infrastructure-related risk and water supply risk yielded the highest risk scores.

Analyses suggest that employees from water utilities that service large populations perceive more risk for physical access, cyber-related, and other uncertain risks than do employees from water utilities that service small populations. Another important finding is that senior managers and non-senior managers have shared perceptions about the risks to water security, apart from a small difference in risk perception for physical access.

2.6. Sector-Specific Workplan

The sector-specific workplan draws on previous studies of existing literature and policy, as well as on a series of interviews with operators from the water sector and an online survey conducted with members of the CWWA.

Recommendations

Create a constructive learning environment within the water sector.

To best mitigate and respond to risks, water providers must have access to comprehensive and relevant information about the challenges their organizations face. To build an environment in which this information is available, water providers should document and share information about the risks associated with their environment and organizational design.

Factors impacting a water provider's individual risk profile include the size of the operator, available capacity, geographic location (northern and remote locations may be more prone to single points of failure, while urban and developed locations may be more prone to chemical spills, for example), access to expertise and funding, stability and knowledge of the workforce, risks in the natural environment, and the potential for source water contamination. Developing a learning environment that takes these factors raised during the interview and survey process into account will ensure that operators have access to information appropriate to their circumstances.

Develop codified risk practices.

While interview and survey data suggest that organizations are familiar with many of the risks in their environments, their responses to some of these risks have not been codified, creating the potential for breakdowns in communication or missed opportunities in mitigating or responding to risks. Implementing codified risk practices by using standards like ISO 31000:2009 will ensure that organizations have a clear understanding of how best to respond to the risks they face.

Adopting a risk categorization framework would also enable organizations to distinguish between types of risks, ensuring that there is a clear understanding of what we know about the risks and what appropriate responses to the risks may be. Using Renn's *International Risk Governance Framework* (Renn's Risk Framework), we can categorize the risks identified in interview and survey data as uncertain (cyber, rare natural disasters, malevolent actors), complex (water supply, infrastructure, physical access) and ambiguous (protestors, fracking). Uncertain and ambiguous risks, for example, require more stakeholder engagement, higher risk tolerance, and more redundancies, while complex risks may be solved by using existing expertise about a risk to develop a management plan.

Increase transparency and public education.

Increasing transparency by releasing more risk information to the public domain would aid in ensuring that water organizations have access to information about the risks they face, while also reducing the conflicts associated with ambiguous risks driven by different values among the public.

Implementation – Increased Learning Opportunities

The above recommendations focus on increasing learning opportunities for both the water sector and the public. The goals of these recommendations would be to:

- Help organizations better understand their risk environment
- Increase the pool of data available about risks
- Connect similar organizations with each other, to facilitate information sharing
- Establish clear risk guidelines
- Develop training opportunities offered through organizations such as the CWWA
- Develop expertise among water organizations, ensuring regional representation among water organizations that can be expected to lead
- Increase public reporting on risks associated with water supply, including probability and consequence data.

3. Emerging Trends and Practices

In 2009, PSC announced the *National Strategy for Critical Infrastructure* (the *Strategy*), which aims to make Canada's CI more resilient [1]. The *Strategy* recognizes that "critical infrastructure owners and operators have the expertise and information that governments need to develop comprehensive emergency management plans" [2]. The *Strategy* is supported by the *Action Plan for Critical Infrastructure* (the *Action Plan)*, which aims to address the strategic objectives outlined in the *Strategy*, namely to: 1) build partnerships, 2) share and protect information, and 3) implement an all-hazards risk approach [2].

As a corollary to the *Action Plan*, PSC is developing a *National Risk Profile of Critical Infrastructure* to address one of the key objectives of the *Strategy*: implementing an all-hazards risk management approach. PSC has defined 10 CI sectors for Canada, one of which is water [3]. Consistent with the *Strategy*, the CWWA will develop a risk profile for the water sector, a profile that describes key risks, interdependencies between the water sector and other CI sectors, and emerging trends.

In this review we examine current grey and academic literature to determine what emerging trends, practices, and theories are guiding management of security in Canada and the United States (US). We draw on selective international examples from countries other than the US to provide a fuller account of trends that have not yet emerged or that are not yet reflected in Canadian water security literature. Literature and examples from the US are included (1) to capitalize on the extensive US literature on water security, and (2) because of the interconnected nature of the two countries' security. We also describe key risks for CI, including their dependencies. The content of this review will inform further research on strengthening resilience within Canada's water sector. Specifically, we will use this review's findings to design surveys for water and wastewater managers across the country. In conjunction with these surveys, this review will help us identify vulnerabilities within the Canadian water sector and develop a sector-specific work plan.

Water has a variety of uses, each of which suggests a different meaning of 'water security' [7]. Water is used for drinking, sanitation, agriculture, industry, generating hydroelectric power, cooling nuclear reactors, and recreation, among others. In developing countries, water security may mean access to clean drinking water and sanitation services. For farmers, it might mean an uninterrupted supply of water at an affordable price. For municipalities, water security could mean an uninterrupted supply of clean drinking water and sanitation services at an affordable price.

Depending on your definition of 'water security,' what you perceive as a risk or threat will vary. To ensure water security (in all of its varied senses), societies must provide population-wide access to potable water and water services, address conflicts of use, and protect water resources against hazards [7] [9]. Historically, water management systems have been designed, built, and operated under the assumption that hydrological variables are well defined, water will be available, and that we can anticipate demand. These assumptions have been revised as factors such as climate change, terrorism, population growth, urbanization, and aging infrastructure emerge [7] [9] [11] [13].

A water system is defined as everything from the point of collection of water to the consumer, including catchments and groundwater systems, source waters, storage reservoirs and intakes, treatment systems, and service reservoirs and distribution systems [13]. All of these components face risks, including security risks, natural disaster risks, and business risks [13]. The varying scales and configurations of water systems create difficulties in risk assessment, and the complexity of interconnected, geographically diverse water infrastructure systems with varied ownership poses significant challenges in maintenance and security [13].

There is uncertainty surrounding the effect of urbanization and climate change impacts on urban water infrastructure due to a lack of data and research [9]. New water supplies need to be sufficiently diverse and adaptable to allow for these uncertainties [9]. Most modern water systems are built with redundancy (the ability for components to assume the functions of failed mechanisms without affecting the system's performance), and backup systems to reduce vulnerability [13]. However, water infrastructure is vulnerable to multiple and simultaneous extreme events, with the potential for 'cascading' failures, increased by reliance on potentially vulnerable energy and communications systems [9].

In *Back to the Well*, de Villiers [14] argues that water crises are all local in nature, and that they can be solved by improved water management. Infrastructure adaptation measures can instil resilience, though there is a need to achieve an appropriate balance between risk and meeting demand for increased service provision in urban areas whilst avoiding unnecessary expense [8]. There is the potential for maladaptation if water-intensive alternative energy supplies powered by non-renewable sources are expanded [9]. Patrick [15] recommends re-proportioning funding for expansion of infrastructure such as dams and pipelines to more efficient technologies, low water demand crops, public education, water reuse, and realistic water pricing [15].

Contamination Risk

All of the case studies in this report address a type of contamination event in a water system. Though other threats to water security, such as barriers to accessing water and diminishing water supplies, exist in Canada, the highest profile events in recent years have been contaminations. In *Drinking Water: A History*, James Salzman [17] concludes that purposeful contaminations of water sources are unlikely. Accidental contaminations, however, have repeatedly occurred in both Canada and the US, and remain a serious threat to water security.

Failing infrastructure, environmental degradation, and deliberate sabotage all increase the potential for contaminants to enter water distribution systems [19]. Cross-connection between water infrastructure and sewage lines or chemical feeds could introduce contaminants at levels low enough to go undetected [21]. Contaminants introduced into a water distribution system after the water has been treated reside in the system for a shorter time and are less likely to be diluted [13].

In 2006, the US Environmental Protection Agency's (EPA) Water Security Initiative (WSI) introduced contamination warning systems (CWS) to monitor water systems online [21]. Increasingly, water utilities are using surveillance technologies, including smart sensor systems, to protect water infrastructure from contamination, especially in the United Kingdom (UK) and

US [7]. There are commercially available technologies that monitor pH levels, chlorine, total organic carbon (TOC), conductivity, and temperature in real time [19]. Other new technologies can measure water system turbidity, TOC equivalent, biochemical oxygen demand (BOD), nitrate, nitrite, and aromatic compounds [19]. Biological monitors can measure toxicity to detect contaminants [19]. Water system managers face a challenge in effectively deploying these technologies to best detect contamination on a time-scale that minimizes damage [19]. Physical security measures can include employing security technologies, improving infrastructure redundancy, enhancing supervisory control and data acquisition (SCADA) security, and limiting public access [13].

Online monitoring has become the accepted method for reducing contamination risks [21]. US EPA Threat Ensemble Vulnerability Assessment (TEVA) used research to develop CWSs that integrate monitoring and surveillance data from multiple detection methods to provide early detection of contamination [21]. Research was carried out to develop algorithms for optimal sensor placements and simulate all perceived contamination incidents and their potential impacts, allowing rapid detection of and response to contamination incidents [21].

Most biological threats can be neutralized through chlorination, though there are natural microorganisms that are highly resistant to chlorine and can survive the water treatment process to cause sickness and potentially death [13]. The emerging practices and standards identified in this report may aid water organizations in identifying potential sources of contamination, safeguarding against contamination, or neutralizing contamination threats to water supplies before they occur.

3.1. Definitions and Limitations

Below are definitions of some terms used throughout the report, as well as the general parameters that guided the report's research and development. Terms defined in this section may be commonly used in the report, or may denote specific interpretations used within the water or emergency management sectors.

Safety and Security

Security risks involve human aggressors who are influenced by a variety of environmental and personal factors and who may come from within or outside the target institution [23]. While their outcomes might be similar, security and safety risks demand different approaches to risk management. "[P]rotecting installations against intentional attacks is fundamentally different from protecting against random accidents or acts of nature" [23] (see also [24]). Human aggressors, for example, are adaptive agents; they will modify their behaviour in light of security practices that organizations adopt. Generally, safety plans tend to be more transparent, are informed by more reliable data, and are regulated more clearly. Safety plans are also more clearly entrenched in the organizational culture and legal tradition of many critical sectors.

Collective Security

In a collective security arrangement, a group recognizes shared security interests and cooperates to address security threats. Groups can operate at regional, national, or international levels. Within the water sector, some examples of organizations with collective security arrangements

include the United Nations Development Programme (UNDP) Water Governance Facility (WGF) at Stockholm International Water Institute (SIWI), the Water Information Sharing and Analysis Centre (WaterISAC), and the Water Utility Climate Alliance (WUCA). The WGF provides support for developing countries to manage water resources and services [26]. WaterISAC is a professional network for sharing security information to improve risk management in the US [27]. WUCA provides information on climate change adaptation to water utilities so they can manage climate change risks [29].

Rights-based Approach to Development

This approach to development assumes human rights as a cornerstone and frames development issues in the context of two stakeholder groups: 1) those with rights that are not being upheld, and 2) those with the duty to uphold rights. The human rights–based approach to development (RBA) sets the achievement of human rights obligations as an objective of aid, and integrates human rights principles into the development process [32]. Filmer-Wilson notes that RBA does not have a set definition, even in the context of water security, but is characterized by a focus on both the process and outcomes of development, and is founded on the Universal Declaration of Human Rights [32].

Resilience

A resilient piece of CI is one that can recover quickly from unexpected disasters and emergencies. Biringer et al. (cited in [34]) define resilience as one's ability to withstand, adapt to, absorb, or recover from change without any aid from outside resources. Some authors term resilience as critical infrastructure's ability to "bounce back" from an unexpected situation (Hyslop, cited in [34]), while others claim that resilience is rather the ability to "bounce forwards," as any change will inevitably permanently alter the status quo that needs to be maintained (Manyena, cited in [34]). Resilient water and wastewater systems would be able to restore the quality and quantity of goods and services – of water – expected by citizens. The public's confidence in a system may also be considered when determining its resilience.

Emergency Management

An Emergency Management Framework for Canada gives a series of components to emergency management, including prevention and mitigation, preparedness, response, and recovery [36]. Emergency management consists of any actions taken before, during, or after an emergency event, whether a natural disaster or terrorist attack. The *Emergency Management Framework* [36] defines emergency management as an attempt to "save lives, preserve the environment and protect property and the economy". In a water and wastewater context, this may include attempts to prevent contaminations, protect infrastructure, and preserve source waters, as well as testing and restoring services after an emergency event.

Emergencies and Crises

PSC defines an emergency as "a present or imminent event that requires prompt coordination of actions concerning persons or property to protect the health, safety, or welfare of people, or to limit damage to the environment" [36]. Conversely, a crisis is defined as a "situation that threatens public safety and security, the public's sense of tradition and values or the integrity of the government" [38]. While crises and emergencies are not interchangeable, emergencies may

develop into crises if events continue without adequate responses from the proper authorities, undermining the public's confidence.

Risk

PSC defines a risk as "the combination of the likelihood and the consequence of a specified hazard being realized" [38]. Risk management, then, is the process of decreasing risk by taking action to prevent specific hazards, or to improve an organization's or object's ability to withstand or recover from a given hazard. Renn's Risk Framework, introduced later in this report, categorizes risks according to the information available about them, using knowledge of a risk as a defining characteristic in its prevention.

Risk Stratification

Risk stratification is a term borrowed from the health sector. In a healthcare context, risk stratification identifies patients deemed "high risk," prioritizing their care to prevent further deterioration of their health [40]. For instance, the Centres for Disease Control and Prevention (CDC) set the acceptable limit for lead in the water supply at 5 ppb; it deems unacceptable the health risks associated with lead contamination at levels greater than 5 ppb, though others argue that there is no acceptable level of lead in drinking water [42]. Figure 8, a case study of the water crisis in Flint, Michigan, explores how risk stratification has been applied to the city's water supply. Though removing all lead from drinking water is preferable [42], 5 ppb has been accepted as the target that will achieve the greatest reduction in adverse effects given the resources available to the city.

Critical Infrastructure

PSC defines CI as "processes, systems, facilities, technologies, networks, assets and services essential to the health, safety, security or economic well-being of Canadians and the effective functioning of government" [3]. Many countries, Canada [44] and the US included [45], have designated water infrastructure a critical infrastructure sector to protect its role in preserving the health and well-being of citizens. As designated critical infrastructure in Canada, the water sector is included in PSC's *Strategy* [44], and owners of critical water infrastructure are encouraged to adopt an all-hazards approach to emergency planning, and to share information throughout their CI networks to improve resilience.

Smart Infrastructure

Smart infrastructure is a term adapted from the 'smart city' theory, a fuzzy concept that harnesses technology, communications technology in particular, to mine data from cities and allow for better, evidence-based policy-making as well as improved communication with citizens [46]. To some, 'smart infrastructure' is synonymous with 'sustainable infrastructure,' an approach to infrastructure development that aims to lower carbon emissions and make infrastructure more resilient to climate change [48]. To others, it is synonymous with high-tech infrastructure. The Cambridge Centre for Smart Infrastructure and Construction (CSIC) defines it as infrastructure that can "influence and direct its own use, maintenance and support by responding intelligently to changes in its environment" [50]. Both understandings of smart infrastructure are relevant to security issues in the water sector, and both will be used in this review.

Limitations

This review was conducted primarily online, and is limited to materials that are publicly available in both Canada and the US. The review focuses on literature, policy, and case studies from Canada and the US, in particular, though occasional international examples are included where relevant. The review does not include Indigenous communities, though we reaffirm our recommendation that a similar project be established to study critical water infrastructure in Indigenous communities across Canada.

Information from PSC about cyber-security as it relates to the water sector appears later in this report. The main body of the review does not include any analysis of cyber-security, though any of the concepts uncovered may be applicable in a cyber context.

3.2. Dependencies and Cross-sector Interdependencies

In Canada, the water sector is dependent on many other CI sectors. Water and wastewater utilities depend on the energy, transportation, government, information and communication technology, and manufacturing sectors in various ways:

- Energy: Water and wastewater treatment facilities depend on the energy sector for electricity and, in the event of a power outage, fuel to run their backup systems.
- Transportation: Water utilities depend on transportation infrastructure to access water infrastructure for monitoring and maintenance. Wastewater facilities rely on transportation to deliver waste from septic systems to wastewater plants.
- Government: Government legislation, policies, standards, regulations, and inspections all play important roles in guiding and controlling water and wastewater utilities.
- Information and communication technologies: These play important roles in developing best practices, planning for future challenges, monitoring the water supply (SCADA systems), responding to threats (both physical and cyber), and communicating water quality issues to the public.
- Safety: Water quality is a key public safety issue.
- Manufacturing: Water utilities depend on manufactured parts and chemicals to build, maintain, and treat their water and wastewater supplies. Concomitantly, the water and wastewater (and manufacturing) sector depends on the transportation sector to receive these goods.
- Health: Water utilities rely on laboratories for water testing. Health organizations like hospitals are equally reliant on water utilities for their regular operations, as well as specific treatments.

Some of the emerging practices listed below, such as network analysis, visualizes these interdependencies to determine system vulnerabilities. In addition to the internal security of its critical infrastructure, the water sector must work with its partners in other sectors to improve water security across all networks.

Case Study: The Walkerton, Ontario, *E. coli* Outbreak (2000)

On May 12, 2000, runoff from a manure-covered field contaminated Walkerton's water supply with *E. coli* and *Campylobacter jejuni.* As a result, 2,300 people became sick and seven died. Operators at the Walkerton Public Utilities Commission (PUC) initially failed to detect the contamination because they weren't monitoring chlorine residuals in wells daily. Once the PUC detected the contamination, the general manager concealed water test results and malfunctioning water treatment equipment from health authorities; as a result, health authorities didn't issue a boil water advisory (BWA) until May 19, seven days after the water supply first became contaminated and four days after the PUC first realized that the water might not be safe to drink.

In January 2002, the Ontario Ministry of the Attorney General released a report by the Honourable Dennis R. O'Connor on the events and issues that led to the water contamination in Walkerton. The Walkerton Inquiry found that this tragedy could have been prevented through continuous use of chlorine residual and turbidity monitors in wells, proper inspections by the Ministry of the Environment, and appropriate training for operators on treatment and monitoring practices [52].

The Walkerton case demonstrates the need for well-trained personnel and well-maintained water distribution systems [54]. Apathy towards water security issues has led to vulnerabilities that threaten the health of Canadians [56] [54]. Water contamination is a bigger threat in small communities, like Walkerton, that rely on small drinking-water systems (Christensen, 2006, as cited in [54]). Furthermore, the BWA failed to reach all members of the Walkerton community [52], a fact that highlights the need for improved communication between health authorities and the public.

In May 2002, the Ontario Ministry of the Attorney General released a second report with recommendations for improving water safety [52]. This report makes extensive recommendations to improve the future safety of Ontario's drinking-water supply. The Walkerton tragedy, and subsequent Inquiry, contributed to the emerging view that water resources need to be managed by watershed, and that watershed management is less about managing water resources than it is about managing human activities that may impact that resource [58]. This view has informed new water policy and legislation in Ontario [60], the Northwest Territories [62], and Nova Scotia [64].

Figure 1: Case Study: The Walkerton, Ontario, *E. coli* Outbreak (2000)

3.3. Emerging Trends in Water Security Practices and Standards

The International Risk Governance Council (IRGC) has developed a framework widely used in the risk governance community. The framework divides risks into four categories, based on knowledge available about the risks [66]. The state of knowledge about the risk will determine the course of action in the risk governance process [66].

Renn's Four Risk Categories

In a white paper on risk governance for IRGC, Ortwin Renn identifies four categories of risks:

Simple risks: "Data is provided by statistical analysis, goals are determined by law or statutory requirements and the role of risk management is to ensure that all risk reduction measures are implemented and enforced." [66]

Complex risks: "[A] major input for risk management is provided by the scientific characterisation of the risk. Complex risk problems are often associated with major scientific dissent about complex dose-effect relationships or the alleged effectiveness of measures to decrease vulnerabilities." [66]

Uncertain risks: "[K]nowledge is either not available or unattainable due to the nature of the hazard… Knowledge acquisition may help reduce uncertainty" [170].

Ambiguous risks: "If risk information is interpreted differently by different stakeholders in society…and if values and priorities of what should be protected or reduced are subject to intense controversy, risk management needs to address the causes for these conflicting views" (von Winterfeldt and Edwards, cited in [66]).

Figure 2: Definitions: Renn's Four Risk Categories

- Simple risk problems are managed using routine strategies, and often draw on "tried and true" methods of eliminating risks. Simple problems are solved with existing tools that may follow formulaic processes or standards. Organizations are able to identify and plan for simple risks in advance.
- Complex risks require that organizations act on the best available expertise to increase their ability to absorb risks. Organizations may alter their day-to-day operations to build the ability to absorb complex risks as they occur, increasing their robustness or "buffer capacity."
- Uncertain risks require precaution-based and resilience-focused strategies. To combat uncertain risks, organizations must be able to reverse critical decisions when risks materialize, and must establish a capacity to withstand surprises. Uncertain risks are unpredictable, though may be deterred by identifying particular vulnerabilities within organizations.
- Ambiguous risks require discourse-based strategies that resolve conflicts through internal consensus. Ambiguous risks may not materialize as specific events or threats, but rather as stakeholder dissatisfaction or disagreement. Responses to ambiguous risks emphasize communication and social discourse.

In Renn's Risk Framework, the state of knowledge about a risk is critical to its definition. Risks may move between the four categories as our knowledge about them increases or decreases, and

the four categories may at times overlap. This report uses these four categories to identify and organize emerging practices and trends in the water sector.

3.3.1. Simple Risks: Existing Practices and Standards

The water sectors in the United States and Canada have adopted a variety of standards for water and wastewater security and governance. The Incident Command System (ICS), ISO 31000:2009, and the *Water Security Risk Assessment Framework* all provide frameworks within which an organization may identify risks, develop a response to them, and implement that response as necessary. The Water Security Status Indicator Framework is used in Canada to establish reliable indicators of water security in a given water system, while Soft Operations Research is used internationally to develop responses to failures identified by these indicators. These existing practices and standards provide methodological approaches to water security that deal with simple risks for which information is assumed to be largely available.

Incident Command System

ICS was developed in response to extensive fires in California in the 1970s. The system is used to facilitate responses to emergency or non-emergency events by providing a clear organizational structure that incorporates all stakeholders [68]. ICS establishes a clear organizational structure, including a chain of command, in order to guide responses to emergency events [68]. As a management system, ICS can be adapted to suit a variety of needs, organizations, and events.

ICS has been adopted by a number of governments at all levels across Canada and the US as an emergency response framework. Most P/Ts in Canada have adopted ICS internally, and many encourage water and wastewater suppliers or operators to use ICS when responding to emergencies. Though British Columbia does not formally use ICS, its emergency response systems are based on the ICS model; Ontario further uses Incident Management System (IMS), as detailed in the previous report. In the United States, ICS has been incorporated into the National Incident Management System developed in 2004.

ISO 31000:2009, Risk Management Principles and Guidelines

Risk assessments for water supplies have become commonplace, with a shift towards a preventative approach that limits vulnerability of water resources and systems through protection and detection, focusing on hazard and uncertainty rather than risk and probability [7] [13]. The World Health Organization's (WHO) *Guidelines for Drinking-water Quality* emphasize 'water safety plans' for managing water quality and include methods for prioritizing risk management measures [13] [70].

Risk management for water and wastewater infrastructure is complex and far-reaching. Managers must anticipate multiple hazards (i.e., various critical points and risks) and barriers (i.e., the complex nature of ownership and responsibilities) [13]. Risk assessment for water delivery and wastewater treatment needs to encompass related infrastructure, including energy and communications [9].

Water vulnerability can be assessed from the top down, using downscaled general circulation models (GCM), or from the bottom up, relying on utilities' internal planning models and

scientific findings [9]. Water security risk analyses determine how well the system a) detects problems, b) measures delays and capabilities, and c) measures the capacity of the response [13]. Risk assessments require knowledge of the susceptibility of the source, the hazard potential, and a measure of the potential consequence [72].

ISO 31000:2009 addresses risk management, while ISO 24518:2015 addresses crisis management specifically for water and wastewater services. Like risk management plans, water infrastructure's crisis management plans must address complex or uncertain risks. Structures like ICS are an example of crisis management plans that incorporate responses to any type of crisis, enabling water and wastewater service providers to plan without precise knowledge about potential crises or risks.

Water Security Risk Assessment Framework

The Program on Water Governance, a Canada-based water sustainability research group, defines risk as a function of vulnerability (aquifer susceptibility and hazard threat) and contamination consequence, and is assessed using the Water Security Risk Assessment (WSRA) framework [60]. Aquifer susceptibility reflects the relative ease with which contaminants introduced on the surface can contaminate an aquifer. Conduits (wells) increase susceptibility by providing a 'short cut' to the aquifer. The assessment of individual hazards is a combination of chemical quantity, intensity, extent, and probability of release from diffuse and point sources. The consequence (e.g., loss) caused by contamination is a function of socioeconomic parameters. The final risk assessment framework is developed as a planning tool with which a community can make management decisions that reduce exposure to risk. Land use activities within a watershed, including anthropogenic infrastructure and anthropogenic changes to the natural infrastructure (such as aggregate pits and quarries), may increase susceptibility of an aquifer by modifying contaminant migration pathways.

Water Security Status Indicator Framework

The Water Security Status Indicator (WSSI) is a framework to guide the selection of indicators, the simultaneous analysis of indicators, and the incorporation of assessment results into water management decisions [60]. It addresses three gaps in water assessment methods for local communities in Canada: 1) few water-related indicators are user-friendly at the local scale, 2) a large number of indicators focus on a small range of issues and do not consider the broader balance of aquatic ecosystem health and human health, and 3) narrowly-focused indicators are not useful for water managers and communities grappling with competing users and integrated water systems, where balancing trade-offs can be a significant management challenge. The steps for application are:

1. Define scope and scale of assessment
2. Identify stakeholders and assemble the assessment team
3. Visioning and goals
   b) Water security objectives and targets
4. Prepare information required to assess water security status
   a) Determine the timeframe of the assessment
   b) Identify key water issues (i.e., which parameters need to be measured)

c) Identify data availability and accessibility
d) Identify prior (water-related) studies and access to information
e) Identify existing indicators

5. Analyze data and report results
6. Risk assessment and back-casting: status in relation to water security goals
7. Governance mechanisms to move towards water security.

The inclusion of stakeholders is an essential component of integrated assessment methods because they provide valuable local knowledge, access to data sources, and long-term commitments to adaptive planning. Methods such as the WSSI may close the gap between scientific assessment, policy, and behaviour change, particularly if these methods are flexible in nature and incorporate adaptive management and community involvement.

Soft Operations Research

Operations research was invented during World War II as a scientific means of determining how best to deploy available supplies. Modern operations oesearch (OR) is divided into “hard” and “soft” categories. Soft OR includes exercises like cognitive mapping, scenarios planning, and Strengths, Weaknesses, Opportunities, and Threats (SWOT) or Political, Economic, Social, Technological, Legal, and Environmental (PESTLE) analysis, all designed to help organizations analyze complex problems using qualitative data [74]. Hard operations research, in contrast, deals with quantitative data and mathematical models information to determine the best course of action. Soft OR allows organizations to analyze ill-defined problems or situations where full sets of information are unavailable [74].

Soft OR is regularly used in disaster operations management because of the unpredictable nature of most natural disasters. It allows organizations to analyze potential emergency or disaster situations before they occur, improving their resiliency through advance planning [76]. A 2012 Defence Research and Development Canada (DRDC) analysis supports the use of soft OR in emergency management, noting that it enables agencies, critical infrastructure operators in particular, to enhance their resilience by preparing in advance for emergency situations [78]. Soft OR is also able to incorporate multiple points of view, including all stakeholders rather than a single institution.

Case Study: The Elk River, West Virginia, Chemical Spill (2014)

On January 9, 2014, Freedom Industries spilled approximately 7,500 gallons of 4-Methylcyclohexanemethanol (MCHM) into the Elk River. Around 300,000 people were left without water for as many as 10 days. West Virginia American Water (WVAW), the utility responsible for managing this contaminated water supply, advised residents to flush their plumbing systems [80], but failed to warn them about the potential dangers of inhaling airborne MCHM [82]. The long-term health impacts of this chemical spill are unknown. Furthermore, this spill had a significant impact on the economy, the day-to-day lives of water customers, and the general public's confidence in the safety of their water supply [84].

Six officials from Freedom Industries – including its president, Gary Southern – were subsequently indicted for negligence and violation of the Clean Water Act. Since this spill, Virginia, Georgia, and Indiana have introduced legislation that mandates inspections of above-ground chemical storage tanks [86]. Canada has a code of practice for above-ground storage tanks [88]; however, this code only applies to petroleum products (MCHM is not a petroleum product) and has to be voluntarily adopted by provinces and territories. The US needs to develop a collective strategy for regulating above-ground storage tanks to protect water from contamination [90] and, arguably, so does Canada.

Figure 3: Case Study: The Elk River, West Virginia, Chemical Spill (2014)

3.3.2. Complex Risks: Ecosystem Management

Current water management practices have limited ability to reduce the negative impacts of climate change on water resources and aquatic ecosystems due to our insufficient understanding of the impacts of urban and underground infrastructure [9]. Short et al. identify an "urgent need for long-term, spatially integrated research at regional, trans-regional, or continental scales to address the impacts of extreme climate variability on ecosystems and water supplies" [9]. This research will enable the development of water governance models that build resilience and increase organizations' capacity to withstand risks associated with climate change.

Projections of future conditions for risk management purposes need to incorporate the uncertainty surrounding future climate change, with a focus on local approaches [9]. GCMs of the movement of energy and water in the atmosphere and ocean system can model smaller-scale features including storm tracks and extreme weather conditions [9]. Climate variability and change are recognized in most jurisdictions, but few have incorporated anticipated climate change into their water allocation systems, with historical patterns continuing to guide decisions [92].

Ecosystem-based management is one form of water security management that incorporates threats posed by climate change to a water supply or source. A holistic approach to managing natural resources, it takes into account all factors that influence the resource in question, as well as the interactions between those influential factors. In 2011, the International Institute for Sustainable Development (IISD) published a report on water security in Canada. It makes a

series of high-priority recommendations to the federal government for improving water security, one of which being: “That the federal government facilitate ecosystem-based management across jurisdictions and sectors towards a systems approach that increases the realization of multiple benefits. We recommend an integrated water resources management (IWRM) approach” [54]. The authors of this report felt that an IWRM approach is so integral to enhancing water security in Canada that they reiterated this recommendation as part of their broader recommendations to the federal government [54].

The IISD report, and its recommendations, reflect a shift in water resource management from a narrow, myopic approach to a more holistic, ecosystem-based approach. Traditionally, water resources have been managed according to political boundaries (and to some extent still are), rather than by watershed, though water security risks like climate change threaten to impact whole watersheds. The United Nations advocates a form of ecosystem-based management – i.e., ecosystem-based adaptation – to combat the threat that climate change poses to water security [94] [96]. To strengthen the resilience of the water sector, Canada needs to protect and restore ecosystem functions within its watersheds. Healthy watersheds are less flood and drought prone, and have higher water quality [98].

Resilience has become a buzzword in emergency management, particularly in relation to climate change. The Carbon Disclosure Project (CDP), for example, tracks carbon outputs around the world to inform climate-based risk assessments. The CDP works with companies to manage environmental risk and provides a global repository for information on climate change, water, and forest risk data [100]. According to the CDP’s annual report, there needs to be a shift from water management to stewardship in the US. The three key findings of this report are 1) water-related risks are increasingly being reported and impacts continue to affect business continuity, 2) the majority of respondents appear to lack strategic responses to water-related risks, and 3) respondents must develop a proactive approach to water stewardship with a focus on external engagement to avoid water-related risks.

Although water is technically considered a renewable resource, on a local scale it may behave more like a non-renewable resource if we use it in a non-sustainable manner. For instance, aquifers can be drained more rapidly than they can replenish themselves, thus lowering the water table. Furthermore, changes in the water table can lead to long-term, irreversible changes in ecosystem functions; in some parts of the world, people are transforming their landscapes into deserts by using too much water while degrading wetlands and watersheds. In 2014, the State of California enacted the Sustainable Groundwater Management Act as part of a state-wide plan to conserve water, restore watersheds, and ensure safe drinking water [102]. However, this legislation conflicts with other water management practices. In many parts of Canada and the US (including California), water subsidies threaten water security by enabling profligate attitudes towards water consumption. People would conserve more water if they were charged the actual cost for sourcing, treating, transporting, and cleaning that water [104].

Case Study: The Cuyahoga River Fire, Northeast Ohio (1969)

On June 22, 1969, the Cuyahoga River caught fire. This marked a pivotal moment in the history of the American conservation movement; the idea of a waterway that was so polluted it caught fire captured the nation's attention and spurred the public to action. While this wasn't the first time the Cuyahoga River had caught fire, it was the last. The 1969 fire prompted the creation of the Clean Water Act and the Environmental Protection Agency (EPA), among other water pollution control initiatives. Today, the Cuyahoga River has recovered to the point that some aquatic life lives within its reaches.

The Cuyahoga River Fire garnered widespread media attention, highlighting the role of public opinion in the policy development process. Though the fire did not have a direct impact on most of the US population, the severity of the event spurred concerns nationwide. As in many of the examples highlighted in this paper, media coverage of the initial event was instrumental in forcing policy changes. Because of the localized nature of events like the Cuyahoga River Fire, most people experience disasters through the media rather than directly. These second-hand experiences form the basis of the public's reaction to water security problems.

Figure 4: Case Study: The Cuyahoga River Fire, Northeast Ohio (1969)

Rights-based Approach to Development

The delegated governance model, described later in this report, recognizes individuals' rights to participate in the governing of their water systems. Rights-based approaches to development or management extend participation from government and corporations to individual citizens, engaging the public in policy- and decision-making. Ecosystem-based management requires holistic approaches that incorporate all factors in water security, including the rights and needs of local populations.

Increasingly, access to clean and safe drinking water and sanitation services is viewed as both a human right and a social justice issue. Rights-based approaches to development rely on legal frameworks like the Universal Declaration of Human Rights to uphold them. Under an RBA to water security, water is recognized as a human right, and unfettered access to water becomes a legal imperative rather than an ideal or standard. Allouche, Nicol, and Mehta [7] note that in this case, "water security" would expand to include security in accessing water as well as the security of the water supply itself.

Establishing water as a human right gives a legal basis to the principles set out in the Universal Declaration of Human Rights – that all humans have the right to live freely, without fear, and with human dignity (Gutierrez cited in [32]). Formally recognizing water security as a human right empowers citizens to have input into and control over their own water security, giving them legal recourse should their water security ever be compromised. Both Canada and the US abstained from a UN declaration recognizing water as a human right [32].

The UN notes that it is not easy to assess the impact of RBAs, as their goals are often intangible concepts like “engagement” [70]. Nevertheless, some Canadian provinces have adopted delegated governance models, allowing citizens to form advisory boards that control regional water supplies. These boards represent a rights-based approach to water security, proactively empowering citizens to manage their own water security rather than waiting for them to mount legal challenges in response to violations of their rights. The delegated governance model will be discussed later in this report.

Adaptive Management

In addition to ecosystem-based management and local solutions, water security is increasingly managed adaptively; change and uncertainties are recognized as inevitable, and policies based on current knowledge, conditions, and social objectives are made flexible enough to adapt to changing circumstances [11]. Adaptive management plans aim to respond to new information as it emerges. For instance, strategic plans to address climate change are limited by a lack of climate change data, and new data are needed to move beyond physical predictions to anticipate cascading impacts on water chemistry and biology [9]. Most literature on adaptive management for water focuses on adaptation to climate change. However, adaptive management is also relevant to managing risks associated with terrorism, cyber-crime, and deliberate sabotage. People are adaptive, so security to manage the threats they pose needs to be equally adaptive to succeed.

Zubrycki et al. recommend that the Canadian government build adaptive management into federal water-planning initiatives, and encourage other orders of government to do likewise by providing resources for the integration of adaptive management [54]. Adaptive management could increase the Canadian water sector’s resiliency to unplanned events, contaminations, or climate change.

Normal Accidents and High Reliability Organizations

Complex risks can also exist outside an ecosystem-based approach to water security. Technological failures, human error, or unpredictable weather events all pose threats to a water system’s security without involving an entire watershed or ecosystem. Renn [66] identifies high-reliability organizations as a recommended response to complex risks. High-reliability organizations can avoid disasters or emergencies when handling potentially hazardous technologies by implementing safety measures in their design and management techniques [106] [108]. These authors argue that, through advanced planning, organizations can avoid risks or accidents altogether.

High-reliability organizations typify an ‘all-hazards approach,’ in which security measures prepare for all types of risks, whether natural or man-made, accidental or planned. This trend is reflected in PSC‘s *Strategy*; one of its three strategic objectives is to implement an all-hazard risk management approach. After the 9/11 terrorist attacks in New York and Washington, CI protection in both the US and Canada shifted to focus more attention on terrorist threats. Hurricane Katrina, however, reminded critical infrastructure owners and operators (particularly those in the US) that natural hazards actually typically cost and kill more than terrorist attacks.

As a result, an all-hazards approach to emergency management has become the new norm, which includes a variety of natural and human hazards.

Contrary to the theory of high-reliability organizations, however, Perrow (cited in [110]) argues that in highly complex systems, errors and accidents are inevitable. Emergencies or disasters caused by these errors are then "normal," part of the regular operating of the system rather than exceptional and preventable events. Normal accidents stem from smaller incidents or localized failures that spread to shut down an entire system [110]. The 2003 blackout in Ontario and parts of the US is one example – a software bug caused an alarm to fail, turning a single transmission line overload into a power failure for more than 55 million people.

Leveson et al. [110] argue that attempts to prevent normal accidents by building in redundancies or backup systems make the accidents more likely because they increase the system's complexity

Case Study: The North Battleford, Saskatchewan, *Cryptosporidium* Contamination (2001)

On March 20, 2001, C*ryptosporidium parvum* contaminated the water supply of North Battleford when filters at the surface water treatment plant broke because operators hadn't removed enough of the suspended solids from the water [112]. The contamination was eventually discovered by the Battleford Health District and Saskatchewan's Environment and Resource Management ministry (SERM) issued a precautionary drinking water advisory (PDWA) on April 25 and a BWA the following day [114]. Health Canada estimates that between 5,800 and 7,100 residents developed cryptosporidiosis. Even after the filtration system was repaired, authorities didn't end the BWA until operators completed new training on how to effectively remove suspended solids from their water [112].

In 2002, Saskatchewan completed the North Battleford Water Inquiry and published a report on the Inquiry [114]. Restructuring and cost-cutting were both implicated in the engineering failure, and a breakdown in communication between the local and provincial governments extended public exposure to contaminated water [112]. The water contamination in North Battleford, as well as in Walkerton, have made all Canadians more aware of the public health issues connected to water quality [60]. There are lots of small communities across Canada, like North Battleford, that need more attention from regulatory agencies [112] and regulatory agencies will need more resources to provide this attention.

Since the Inquiry, Saskatchewan has implemented new safety standards, certifications for operators, regulations for monitoring water treatment facilities, and routine inspections to ensure compliance [116]. Municipalities now need permission from the provincial government to construct new water and wastewater facilities or expand existing ones. Presumably, this new requirement serves – among other things – to prevent municipalities from building water treatment facilities 3.5 km downstream from their wastewater treatment facilities, as North Battleford did. This case study highlights the important role that planning and communication between local and provincial government play in preventing water crises.

and thus the likelihood of failure. Systems with a number of interdependencies are more prone to normal accidents, as every connection provides an additional point for failure. Despite their inevitability, most normal accidents are unacceptable to the public, and organizations must strive to avoid them.

Figure 5: Case Study: The North Battleford, Saskatchewan, *Cryptosporidium* Contamination (2001)

3.3.3. Uncertain Risks: Terrorism

In 1998, the US identified water as one of 16 CI sectors [45]. Prior to 9/11, man-made threats to the water system were focused on vandalism and theft [19]. In response to 9/11 and the War on Terror, CI systems, including water, became global security concerns [7] [45], and the US dedicated unprecedented resources to protecting the water supply. These resources went towards employee background checks, training, security, audits, assessments, and emergency response and communications plans [45].

Modern water systems are complex, with numerous points vulnerable to sabotage, ranging from raw water sources, computer and cyber networks, to distribution networks, pumping stations, and the treated water itself [13]. Since 9/11 many utilities in the US and Canada have conducted risk assessments to identify and reduce vulnerabilities and install protective measures [21], identifying their most significant vulnerabilities and working with local first-responders to coordinate planning [45]. Cooperation among health-care providers, public health and water utility practitioners, law enforcement professionals, and community leaders is needed to mitigate the potential likelihood or impact of an attack [13].

Physical components and control centres are most susceptible to tampering [19]. Physical attacks generally target structural facilities [13]. Since water flow is governed by nonlinear hydraulic laws, the destruction of network components can easily cause severe disruptions [13]. The ‘downstream’ post-treatment storage and distribution network is more vulnerable to sabotage or contamination than the ‘upstream’ pre-treatment part of the system [13]. Vulnerable points include water towers and clear wells, as they are not usually under pressure and are easily accessible, and distribution pipelines, which are by design often exposed with numerous accessible maintenance points [13]. Control centres are increasingly at risk to more sophisticated threats such as cyber-attacks, like the one in Queensland, Australia, in 2000 [13] [19]. Remote computers can execute cyber-attacks on valves, pumps, and chemical processing equipment, such as SCADA systems [13].

There are many industrial chemicals, hazardous materials, pesticides, and fungicides that are legal to obtain, relatively easy to produce in large quantities at low to moderate cost, and are colourless, odourless, and tasteless [13]. Effective biological/chemical (B-C) weapons are potentially easy to produce with access to basic chemical, petrochemical, pharmaceutical, biotechnological, or related industry knowledge and provisions [13]. Introducing B-C weapons or other contaminants at the storage and distribution network stage has the potential to reach a very large population, requires a low-level chronic dose, and is exposed to lower detection thresholds, with the potential to cause significant harm [13].

In order to prevent attacks or purposeful contamination events, organizations within the water sector employ a variety of security practices and standards. “Guns and gates” was a common approach among organizations that required physical security measures. The province of Alberta, for example, requires that water system operators include physical barriers and biometric security systems in their facilities, while also prescribing specific building layouts to ensure that hazardous chemicals are not easily accessible to intruders [118]. With the development of cyber-attacks, however, guns and gates are no longer sufficient as standalone practices. The AWWA states that it has shifted away from these types of defences and towards a “culture of preparedness,” attempting to prevent the need for guns and gates while remaining ready to respond should an incident occur [120]. This change in attitude conforms to Renn’s assessment of uncertain risks like terrorism, which encourages organizations to avoid vulnerability while remaining ready to change plans and react to risks as they occur [66].

“Half a fence is no fence” holds that partial security attempts will do little, if anything, to protect a system from harm. Guns and gates, if implemented without a full understanding of an organization’s risks and vulnerabilities, may fail to reduce risk because they focus on improbable or unlikely events. Security measures need to be comprehensive in order to function, and should form a network of defenses that complement each other. As previously mentioned, Alberta requires physical security measures from its water operators. These physical requirements are complemented by mandatory threat assessments, which identify the most likely threats to a water system as well as likely deterrents [118].

In order to complete threat assessments, some organizations practice “red teaming.” Red teaming is a type of security review where a group is designated to examine and challenge organizations and their security systems in order to identify flaws. The term is drawn from military practices, particularly in the US, where red teams would imitate attackers and attempt to breach the organization’s physical or cyber-security measures [122]. The practice may simulate an attack on CI to determine the infrastructure’s weak points, as well as flaws or gaps in the infrastructure owner’s response to the event.

The Insider Threat

The Department of Homeland Security (DHS) and PSC have both identified the insider threat as a growing concern for critical infrastructure. Unlike terrorism, where an individual or organization purposefully infiltrates an organization, insider threats stem from existing employees with access to critical infrastructure who damage it in some way, either accidentally or on purpose [124]. The insider threat may stem from incompetent, negligent, or disgruntled employees who have already been granted access to a piece of infrastructure [124]. These employees may actively choose to harm the critical infrastructure by introducing outside materials, like malicious software, or may simply fail to carry out their duties in a timely and appropriate manner. Edward Snowden is one contemporary example of a successful insider threat, having leaked classified documents to the media and public. WikiLeaks, another contemporary example, solicits leaked documents from disgruntled employees, providing a platform for leaking classified materials.

DHS identified employee screening practices as essential in preventing insider threats [124]. Psychological evaluations are also important in identifying insider threats, as are screening practices undertaken on a regular basis after an employee has been hired. Noonan and Archuleta [124] further noted that there has been little formal research to date on insider threats, particularly on how to prevent them.

Though water systems are vulnerable to terrorist attacks, *how* vulnerable they are is debatable. Our understanding of terrorism threats to water systems may determine how many resources are invested in protecting the water systems against chemical or biological contamination, cyber-attacks, or being physically blown apart.

James Salzman [17] discusses these questions at length in his book, *Drinking Water: A History*. One of Salzman's key conclusions is that it is difficult to contaminate water systems; our water systems are specifically designed to prevent water contamination. Water treatment plants use chemical and mechanical treatments that are effective at removing biological contaminants. The sale and distribution of chemicals that could be used to contaminate water systems (e.g., cyanide) are closely monitored and controlled by government authorities. Furthermore, one would have to add a large quantity of any given chemical contaminant to a water system to overcome the effects of dilution and contaminate the entire system. Water reservoirs and water treatment facilities are generally well-protected, and though water distribution systems are more vulnerable, their water mains are generally under such high pressure that it would be difficult for a terrorist to introduce a backflow containing biological or chemical contaminants. Backflow would additionally result in local contamination. To maximize their impact, terrorists would need to know precisely where to introduce contaminants, but water systems are generally convoluted in their design (i.e., not intuitive) and maps of water systems are not publicly available. In the final analysis, Salzman [17] concludes that smaller water systems can benefit more than larger ones from security investments, because larger water systems are already relatively secure.

One small but significant concession that must be made in this section, however, comes from the psychology of risk. At an emotional level, people are typically more concerned about risks that are unobservable, unknown to those exposed, have immediate effects, and are relatively unknown to science [126]. People dread risks that seem uncontrollable, globally catastrophic, inequitable in their reach, individually catastrophic, pose high risks for future generations, are difficult to reduce in terms of exposure, and are increasing and involuntary in nature. These typify the characteristics of a terrorist attack on a water supply. While the literature may suggest that a terrorist attack is unlikely for a number of valid reasons, an attack on one facility with a vulnerable population – such as a school – could generate considerable media coverage, followed by increased public anxiety and loss of trust in the water supply.

Communication and Uncertain Risks

In Renn's Risk Framework, uncertain risks are best managed through knowledge acquisition, which enables organizations to reduce uncertainty about a given issue and make informed decisions. The tools outlined below may aid water suppliers and organizations to reduce uncertainty by facilitating the acquisition of information from a variety of sources.

In the aftermath of the North Battleford contamination in 2001, Saskatchewan's WSA began tracking the public's confidence in drinking water. The WSA has conducted annual surveys ever since that indicate a generally high level of trust from the public [128]. In 2015, the WSA conducted an awareness campaign emphasizing the value of water security, and later determined that more than half of the population would be willing to pay more for their drinking water, given its quality [130]. Tracking and attempting to increase the public's awareness of their water security allowed the WSA to establish how quickly they recovered from a contamination event, and also provided justification for increasing the cost of water.

Dashboards

Increasingly, water regulators are using dashboards to provide a graphical overview of their management activities. In the US, the EPA's *Safe Drinking Water Act* program maintains an online dashboard on public water systems with details on water treatment faculty inspections, violations, and compliance [98]. Dashboards are an example of smart infrastructure [50], allowing water operators to track their security progress against their own historical results and against those of the larger water sector. As a comparative tool, dashboards may highlight specific vulnerabilities for a given organization. Because dashboards measure management activities, they also suggest means to address an organization's vulnerabilities by highlighting practices adopted in another network.

Dashboards allow water system operators to communicate more effectively with each other, translating security measures into standards that are universally applicable regardless of location, climate, or other factors. Dashboards may also be used to provide the public with more information about their water supplies and infrastructure, disclosing the relative security preparedness of a water system in an easily accessible format.

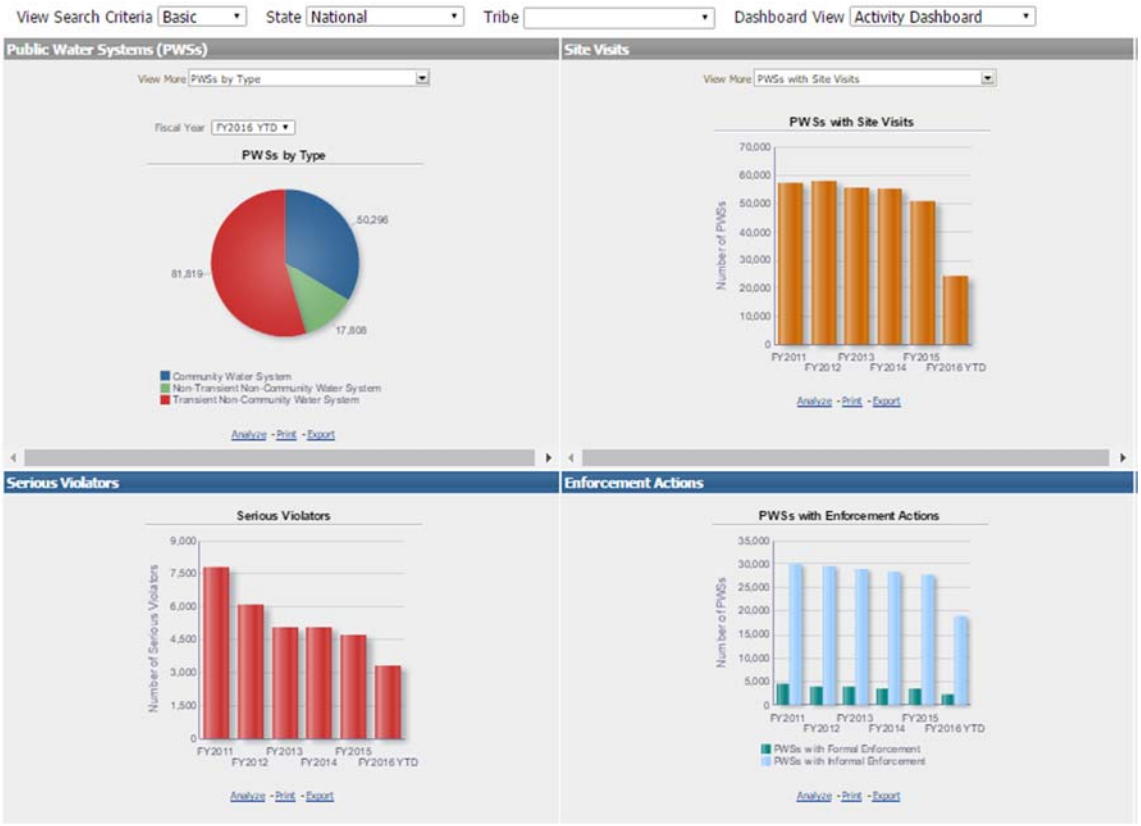

Figure 6: Image: A Sample of the EPA's Dashboard.

Collected from https://echo.epa.gov/trends/comparative-maps-dashboards/drinking-water-dashboard

Network Analysis

Network analysis may be used to model any type of network, from financial systems to social networks. Infrastructure network analysis serves to display internal and external connections, highlighting interdependencies between infrastructure systems [132]. Network analyses of water systems may model potential disruptions in services, assessing how the network will function if a specific connection (or source of an essential resource) is removed. Network analyses also allow infrastructure operators to envision how resources will need to be redirected in an emergency or disaster situation, improving resilience by allowing operators to plan for these situations.

The National Infrastructure Simulation and Analysis Centre (NISAC) in the United States has developed a series of modeling tools that uses network analysis approaches to determine key dependencies and the effects of potential disruptions [132]. The toolkit, named “Loki,” allows users to create their own models of a variety of networks including power, financial, and social. In addition to Loki, NISAC created system-specific models to visualize aspects of a particular sector or network; one example is a map of railway networks in the US, with projected volumes after a natural disaster like Hurricane Katrina overlaid on major routes [132].

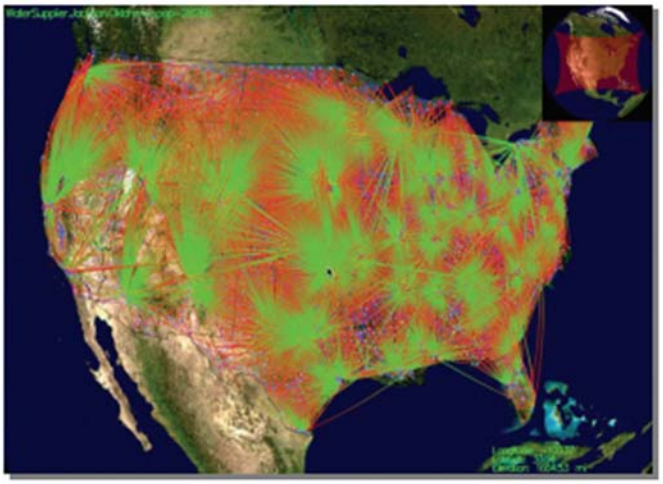

Figure 8. N-ABLE™ Chlorine producer (green) and consumer (red) relationships

Figure 7: Image: Sample Network Analysis of Chlorine use in the United States. Reproduced from [132].

Figure 7 (Sample Network Analysis of chlorine use in the United States) illustrates a visual network analysis of chlorine production and use in the US, which can show areas of the country that would be particularly vulnerable if a given chlorine-producing region experienced a disruption in its production. While this example notes the use of a physical resource, network analyses may also be used to model non-physical goods or resources, like the spread of information over social networks.

Information Sharing

As part of Canada's *Action Plan*, PSC has established a National Cross-sector Forum on CI to promote collaboration between different CI sectors to share information and address interdependencies [2]. Many water security issues, such as climate change, population growth, and protection from terrorism, have an international dimension, increasing the need for coordination and international arrangements in global water governance [134].

One response to the need for increased information sharing is the development of a knowledge commons. The knowledge commons understands knowledge as an ecosystem shared with many actors, and subject to social dilemmas like cultural or language barriers [136]. Comfort and Okada [138] argue that a knowledge commons is useful during emergency events, when communication between people, organizations, and networks becomes increasingly important. Comfort and Okada write that during emergency events, information infrastructure in the form of a knowledge commons facilitates information sharing and access, allowing for more timely responses. Hess and Ostrom [136] argue that the knowledge commons faces the same threat presented in the original tragedy of the commons, subject to privatization, overuse, or abuse. A knowledge commons requires clear standards and upkeep in order to keep it functional for everyone. In cases involving security or sensitive information, where membership must be reserved for a select few, the knowledge commons may also suffer because of its exclusivity.

Creating a knowledge commons within a given field, like water security, provides organizations with a common space in which they can interact with each other [140]. A knowledge commons

becomes a resource that increases capacity and resiliency by sharing experiences across a network, allowing all users to learn from each other's practices [140]. The knowledge commons is particularly useful in dealing with rare emergency events like natural disasters, where an institution may have little or no prior experience with a situation that has never occurred or is infrequent in the region.

In 2012, the SWSA published a water security plan for the next 25 years. Saskatchewan's plan recognizes that we need to collect and assess information about water to understand and address threats to our water supply. As such, one of the goals of the plan is to ensure that adequate data, information, and knowledge are available to support decision-making [116]. The plan outlines actions to improve: 1) data collection and management, 2) communication of information, and 3) research partnerships. Among other things, the SWSA plans to establish protocols for informing the public about water quality issues and infrastructure failure during emergencies. To effectively communicate information to the public, water authorities need to distribute information through channels that will reach all segments of the population in a timely manner. Authorities have been criticized for failing to effectively notify the public of water quality issues as soon as these issues came to their attention (for example, see our case study on the 2014 Elk River, Pennsylvania, chemical spill).

Water Information Sharing and Analysis Centres

Information Sharing and Analysis Centres (ISACs) promote the exchange of information to improve security practices and standards. The WaterISAC was created by the US federal government in 2002 in response to the Public Health Security and *Bioterrorism Preparedness and Response Act* [45]. It supports a professional network for water and wastewater utility managers and provides a forum on risks and threats to the water sector, including intentional contamination, terrorism, and cyber-crimes [27]. The WaterISAC facilitates networking on best practices, maintains a database on chemical and biological water contaminants, and provides tools for water and wastewater utility managers to assess vulnerabilities in their systems and materials on security preparedness. It also collects information on security incidents for analysis and notifies members of emerging threats by e-mail and through a regularly published e-newsletter.

Individuals who work for organizations headquartered in the US, Canada, Australia, New Zealand, the UK, and the Netherlands are all eligible for membership provided their organization is a water or wastewater utility, a government department or agency that relates to water, a firm that contracts with water or wastewater utilities, or some sort of water/wastewater industry association or network. At present, Canada possesses no comparable organization. While Canadian water and wastewater utilities may hold memberships in the US WaterISAC, they can neither share security information with the network nor receive information through the network on vulnerabilities within the US water sector.

Because actors in the Canadian water sector do not generally compete with each other, they are more willing to share information with each other than actors in other sectors; however, at present there is no Canadian WaterISAC.

3.3.4. Ambiguous Risks

Under Renn's [66] Risk Framework, ambiguous risks are neither fully understood nor identified, or are risks that involve competing interpretations of available data. Sources of conflict between stakeholders cause risks within a system, highlighting areas in which an organization does not function or communicate well and is thus susceptible to risks. Renn's solution to ambiguous risks is improved communication and conflict resolution within an organization or between stakeholders.

Nova Scotia recently commissioned a report on fracking in the province, known as the Wheeler Report. While the report was able to identify many of the known risks associated with fracking, as well as current gaps in knowledge, its conclusions and recommendations stressed the prevalent mistrust and conflicting information available about the issue [142]. Though the report stated that most risks could be adequately managed, it concluded that the government lacked a public mandate to proceed with fracking because of the misinformation present. The risks in this case were highly disputed by pro- and anti-fracking organizations, leading to the lack of consensus. Integrated management and delegated governance, explored below, offer two potential solutions to these types of situations. Including the public and other stakeholders on governance boards brings differing points of view together, ideally including them in the decision-making process.

Integrated Management and Delegated Governance

Ontario and Québec have both adopted delegated governance models, incorporating ecosystem-based management into their water security priorities. In a delegated governance model, committees comprising citizens, experts, and government representatives are formed on a regional or watershed basis [58]. Each committee is charged with governing a given watershed or region, determining regulations and policy priorities based on local rather than provincial or national needs [58]. By devolving power to local committees, both provinces have encouraged water security policy-making that incorporates watershed thinking, ensuring that decisions incorporate local knowledge of a water system. Prioritizing a watershed or ecosystem as the basis of water management allows policy to address an ecosystem's need, rather than a single municipality's. Delegated governance requires the support of a central government, in organization and planning as well as in intra-provincial or international agreements governing larger watersheds.

In 2010, the DHS and PSC completed the *Canada–US Action Plan* (the *Plan*) [144]. The *Plan* aims to promote an integrated approach to CI and represents the latest installment in a longstanding collective security arrangement between the two countries on emergency management issues. Both recognize water as a critical infrastructure sector. Collective security initiatives (e.g., the *Canada–US Action Plan*) have been established to provide strategic guidance on water security [9]. The UNDP WGF calls for the "clarification of the roles of government, civil society and the private sector and their responsibilities regarding ownership, management and administration of water resources and services" (UNDP, 2013, as cited in [134]). Trans-national water boundaries can have a significant impact on water security [104]. As such,

agreements like the *Canada–US Action Plan* are critical to ensuring water security in the Canadian water sector.

Ecological watershed management is an opportunity to address climate change vulnerabilities and adaptation through integrated watershed management and planning. Scientific assessments of climate change's impact on Western Canada and Manitoba outline challenges of higher aridity and more frequent extreme rainfall shifting seasonal precipitation, more frequent drought, and negative water quality impacts from heavy nutrient loads and longer periods of low river and stream flow. The IISD highlighted the following opportunities in Manitoba as part of an integrated watershed management plan;

- Position climate adaptation internally and publicly as an opportunity to link responses to increased drought and flood resilience through an agenda centred on the technological and institutional requirements for watershed management and governance
- Build internal and external technical capacity on climate change impacts and adaptation responses
- Conduct reviews of water sector climate change adaptation programs
- Develop a legislative framework to make long-term fiscal commitments consistent with necessary institutional reform [146].

Alberta and Saskatchewan have expressed a desire to implement some form of integrated water management [116] [172], while the Canadian Water Network further calls for water and wastewater operators across the country to integrate monitoring results into their decision-making processes [148].

Rahaman and Varis [150] define integrated water resources management as a process that "promotes the coordinated development and management of water, land and related sources in order to maximize the resultant economic and social welfare in an equitable manner". The authors argue that while integrated water resources management is popular in modern water security discourse, it has yet to be implemented in any systemic manner, and will need to be expanded and refined before it can be utilized universally [150]. Some aspects of water management, like water allocation and land use planning, remain separate in most jurisdictions, and knowledge gaps (concerning groundwater in particular) remain [92].

Case Study: The Flint, Michigan, Water Crisis (2014)

In 2014, a state-appointed emergency manager switched Flint's water source from Lake Huron to the Flint River to save money. Water from the Flint River is more corrosive than Lake Huron's water; not only did the city of Flint fail to implement measures to control corrosion, its water treatments made the water even more corrosive [42]. As a result, the city's water damaged its old lead pipes and fittings, contaminating Flint's water supply with lead.

For the purpose of risk stratification, the CDC has set the acceptable limit for lead at 5 ppb, though there is no safe level for lead contamination [42]. That noted, 40.1% of homes in Flint had lead concentrations in excess of 5 ppb, and one home had lead concentrations exceeding 1000 ppb [152], which means the water coming out of the taps in that home qualified as hazardous waste. Moreover, corroded water mains reacted with the chlorine that Flint was using to sterilize its water supply, effectively removing the chlorine treatment from the water, which led to rashes, staph infections, and an outbreak of Legionnaires' disease [154].

According to the Flint Water Advisory Task Force's final report, a series of failures at every level of government led to the water crisis [156]. To start, the Governor of Michigan eliminated public accountability when he appointed an emergency manager to manage Flint. Regardless of how much money it saved the city, this emergency manager should not have chosen to source the municipal water supply from the highly polluted Flint River. The Michigan Department of Environmental Quality failed to enforce water regulations and conspired with the Flint Water Department to conceal evidence of water contamination. Concurrently, the Michigan Department of Health and Human Services delayed response to the emerging health crisis. The state of Michigan has charged three officials with a total of 13 felonies and five misdemeanors for their roles in this water crisis.

Although Flint has switched back to Lake Huron for its water, damage to its water infrastructure continues to threaten Flint's water quality [158]. Prevention is generally cheaper than remediation; while it might cost as much $1.5 billion to decontaminate Flint's water supply, it would have cost around $100 a day to have prevented that contamination from happening in the first place [42]. On January 16, 2016, President Obama declared a state of emergency in Flint, Michigan [158], where the water crisis continues.

As of 2015, over 18 million Americans depend on water distribution systems that violate the Lead and Copper Rule by improperly monitoring their water, failing to report lead contamination to state officials and the public, and not treating water to reduce corrosion [160]. More generally – as the Flint water crisis demonstrates – aging infrastructure threatens water security. To reduce the threat of water contamination, we need to invest in national water infrastructure, including service lines, distribution systems, and water treatment facilities [160].

Figure 8: Case Study: The Flint, Michigan Water Crisis (2014)

3.4. Smart Infrastructure

In 2011, the UK created the *Cambridge Institute for Smart Infrastructure and Construction* (CSIC). The Institute aims to strengthen CI through communication and information technology, such as fibre optics, wireless sensor networks, energy harvesting, micro-electro mechanical systems, and computer vision. To accomplish its aim, the CSIC works with both researchers and the construction industry to translate new technologies into industrial applications.

The CSIC recently completed a project that installed fibre optic temperature sensors in sewers. The sensors were able to detect changes in temperature and water flow, identifying unwanted sewage discharges by measuring changes in temperature at the site of pipe breaches [162]. This enabled the CSIC to flag specific locations for further investigation. The CSIC noted that while illicit sewer connections are a particular concern, their fibre optic sensors were also able to detect rainwater infiltration and domestic connections [162], providing data on system usage and integrity while securing the pipes from illicit use. Raw data were collected and developed into a number of data visualizations, exemplifying a network analysis approach.

The CSIC case exemplifies the use of new technologies and emerging management practices to secure a water or wastewater system. By integrating fibre optic sensors into a network analysis approach, the CSIC was able to collect previously inaccessible data in a cost-effective manner. The data itself may also provide important insights into network usage, potentially identifying over- or under-utilized segments of the sewerage network and guiding future infrastructure investments.

3.5. Conclusion

The traditional risks associated with the water supply were understood to be, in Renn's terms, simple risks. Threats like chemical or bacterial contaminations were thought to be largely understood and measurable, and water and wastewater operators developed comparatively straightforward protective measures to guard against them. However, risks associated with the water supply are increasingly becoming complex, uncertain, and ambiguous. Governments face disagreements over how best to respond to aging infrastructure, a complex risk, terrorism, an uncertain risk, and fracking, an ambiguous risk.

These new and emerging types of risks, in Renn's Risk Framework, require different types of engagement strategies. Complex risks require close engagement with experts as well as consideration for the public's concerns, and demand that organizations increase their robustness, or ability to absorb risks as they occur. Uncertain risks, on the other hand, are volatile enough that experts alone are not able to predict their impact, requiring that organizations increase their resilience and examine their tolerance for failure in their supply or intake systems. Ambiguous risks are the most politically contentious and require close engagement with stakeholder groups in order to build a consensus about the nature of the risks and an appropriate response to them.

Much of the literature reviewed acknowledges the increasingly intricate nature of water and wastewater governance. Throughout our review, we have highlighted forms and techniques that can accommodate competing or contradictory views, in order to respond to complex, uncertain, or ambiguous risks. Some of the techniques identified have been successfully implemented by

governments in Canada or internationally, but far more remain aspirational concepts that have yet to be put into practice. By mapping risk types to appropriate processes, as we have done above, organizations can develop more robust risk governance processes that respond to a variety of risk problems.

An implication of this study relates to the concept of trust and trustworthiness. Research from the Pew Research Centre suggests that public trust in government has declined overall since the early 1960s; less than 20% of the US population, for example, believes that they can trust the government to do what is right always or most of the time [164]. Trust in government among Canadians, though it is higher than in the US, has hovered around 50% for most of the past decade [166]. The case studies highlighted here demonstrate failures not only of the water supply but also of the form of governance under which they occurred, contributing to this loss of faith in the government. The threat of eroding trust, whether in government or in water and wastewater regulators or operators, is a serious one, as demonstrated by the West Virginia chemical spill, which resulted in indictments.

Kramer [168] argues that trust is predicated on three conditions: openness, knowledge, and concern. An examination of current practices yields mixed results on these categories as well. Some water and wastewater regulators have become more transparent, publishing regular reports and updates on water quality, delivery, and efforts at improvement. Others, however, have yet to adopt an open or transparent approach. The case study of the water crisis in Flint, Michigan, highlights this attitude, where an ongoing lack of public accountability has contributed to lead-contaminated water with no clear solution in sight. The level of complexity involved in water systems compounds the issue, making it difficult to establish clear knowledge about issues facing water and wastewater systems, and to communicate that knowledge in an acceptable format to the public. The next stage of this research project will include a national survey to help fill some existing knowledge gaps in this area, with an eye to helping to increase trustworthiness for the sector.

4. Literature and Policy Review

The 2000 Walkerton contamination remains one of the largest and best-known instances of drinking water contamination in Canadian history. In its aftermath, provinces and territories around the country worked to implement or update drinking water policy and legislation, attempting to prevent further contamination events. Today, though Canada has not seen another biological contamination of a similar scale, Canada's water supply continues to face new challenges from a variety of sources. From the Mount Polley dam collapse in British Columbia [20] to the recent oil spill in the North Saskatchewan River [22], Canadian water suppliers have had to respond to a multitude of threats to their water's security. New threats, like climate change, untreated sewage discharge and cyber terrorism have also emerged or become prominent, making proactive approaches to water security all the more important.

In their 2011 review of water security in Canada, Zubrycki et al. outline definitions of water security across academic disciplines [24]. They conclude that Norman et al.'s definition, used throughout this paper, falls within a social science understanding of water security [24]. Zubrycki et al. find that social science understandings of water security "appear to be more holistic and integrative than those in political or physical science discourse" [24], noting that political science, for example, tends to focus on security as protection from planned attacks. The authors further argue that social science definitions, being as broad as they are, provide more comprehensive approaches to water security, ultimately best informing decision-making by incorporating all aspects of the topic [24]. Zubrycki et al. note that social science definitions of water security may already be the dominant view in Canada, as it includes sustainability, the most frequently cited aspect of water security in Canadian literature [24].

Norman et al. define water security as "sustainable access on a watershed basis to adequate quantities of water, of acceptable quality, to ensure human and ecosystem health" [169]. Working within that definition, this review focuses on the water sector's legislated responsibilities, which emphasize preventing contamination of potable water supplies. Water security policy similarly includes human health, economic costs, and social and environmental considerations. This manifests itself not only in plans to mitigate or prevent a loss of access to water whether by maintaining a clean water supply or safeguarding treatment plants against natural disasters, but also in plans meant to restore access after an emergency event. When such an event arises, emergency management legislation and policy often dictate a government's, wastewater plant's, or water supplier's response, and may be instrumental in restoring access or preventing contamination from spreading. Under an all-hazards approach, one commonly used in Canada, emergency plans are designed to provide organizational structures and practises that cover disaster mitigation, response, and recovery for any type of emergency or "hazard," whether it be a natural disaster or a man-made contamination [36]. Water security and emergency management plans frequently encompass CI, including public and private water and wastewater system operators in the process.

The legislation that regulates both water management and emergency planning, however, varies greatly across the country. In 2014, PSC updated the *Action Plan for Critical Infrastructure*, a policy framework that encouraged cross-jurisdictional cooperation on maintaining and securing

critical infrastructure like water supplies, while acknowledging that owners and operators are ultimately responsible for their own risk management [2]. No two P/Ts have adopted identical approaches in their emergency plans or water security policy, and it is rare to find even two jurisdictions with the same water testing standards [13]. P/Ts have created water security legislation that aims to respond to their unique geography, economic situation, history, and political attitudes, allowing provinces like Saskatchewan to have highly centralized regulatory systems while Québec's municipalities play a strong regulatory role. Differences in economic capacity, too, affect the legislation and policies that P/Ts enact, as funding for public water and wastewater systems and emergency agencies ultimately comes from public funds.

This legislative review aims to provide an overview of existing, publicly available legislation and government policy concerning water security in Canada, focusing on physical security and preparedness, including emergency management. Cyber-security, an important consideration for critical infrastructure, will be included in the next task, "Emerging Standards and Practices," as it is largely not represented in P/T legislation. The review covers legislation at the F/P/T levels, and is meant to provide a sense of the general approach towards water security every region has adopted, as well as their requirements for their water sectors. Since Walkerton, there has been a willingness and desire to reform water security throughout the country, but recent and emerging threats to water security have demonstrated that there is still work to be done.

4.1. Definitions, Limitations, and Methods

This review is limited to publicly available information, primarily that available online through government and industry websites. The review is limited to P/T legislation and regulations, as well as an overview of federal water security legislation. Despite the study's limitations, many municipalities across Canada have enacted their own sets of emergency policies and water regulations, which are often more stringent than their respective provinces or territories require.

The review was conducted primarily online, through government and industry website searches for information or formal documents concerning emergency planning, water, wastewater, or both areas. Background research began in winter 2016, and searches took place from June 15 through September 10, 2016. While multiple provinces have emergency plans or water security policies in force, only those that were publicly available were included in the review, and so requirements may be stricter than this review was able to determine. Conversely, the review focused only on legislation and policy, and data concerning enforcement and compliance rates were not available across the country. As such, it may be that regions with strict requirements on paper have little enforcement in practice.

As a review primarily of P/T, this work does not cover existing water security legislation or practices in First Nations Communities, the bulk of which are enforced by the federal government. Though beyond the scope of this document, a review of First Nations water security would help to provide a more comprehensive review of water security in Canada. Additionally, this review does not incorporate local or municipal laws or regulations, which may provide stricter requirements than reflected at the provincial level.

The legislative review used cybernetics, or the study of information processing and control [28] as its guiding principle. There are three elements to a cybernetic control system – information gathering, standard setting, and behaviour modification. In this sense, control means the ability to keep the state of a system within some preferred subset of all its possible states. If any of the three components is absent, a system is not under control in a cybernetic sense. With this in mind, we reviewed not only when and how government gathered information and according to which standards but also any audits that reported the effectiveness of the water regulation, which relates to the behaviour of the regulators and regulated. The review was conducted primarily by using search terms relating to both water and emergencies on each of the F/P/T websites to find relevant legislation. The review also included emergency plans of the provincial or territorial governments, and those of their departments responsible for water. The review expanded to include emergency plans, governing documents, and annual reports of provincially owned water corporations, where applicable. The review's results included general searches for recent (since 2000) auditors' reports and selected media coverage of water security, particularly of recent contamination or emergency events. Results of training practices, internal audits, or compliance tests are not regularly available to the public, leaving real emergency responses as the best tests of a province's or territory's water resiliency.

In this legislative review, "water supplies" are meant to indicate any body or system of water that has been appropriated for human consumption, rather than for ecological, industrial, or other commercial purposes. These water supplies may take the form of treatment plants, trucks or tankers, wells, dams, or any combination thereof. Water suppliers, whether government or private corporations, are those that own and operate these water supplies, ultimately providing potable water to consumers, citizens, or customers. Regulations concerning water quality address any or all of biological contaminants, chemical contaminants, or turbidity (a measure of particulate in water); acceptable levels of each vary from province to province, and often from supplier to supplier.

There are also three levels of water suppliers generally recognized in legislation. Public water systems, like municipal systems, provide drinking water directly to consumers. Semi-public systems include schools and restaurants, and may not be publicly owned but provide water to the public, and are thus also regulated. Privately owned systems, regularly exempt from regulation, supply a single consumer or a small group with water. The most recent data indicate that 95% of Canadian households get their drinking water from public water supplies, varying from a low of 66% in New Brunswick to a high of 98% in Saskatchewan [8].

4.2. Federal Policies and Legislation

In their 2011 review, Zubrycki et al. argue that Canada has a duty to ensure water security under the "peace, order, and good government" clause of the constitution [25]. While the authors promote the view that the best way to ensure water security is to manage water on a watershed basis, the reality in Canada is that most bodies of water are regulated by provinces and territories, and may be subject to several sets of regulations if they cross provincial, territorial, or even international boundaries [25]. The federal government may provide aid to provinces, and has established drinking water guidelines [30], but is ultimately only legislatively responsible for

water in one of the three territories, on federal land, and for drinking water on First Nations reserves. The federal government has also historically worked with international partners like the US to solve water security issues that cross borders, including the 1991 *Acid Rain Treaty* meant to preserve waterways by eliminating airborne pollutants [31].

Though water and wastewater are regulated at the provincial and municipal levels, the Canadian federal government (in partnership with provincial and territorial governments) has established the *National Strategy and Action Plan for Critical Infrastructure* to enhance the resilience of CI across the country. The current *Action Plan* seeks to implement an all-hazards approach across CI sectors, encouraging P/Ts and CI owners and operators to work with the federal government to identify and prevent or mitigate potential threats [2]. As every P/T government has its own standards, the *Strategy* aims to respect local legislation while improving resilience across the country [1].

In addition to water in First Nations communities, the federal government has unique relationships with each of the three territories and its water supplies. At present, it upholds the *Nunavut Waters and Nunavut Surface Rights Tribunal Act* [33], which devolves power over drinking water systems in Nunavut to a territorially appointed board, leaving the federal government as the nominal owner of water in the region (wastewater is currently territorially regulated). In 2014, control over drinking water in the Northwest Territories was formally devolved to the territorial government, as the *Northwest Territories Waters Act* [35] was repealed. Yukon's water supplies are owned either by the territory or by local communities, and the federal government does not have jurisdiction over the territory's water. According to Health Canada documents, the territories are responsible for their own drinking water systems [37], while Indigenous and Northern Affairs Canada (INAC) remains responsible for maintaining source water quality and aiding in the development of new legislation and policy [39].

Finally, under the *Emergency Management Act* [41], the federal government has the power to declare national emergencies or respond to requests for aid from provinces and territories. The *Emergency Management Framework for Canada* [36] assumes that the latter is more common, pointing out that most emergencies are managed on a provincial or territorial, if not municipal level. Though the federal government usually provides financial or logistical support during emergencies, it has collaborated with all three territories on Operation NANOOK, an annual military exercise that takes place in the north. The exercise simulates emergencies in one of the three territories, and prepares both territorial governments and the Department of Defence for potential disaster situations [43]. Recent exercises have included oil spills threatening both the local environment and drinking water security [43].

4.3. Provincial Policies and Legislation

British Columbia

British Columbia has comprehensive water security and emergency management and prevention policies aimed at potential chemical spills and earthquakes in particular. Most documents directly concerning the water supply, like the *Water Sustainability Act* [45] and *Groundwater Protection Regulation* [47] focus on the security of the water system starting at its source, aiming

to ensure that the supply remains uncontaminated and meets standard testing requirements as set by the federal government. Documents like the *Drinking Water Protection Act* [49] and *Drinking Water Protection Regulation* [51] further focus on regulating private and public water suppliers or infrastructure owners to ensure regular inspections, and ultimately compliance with federal water quality standards.

Drinking water in public and semi-public water systems in British Columbia must be tested on a regular basis, determined by Drinking Water Officers based on the type of water supply as well as its previous history [53]. Water samples are sent to any of the pre-approved private laboratories in the province [53]. The results of all water testing, whether pass or fail must be made available to the public; the province's five regional health authorities host results on their websites, along with any resulting water advisories [51]. Water system operators are ultimately responsible for testing their own water [55] and ensuring the security of the water supply on a day-to-day basis.

While the Ministry of Environment regulates water utilities and oversees the governance of source water, the Ministry of Health is responsible for drinking water through the *Drinking Water Protection Act* [49]. Each of the five regional health authorities under the Ministry of Health may set further requirements for drinking water systems, and manage regional drinking water officers responsible for enforcing existing legislation. This division is repeated in the province's *All Hazard Plan*, which has the Ministry of Environment monitor water quality while the Ministry of Health manages potable water availability [57]. Both departments have their own emergency management plans, though the *Comprehensive Emergency Management Plan (Health Annex)* does not provide additional information on potable water monitoring [59].

The *Water Sustainability Act* [45] and *Drinking Water Protection Regulation* [51] further require that dams and water utilities have their own emergency plans, approved by a dam safety or drinking water officer, respectively. Emergency dam plans must be provided to local authorities so that they can be incorporated into local emergency planning, while water utility emergency plans must be provided to all users and customers of the water utility (without providing information that could endanger the system) [45] [50].

British Columbia has adapted the ICS to its own British Columbia Emergency Response Management System (BCERMS); the system is used throughout provincial departments and is recommended to local governments as well [61]. *The Emergency Response Planning for Small Waterworks Systems*, the province's guide to emergency management, provides short and basic recommendations primarily aimed at small water system operators (like trailer parks), but is not binding [63]. The guide was last updated in 2000, well before British Columbia's *All Hazard Plan* [57] and reference manual [61] were introduced. The province has additionally prepared the *Small Water System Guidebook* [53], which recommends preventative measures like fencing around water sources, but is also not binding.

In addition to its *All Hazard Plan*, British Columbia has made extensive preparations for potential environmental or chemical spills though the *Spill Reporting Regulation* [65] and the *Spill Cost Recovery Regulation* [67], as well as its *B.C. Earthquake Immediate Response Plan*

[69]. The latter notes that CI owners (including water utilities and dam owners) are jointly responsible for restoring their own services along with the province [69]; the exact details of this joint response are not outlined. Despite these preparations, a 2012 audit of BC Hydro found that the utility was not prepared for an emergency; emergency plans existed but were not complete, staff were inadequately trained, and there were no protocols in place for coordinating with the province [38; 39]. *The Emergency Program Act* [40, introduced in 1996, is being revised with the aid of public and stakeholder consultations [77].

Alberta

Alberta's water supply is governed by a lot of legislation and regulations, aiming to protect both the security and safety of water from source to tap. Only privately owned water systems for private use are exempt from regulation [79]. The *Environmental Protection and Enhancement Act* [81] and *Water Act* set out a legislative framework for water supply systems, including licensing water rights [83], while Alberta Environment's *Drinking Water Program* enforces the *Guidelines for Canadian Drinking Water*, as well as provincial inspection and approval requirements [85]. Alberta's dams are subject to the *Dam Safety Regulatory System*, which focuses on information about potential hazards as well as the prevention of emergencies and the enforcement of safety standards [87].

Source water and municipal drinking water systems in Alberta fall under the jurisdiction of the Ministry of Environment and Parks, while the Ministry of Health provides further guidance through the *Public Health Act* [89]. Working in the Ministry of Environment and Parks, Alberta's environmental protection officers are responsible for inspecting source water and drinking water systems under both the *Water Act* [83] and the *Environmental Protection and Enhancement Act* [81], while the province's environmental health inspectors inspect public drinking water supply systems. The *Alberta Emergency Regulation* [91] requires that every department have an emergency management plan in place.

Alberta is one of six provinces to have formally adopted the *Guidelines for Canadian Drinking Water Quality*, created by the F/P/T Committee on Health and the Environment. Samples, which must be sent to the Provincial Laboratory for Public Health by water supply operators and provincial officers, are tested for bacteria and contaminants along these guidelines, and testing results from publicly regulated water supplies are posted online [85]. Drinking water supplies must be tested at regular intervals according to their operating licenses [85]. In addition, water supply operators must hold valid certification, available from a number of institutions throughout the province [93]. Certifications must be renewed through re-testing every three years [93].

Guidelines for Municipal Waterworks, the second part of the *Potable Water Regulation*, provides extensive physical and cyber-security requirements. All water systems covered by the regulation must have physical barriers like fences, as well as electronic or biometric security systems and network security training for staff [18]. The regulations also require self-reported safety assessments from every water supply operator. These assessments must report potential threats to the water supply based on location (including local crime rates), socio-economic situation (including labour disputes), and security warnings from external agencies like the RCMP [18]. These assessments are forwarded to the Ministry of Environment and Parks [18]. The *Alberta*

Environment Compliance Assurance Program allows staff to audit and inspect water facilities to ensure compliance with existing legislation, and to provide feedback to the ministry regarding the effectiveness of existing regulation [95].

The Emergency Management Act [97] requires all local authorities to have an emergency plan in place, as well as an established emergency management agency. The *Standards for Municipal Waterworks* [18] requires emergency plans be in place, and further recommends emergency reaction plans be created and that they follow CSA Z731, an emergency management standard established by the Canadian Standards Association. The *Water (Ministerial) Regulation* [99] states that dam operators may be required to create emergency preparedness plans; once created, they must be disclosed to the public. The *Water Act* [83] also allows the Minister of Environment and Parks to request emergency plans from water suppliers at their discretion.

While Alberta's provincial and departmental emergency plans are not available online, the province's handling of recent emergencies including the 2011 Slave Lake fire, the 2013 Calgary floods, and 2016 Fort McMurray fire received widespread praise [100] [102] [104]. An in-depth investigation into the province's emergency management practices after the Calgary floods did recommend that the province formally adopt ICS in its emergency planning, but noted that the province's existing practices had been effective overall [103].

Saskatchewan

Saskatchewan is the only province in Canada to have a crown corporation dedicated to managing and delivering the province's water supply. Created by *The Water Security Agency Act* [107], Saskatchewan's Water Security Agency (WSA) regulates and operates dams, wastewater facilities, and drinking water supplies [109], while the Ministry of the Environment remains responsible for water through *The Environmental Management and Protection Act* [111]. *The Waterworks and Sewage Works Regulations* [113] provides additional water security requirements, while health regions regulate public water supplies not covered by the *Health Hazard Regulations* [115]. *The Saskatchewan Water Corporation Act* [117] created an additional crown corporation (SaskWater) tasked with supplying water to municipalities across the province. The province does not regulate water supplies for private use, like wells.

Testing standards for public water systems are set out in the *Waterworks and Sewage Regulations* [113]. In addition to meeting the provincial chemical and bacterial standards (through testing at an accredited laboratory), water suppliers must also undergo an independent engineering review at least every five years [113]. The regulations further require that all test results be mailed directly to consumers annually (including information on regulatory compliance). The WSA aims to host all test results online, and views have steadily increased since the service launched to reach almost 250,000 in the past year [109].

In 2001, Saskatchewan experienced an outbreak of the *Cryptosporidium parvum* parasite in the North Battleford water system, less than year after the Walkerton contamination in Ontario. The outbreak affected as many as 7,000 people [119] and attracted widespread media coverage [121]. The resulting inquiry recognized that the municipality had no water safety regulations in place at the time, and recommended that the province regulate drinking water and report regularly on

drinking water quality in the province [123]. *The Health Hazard Regulations* were introduced the same year, and Saskatchewan has since implemented a *25 Year Water Security Plan* to further reform its water system governance. Bacterial compliance with provincial standards (defined as passing at least 90% of the time) has increased from 72.6% to 98.9% since the inquiry's final report [109], and the province continues to place a strong emphasis on the importance of public confidence in its water system [109].

The Waterworks Emergency Response Planning Standard requires that all water and wastewater systems have emergency response plans in place, including responses to potential acts of terrorism, riots, or vandalism [125]. The document requires operators to prepare a list of potential dangers, their consequences, and what will need to be done after the fact to mitigate damages, but does not provide concrete recommendations as to mitigation or prevention of emergency events. The *25 Year Water Security Plan* notes that no such requirement exists for the provinces' dams, and that while dams owned through the WSA or SaskPower conform to federal standards, private dams are unregulated [127].

Under *The Emergency Planning Act* [129], all local authorities must have emergency plans and agencies, as must the province. The province offers ICS training through its Emergency Management Department [131]. *The Water Quality Emergency Planning Standard* [125], a guide created by the province and the WSA, states that all water system operators must have quality control plans in place, and that they should ideally contain emergency plans, particularly if local municipal emergency plans do not already include the water system in question. It is unclear which department would be responsible for water systems in the case of a provincial emergency, as the provincial emergency plan is not available online. Individual departments are not required to have their own emergency management plans.

Saskatchewan is also served by a crown corporation water utility, SaskWater. In addition to providing water to local water suppliers and wastewater management services, SaskWater may assist local suppliers or communities with emergency planning for their water supplies [133]. SaskWater itself has an emergency plan that is unavailable to the public, but notes that emergency plans are crucial for all water supplies and systems [133].

Manitoba

Manitoba's Ministry of Sustainable Development is tasked with regulating and securing the province's water supply through *The Water Protection Act* [135] and *The Water Rights Act* [137]. The Office of Drinking Water, the department directly responsible for all potable water in the province, administers legislation and regulations concerning the drinking water supply, like *The Drinking Water Safety Act* [139] and *Water and Wastewater Facility Operators Regulation* [141]. Regulations and acts concerning drinking water sources only apply to public or semi-public systems; private systems throughout the province are unregulated. Manitoba does not have specific dam regulations in place, though Manitoba Hydro has emergency plans in place for at least one of its planned dams [143].

Through the Office of Drinking Water, Manitoba employs drinking water officers who test water and audit water systems [139]. These inspections are conducted on top of the regular sampling

process, where water suppliers must submit water samples to private laboratories to be tested against provincial standards [139]. Additionally, Manitoba requires that all water suppliers conduct infrastructure assessments at least once every five years [139]. These assessments must be completed by professional engineers that are not employed by the system owner, and the results must be forwarded to the director of health [139]. Assessments focus on the potential for contamination within a system, but do also include physical reviews of a building's plumbing, equipment, and other mechanical or electrical systems [145].

Under *The Emergency Measures Act* [147], the province, all departments, and all local authorities must have emergency plans in place. The *Manitoba Emergency Plan* [149] is available online, and details Manitoba's all-hazards approach to emergency planning. The province follows *An Emergency Management Framework for Canada* [36], using the Incident Command System (ICS) in its emergency operations. While the province does rely on local authorities to have emergency plans in place, its provincial plan acknowledges the large role the province should play in emergency responses, providing services and expertise that are often unavailable to small municipal governments [149]. The plan treats emergency management as a shared responsibility between the province, local authorities, and non-governmental organizations.

Though departmental emergency plans are not available online, the provincial emergency plan notes that the Department of Sustainable Development would be responsible for initial water testing during an emergency, while the Engineering and Operations Division would be given control of water and wastewater infrastructure, in coordination with the Department of Water Stewardship [149]. The Drinking Water Office would oversee all other aspects of the response relating to water, while Manitoba Hydro would retain control of its own infrastructure, including dams [149].

"Critical services," those that mitigate threats to the health and safety of Manitobans, must also have business continuity plans approved by the province, meant to ensure that critical services remain available in emergencies or crises [147]. The *Emergency Measures Act* does not provide a list of potential critical services, but the *Water and Wastewater Facility Operators Regulation* [141] does require all public or semi-public water or wastewater organizations to have emergency plans in place, approved by a director. The provincial guide to emergency planning for water and wastewater utilities notes that even in a state of emergency, all water utilities have a legal responsibility to provide clean and safe drinking water to their customers, placing a unique emphasis on the utility's responsibility [149]. The guide further recommends that operators regularly practice and train staff on emergency responses [149].

Ontario

Norman et al. note that Ontario has moved towards a 'delegated governance model' in recent years, devolving responsibility for water and wastewater throughout the province to committees, municipalities, and watershed authorities [169]. The province of Ontario has established the Ontario Clean Water Agency (OCWA) as a provincial crown corporation to offer municipalities, businesses, and First Nations communities throughout the province another supplier of potable water [151]. Municipalities can also hire OCWA to provide staff, training, and supplies to

municipalities in preparation for and during emergencies [152]. The agency receives dedicated funding from the province for emergency preparedness projects, and has 25 full-time staff in its emergency response team [152].

In 2006, Ontario introduced the *Clean Water Act* (the *Act*), which established local source water protection committees under the delegated governance model [155]. Through the *Act*, these committees develop source water protection plans, consulting with members of the community to identify potential risks or threats to their water sources as well as potential solutions. The committees work with both provincial departments and municipalities to pass or update regulations, secure funding, and institute policies that will prevent threats to local water sources (for example, the Saugeen, Grey Sauble, Northern Bruce Peninsula Source Protection Region developed a policy requiring a Risk Management Plan for hazardous materials in conjunction with their local Risk Management Officer) [157].

Ontario has received accolades for the strength of its water testing, training, and public reporting programs [159], overseen by the Drinking Water Branch of the Ministry of the Environment and Climate Change. Regulation 242/05, "Compliance and Enforcement" under the *Safe Drinking Water Act* [161] requires annual inspections and audits of all water systems and bi-annual inspections of all accredited laboratories, whether public or private. Ontario has set its own drinking water quality standards [163], and has also released comprehensive *Design Guidelines for Drinking-Water Systems* [165]. While not legally binding, the guidelines are enforced during the approvals process and encourage water suppliers to include a variety of physical security measures, including fences and alarms on all facilities, and continuous monitoring equipment, as well as cyber-security measures and vulnerability assessments [165].

Ontario's provincial emergency response plan [167] details the province's overall emergency management structure, leaving situation-specific plans to individual departments. Under the Ontaria model, the province and all of its ministries follow IMS to coordinate emergency responses [167], regardless of which agency is in control of the emergency. The provincial plan also provides a list of operational priorities to be applied to any emergency situation; repairing CI like water supplies is included [167].

Under the *Safe Drinking Water Act* [169], the Ministry of the Environment and Climate Change is responsible for regulating potable water in the province. Its officers work in conjunction with medical officers from the local health units to audit drinking water systems, enforcing provincially mandated guidelines through routine tests and sampling [169]. Small drinking water systems are regulated under the *Health Promotion and Protection Act* [171] by the local Medical Officer of Health. Owners and operators of drinking water systems are ultimately responsible for maintaining the safety of their water, and are required by the *Safe Drinking Water Act*, regulation 170/3, to follow established emergency response procedures in case of a contamination event [169]. The Ontario Regulation for *Small Drinking Water Systems* [173] also requires operators to be trained to respond to emergencies. In addition, the *Emergency Management and Civil Protection Act* [174] requires that municipalities have emergency plans in place that cover all pieces of large infrastructure, including water and wastewater utilities.

The Walkerton crisis remains one of the best-known cases of drinking water contamination, both in Ontario and across Canada, and is perhaps the reason for the unique approach to water security that Ontario has adopted. In 2000, more than 2,000 fell ill and seven died after drinking water that had not been properly treated at Walkerton's water treatment plant [4]. In the aftermath, Ontario further licensed water suppliers, created a small waterworks assistance fund, and resumed overseeing testing laboratories. The province also established the WCWC to provide safety and emergency training to water supply operators throughout the year. While the contamination and inquiry caused significant change in Ontario's water policy, it also impacted attitudes towards drinking water across the country, and remains frequently cited both as an example of the importance of drinking water safety and of emergency water management.

Québec

Québec's requirements for water and wastewater systems are particularly stringent in that they require operating permits, testing, reporting, and strict water quality guidelines even for small operators [176]. In 2002, following the Walkerton outbreak, Québec updated its water policy and introduced requirements for operator certification, regular testing, and accredited laboratories for water testing (both public and private). The province also established the Centre d'expertise hydrique du Québec through the Ministère du Développment durable, Environnement et Lutte contre les changements climatiques, in order to centralize its water policy and provide a provincial organization to enforce its *Dam Safety Act* [177]. The province continues to update its water regulations today, with plans underway to establish a compliance monitoring system [178].

Québec has instituted a temporary five-year ban on fracking in specific regions of the province, stating that there was not adequate social support for the practice [179]. A recent report commissioned by the province found that the potential for pollution and environmental damage meant that there was no guaranteed benefit for shale gas exploration in Québec [179]. The ban is currently the subject of a lawsuit under NAFTA regulations [180].

Under the *Environmental Quality Act* [181], water and wastewater system operators are required to submit five year plans to the Ministère du Développment durable at the time of the construction of their systems, detailing any potential impacts the water system may have on consumption, the local environment, and the larger drinking water or wastewater network. Under the *Regulation respecting the quality of drinking water* of the *Environmental Quality Act*, water and wastewater system operators must prepare emergency plans for natural or man-made disasters, and provide the plans to the Minister [182]. Operators must also make results of water samples (tested through accredited laboratories) available to consumers, and the samples must be collected throughout the distribution system to ensure that water quality is consistent for all users [182]. Municipal employees must also have access to water systems for testing and sample collection purposes.

Like Alberta, Québec has released a set of *Design Guidelines for Drinking Water Facilities*, updated every five years [183]. The *Guidelines*, in conjunction with *Directives 001 et 002*, provide regulations for water intake, treatment, and distribution plants in the province. In addition to detailing appropriate decontamination and monitoring methods, all three documents require emergency plans from operators, including emergency preparedness measures like

emergency backup generators. The *Guidelines* also require physical security measures for water intake systems, like fencing, gates, and other anti-vandalism measures around water intake systems in particular. In addition to these documents, the province established the Comité sur les technologies de traitement en eau potable (CTTEP) to approve new water testing and treatment technologies to be used by water operators in compliance with the drinking water regulation referenced above [184].

Outside of emergency situations, the Ministry of Environment is responsible for enforcing the *Environmental Quality Act* [181], the *Regulation Respecting the Quality of Drinking Water* [182], and the *Regulation Respecting Waterworks and Sewer Services* [185] in Québec. Under the *Environmental Quality Act*, the Ministère du Développment durable may create plans for environmental emergencies, though municipalities are specifically required to include excessive air pollution as a potential emergency in their plans [181].

Emergency management in Québec is led solely by the Ministère de la Sécurité publique du Québec, and regulated by the *Civil Protection Act* [186]. Québec's emergency management and planning legislation focuses on supporting regional authorities and municipalities without taking responsibility away from them; the province views emergency response as a joint responsibility that ultimately begins with the individual [187]. The Ministère de la Sécurité publique does not have an emergency plan publicly available, and there are no legislative requirements for the province or any of its departments to have such plans in place. The *Civil Protection Act* [186] does, however, require all municipalities to have an emergency plan in place through their regional authority, and those plans must include provisions for all important physical, commercial, social, or environmental aspects of the community.

Like Ontario, Québec has moved towards a delegated governance model, establishing watershed authorities to develop and administer "water master plans" in specific regions across the province [188]. Water master plans outline source-to-tap protections for watershed regions, encouraging sustainable development methods that preserve the quality of local source waters [189]. The watershed authorities are composed of citizens, representatives from environmental groups, users of water in the region, and municipalities. While the provincial government does not receive a vote within these bodies, many of its departments work in conjunction with them to provide technical expertise [189]. In contrast to other larger Canadian provinces, both Québec's water supply and emergency management planning are largely left to municipalities, without crown corporations or government agencies providing regulatory, physical, or administrative support. Recent consultations on the water supply highlighted that the decentralization of water security management has led to a lack of information about water supplies, and notes that data about maintenance and funding needs are particularly difficult to find [190]. A public consultation on the issue is underway.

New Brunswick

Similar to other provinces, New Brunswick divides responsibility for water between the Department of Environment and Local Government, and the Department of Health. While the former is responsible for the construction and maintenance of water and wastewater systems, the latter sets and enforces water testing and quality standards; New Brunswick has adopted the

federal drinking water guidelines [191]. In addition to manual testing by water suppliers, New Brunswick also relies on electronic data management systems to trigger automatic notifications in the case of any outbreaks or problems, notifying the Department of Health directly [192].

New Brunswick, like Nova Scotia, has implemented a formal moratorium on fracking in the province [193]. The moratorium was put in place after protests from First Nations communities, and concerns that the practice could contaminate the province's groundwater [193]. The moratorium has no set end date.

Water supply operators are only required to submit sampling plans to the Minister of Health when their systems are first built, and must use provincially owned laboratories for sampling [194]. The Conservation Council of New Brunswick has raised concerns about New Brunswick's lack of a provincial water management policy, arguing that the lack of such a plan weakens water protection within the province and fails to fulfil the province's requirements under the *Climate Change Action Plan* [195].

New Brunswick's *Emergency Measures Act* (the *Act*) [196] requires that all municipalities have emergency plans and coordinators in place, though they are not required to be provincially approved. Provincial departments must also have emergency plans in place [196], but they are not publicly available. The *Act* itself specifies the roles that each department would play; the Department of Environment and Local Government would be primarily responsible for floods or other water or wastewater related emergencies, with the Department of Health providing support as necessary [196]. Legislation does not require that the province have an emergency plan, though the Department of Justice and Public Safety, which coordinates emergency responses in the province through the Emergency Measures Organization, provides training in the Incident Command System approach [197].

There are no legal requirements for water or wastewater suppliers in the province to have emergency plans in place. Further, New Brunswick does not have specific dam regulations in place and dams do not need emergency plans to operate. This lack of regulation is consistent with the overall approach of the province; though water suppliers and wastewater operators must undergo regular testing [194], there are relatively few pieces of legislation concerning drinking water in place at the provincial level. The province is currently undergoing a consultation process in order to draft its first water strategy [198], which may result in additional legislation. New Brunswick was also recently criticized for its "thin" emergency plan, though the province disputes the claim [199].

Nova Scotia

Nova Scotia Environment, the province's department of the environment is primarily responsible for water management under the *Environment Act* [200] and *Water Resources Protection Act* [201], while the Department of Health and Wellness manages any bacterial outbreaks in the water system as per the *Health Protection Act* [202]. All public water systems are also regulated by the Nova Scotia Utility and Review Board under the *Public Utilities Act* [203]. Nova Scotia has formally adopted the *Guidelines for Canadian Drinking Water Quality* [204], and requires regular water testing and audits [205]. In 2010, the province's drinking water strategy was

formally updated with the release of *Water for Life*, a report that documented the province's increased water security measures (including mandatory source water protection plans for any new water system permits), and called for better emergency and hazard preparation on the part of water suppliers and wastewater operators [206]. The updated plan, and Nova Scotia's approach to water management, was well received by the environmental community in particular, which noted that Nova Scotia had very stringent water regulations in place [207].

Nova Scotia has additionally implemented a moratorium on fracking in the province, following a public consultation process. The moratorium was implemented in response to a lack of social support for the practice, and will require a legislative change to lift [208]. The report that triggered the moratorium highlighted the lack of public support as well as potential environmental and social impacts, including contaminated groundwater, as reasons to prevent fracking in the province [209].

The *Nova Scotia Emergency Act* [210] places the Department of Justice in charge of emergency planning in the province, and creates the Emergency Management Office to oversee all emergency responses. Under the *Act*, all municipalities may be required to develop and submit emergency plans to the Minister of Justice, who is also responsible for approving the provincial emergency plan [210]. The Emergency Management Office's website notes that the organization follows the Incident Command System, and operates a unique joint operators centre that allows all stakeholders in an emergency situation to operate together in a single space [211]. The province has further adopted an all-hazards approach, but its emergency plan, along with those of its departments, is not publicly available [211].

The *Nova Scotia Treatment Standards for Municipal Drinking Water Systems* require municipally operated water systems to have both emergency notification procedures and contingency plans in place, provided to the Department of the Environment on request and updated on an annual basis [212]. Annual updates on any changes made to emergency plans, and how they were communicated to staff, must also be provided to the province [212]. Additionally, equipment such as UV units must be equipped with alarms and automatic shutdown features in case of any emergencies [212]. These measures, however, only apply to municipally operated water systems in the province, which provide drinking water for only 60% of the population [128; 46% of residents draw water from private wells, which are not regulated by the province [214]. Dams are not directly regulated in Nova Scotia.

While Nova Scotia has not had a contamination event on the same scale as Walkerton in Ontario or North Battleford in Saskatchewan, the province did suffer from a contamination scare in 2002, when it was thought that public water contained elevated levels of a radioactive isotope [215]. *Water for Life*, the 2010 update to Nova Scotia's drinking water strategy, continued to strengthen water regulations that had been introduced in the wake of contamination fears [206]. Though the excessive radiation readings were determined to have been caused by faulty testing, the province has been praised for its handling of the event, and is the subject of an upcoming World Health Organization (WHO) study on effective public communication and emergency management [215].

Prince Edward Island

Water in Prince Edward Island is currently governed by four pieces of legislation: the *Environmental Protection Act* [216], *Drinking Water and Wastewater Facility Operating Regulations* [217], *Water Well Regulations* [218], and *Watercourse and Wetland Protection Regulations* [219], all of which are enforced by the Departments of Community, Land and Environment, and Health and Wellness. Under existing legislation, only privately owned water systems for private use are not regulated; all other systems are subject to regular testing, audits, and compliance with Canadian federal drinking water standards [217]. The province operates a public laboratory for water testing, which tests all municipal and private water samples [220]. The province's legislation, which was all introduced in 1988, is currently undergoing a public review and will be consolidated into a single act in the near future [7].

Only water supplies drawn from wells owned by municipalities are legally required to have emergency plans in place in Prince Edward Island [216], and there are no other water security requirements currently in place for water system operators. Public wells serve approximately 45% of the province's population, while the rest draw their drinking water from other private systems [221]. Under the *Emergency Measures Act* [222], Prince Edward Island's Emergency Measures Organization (EMO) oversees its emergency responses, and is currently housed in the Department of Justice and Public Safety. The *Act* allows both the province and municipalities to have emergency plans in place, but does not require them from either level of government, or from provincial departments [222]. The province's emergency plan is not available online, and it is unclear who would be responsible for water and wastewater management in an emergency.

Prince Edward Island has publicly released a guide to emergency planning for municipalities, meant to be supported by training from the province's EMO [223]. While the guide does not call for water utilities or suppliers to have their own emergency plans, it does encourage all municipalities to include representatives from critical infrastructure systems in their emergency planning boards and committees [223]. Prince Edwards Island's EMO also offers ICS training on the island [224]. The EMO notes that municipalities are responsible for ensuring they are ready to handle emergencies on their own, and asserts that most emergencies are dealt with entirely at the municipal level [223].

Newfoundland and Labrador

Newfoundland and Labrador recognizes water as a shared responsibility between the Departments of Municipal Affairs and Environment, Municipal and Industrial Affairs, Health and Community Services, and Government Services and Lands. The Department of the Environment and Conservation is primarily responsible for inspecting, licensing, and auditing water sources and systems [225] through a dedicated Water Division. The Department of Health and Community Services provides additional support in monitoring water quality and operates the public health laboratory required for testing water samples, and the Department of Municipal Affairs aids local governments in building and maintaining their water and wastewater systems [225].

This joint approach of all four departments allows the province to implement its "source to tap," or multi-barrier approach to water security, ensuring that water is protected from its source

straight through its delivery to consumers and collection as wastewater. Under Newfoundland and Labrador's model, communities may initiate the process to obtain source water protection for their own water supplies at their discretion, working with the Department of Environment and Conservation. Since 2010, a protection plan has covered 85% of public surface water sources and 30% of public groundwater sources [226].

Despite this proactive approach to water security, a recent report by Conestoga-Rovers and Associates documented the high number of BWAs in the province, linking them to a lack of funding for water supply infrastructure, available parts, and trained employees [227]. The report also pointed to the lack of treatment regulations, policies, and programs in the province as a barrier to water security, arguing that Newfoundland and Labrador suffers from vast differences in the operating methods and funding of its water systems, leaving rural or remote communities particularly vulnerable [227].

During an emergency, as at all times, the Departments of the Environment and Municipal Affairs would share responsibility for water supplies, jointly ensuring that water remained available and safe to use for all residents [228]. Under the *Emergency Services Act* [229], both the province and all municipalities must have emergency plans in place. Newfoundland and Labrador is the only province in Canada to fully incorporate municipal emergency plans into the full provincial plan, ensuring that they exist and are regularly updated [228]. The province's dams are further subject to the Canadian Dam Association's regulations, which do require that emergency plans be in place [230].

Under the *Municipalities Act* [231], local governments are responsible for owning and operating their own water systems, given support from the province. Neither the *Municipalities Act* nor the *Water Resources Act* [232] provides a clear requirement for water suppliers to have emergency plans in place for their water systems, though these pieces of infrastructure may be covered under pre-existing municipal plans. A recent report on water infrastructure commissioned by the province did examine emergency preparedness, and found that smaller drinking water systems lacked access to emergency repair materials and were much more vulnerable than larger, municipally run systems [227].

While Newfoundland and Labrador does not have strong legislative requirements for emergency preparedness in water systems, it is aware of the importance of the water supply as CI [233]. The Department of Fire and Emergency Services has also been called on to provide drinking water to towns facing contaminations and flooding in the past three years [233], and its website is careful to list examples of past disasters and contaminations (and the provincial response to them) as well as resources and information about water security.

4.4. Comparative Analysis of Provincial Policies and Legislation

Provinces across Canada have adopted a wide range of approaches to water security, including wastewater, from highly centralized systems in Saskatchewan with dedicated crown corporations to the less stringent regulations in place in New Brunswick. Though all provinces were included on the committee that developed and approved the federal drinking water guidelines [30], they have been unevenly adopted across the country, allowing for variations in basic water quality

from province to province. These differences are only exacerbated when examining requirements for water system suppliers; where some are required only to obtain construction permits, others must undergo infrastructure assessments on a regular basis. While these standards have evolved to suit the individual needs of each province, and were generally reviewed after Walkerton, the success of certain provinces in effectively managing or avoiding emergency situations indicates that there are emerging best practices in the field.

British Columbia, Alberta, Saskatchewan, and Manitoba all have clear requirements for their water suppliers and wastewater operators to enact emergency plans, while Prince Edward Island only requires emergency plans from water suppliers who use wells. Though there are no guarantees that an emergency plan will be effective once enacted, requirements for plans are a first step towards general emergency preparedness, and allow provinces to benchmark compliance with regulations. Suppliers in these five provinces may also elect to practice their emergency plans on a regular basis, using them as training tools for staff. Some provinces have additionally adopted ICS, a site command and control system that manages emergency responses by coordinating networks of organizations [16], most did not have public information about their emergency response system available.

Saskatchewan established a full crown corporation, the WSA, to centralize all aspects of its water governance, while Ontario established a provincial water supplier to compete with private water utilities and provide emergency support to municipalities and other groups responsible for water. Ontario further established the WCWC to provide safety and emergency training to water supply operators. Both provinces faced large, widely covered contamination events in the early 2000s – Walkerton in Ontario and North Battleford in Saskatchewan – and their reforms were directly influenced by the potential for similar contamination events in the future. The existence of these water agencies, the WCWC in particular, ensures that consumers will have access to safe water supplies even in the case of an emergency. Saskatchewan's WSA ensures centralized access to water supply information for consumers, whether it be legislation or testing results, something that Québec holds as a working goal [190]. Both the WSA and WCWC further bolster access to training and resources for other water suppliers, addressing concerns about a lack of qualified employees in provinces such as Newfoundland and Labrador [227].

The Walkerton and North Battleford contaminations were both caused in part by a lack of regulation, leading to improper testing and sanitation techniques [122] [233]. Recent policy changes in provinces such as Québec and Ontario have introduced mandatory certification programs, and all provinces require some sort of regular testing program, but the threats that the water sector faces continue to evolve. The recent, second contamination of North Battleford's water system stemmed from an oil leak caused by local industrial activity, and while strict regulations have been credited with preventing oil from entering the drinking water system, the city has been forced to find an alternative source for its water. Discussions of the recent spill focused on oil contaminants, though similar problems could arise in the case of an untreated wastewater discharge [235]. Though policies in place prevented contaminated water from reaching taps, the spill demonstrated the importance of a holistic water security policy that

incorporates source water protections. Ontario's delegated governance model may be one solution that allows for watershed security planning.

Alberta's *Regulation for Municipal Waterworks* [18] was the only document uncovered that required strict physical and cyber-security measures from water suppliers, though Ontario's *Design Guidelines for Drinking Water Systems* [165] encouraged the same. Both documents recommended that water suppliers conduct vulnerability assessments to determine potential threats or hazards and that they not only prepare responses to these threats but also attempt to mitigate them. Water systems in Canada have not been successfully attacked, though there was one attempt in 1980 and a threat of biological contamination made in 1991 [236]. Physical and cyber-security measures may also prevent simple unauthorized access to water and wastewater systems, thus avoiding accidental breaches and contamination as well as vandalism.

Despite the varied nature of water security policy among Canadian provinces, there are continuous improvements to legislation being made across the country. Increased regulation of water suppliers has the potential to improve water security for Canadian citizens, though governmental support, whether financial or technical, is always needed to ensure regulations can be followed.

4.5. Territorial Policies and Legislation

Yukon

Home to approximately 36,000 people, Yukon's approach to water management and legislation is the most self-directed of the three territories, in contrast with the Northwest Territories and Nunavut, which have both partnered heavily with the federal government. The *Waters Act* [237], which regulates both source and drinking waters in Yukon, sets out a standard application process for all water use, particularly focused on regulating mining operations in the region. While Yukon does enact its own water legislation, it does not regulate waters owned by Yukon First Nations governments, or water located in First Nations communities; the latter are subject to federal guidelines.

Under the *Public Health and Safety Act* [238], large water suppliers may be required to prepare plans detailing potential threats to drinking water from local activities, as well as provide measures that can be taken to address these risks. The *Act* further requires that water treatment facilities be constructed so as to prevent unauthorized access, and that they have contingency plans in place (updated yearly) to provide for emergency situations [238]. Health officers may determine at their discretion what information must be included in a contingency plan, beyond that concerning information, equipment, and potential emergency situations [238].

Yukon's guide for licence applications [239], in addition to requirements listed above, require municipal water systems to enact adaptive management plans, which prepare for unpredictable situations by identifying information that must be gathered before a response can be formulated [240]. This style of preparation ensures that municipal water supplies will be able to respond to unpredicted situations in a timely manner, even if the cause of the situation had not been previously considered. Yukon's municipal water supplies' contingency plans are required to

cover the shut down or abandonment of a water system as well as its regular operation, extending planning requirements through a system's full life cycle [239].

The *Civil Measures Emergency Act* [241] requires that all municipalities have emergency plans in place. The territory has partnered with the federal government and the Department of National Defence's Joint Task Force North, meant to ensure sovereignty in Canada's northern regions. The task force conducts Operation NANOOK annually, rotating the exercise through the three territories [43]. Previous exercises have simulated oil spills, allowing the territory to practice its response to this type of emergency.

Northwest Territories

In 2014, the federal government repealed its legislation concerning water in the Northwest Territories, devolving regulatory power including over wastewater to the territorial government. The same year, the Northwest Territories introduced the *Waters Act* [242] and updated its *Public Health Act* [243] to accommodate its new legislative and regulatory responsibilities. Water systems in the Northwest Territories continue to follow federal drinking water guidelines, and are subject to regular testing as set out in its operating permits [242]. The *Waters Act* requires contingency plans from any organization handling hazardous materials or petroleum products, but does not require contingency, emergency, or security plans from water system operators [242]. Oil spills are of concern in the Northwest Territories, which additionally adopted the *Guidelines for Spill Contingency Planning* in 2007 [244].

The territory continues to follow its 2005 plan for drinking water, though it has not been updated since the devolution of powers [245]. The Northwest Territories introduced a broader water stewardship strategy in 2014, which identified developing security policy for water systems as a priority in the coming years [245], among other goals. While the territory's *Waters Act* was updated in 2014, the Northwest Territories continues to identify areas in which its legislation is lacking [245], and will be updating its policies as it continues to adapt to its new devolved water management powers.

The Northwest Territories also conducted a report on modernizing its *Civil Emergency Measures Act* [246], and completed a *Hazard Identification Risk Assessment* [247]. The risk assessment includes a complete list of all recent emergency events, including water contamination, which it notes is a large issue because most residents rely on a single water source. The territory has multiple long-term BWAs in place as well, despite recent changes to legislation [247]. The risk assessment expresses concerns regarding spills and contamination, particularly from oil, and notes that it is vulnerable to contamination caused by industrial activities in northern Alberta [247]. Though the Northwest Territories does not have regulatory power over industries in Alberta, those operating in the north of the province do use water sources that are shared with the Northwest Territories, threatening contamination events that the territory can do little to defend itself against.

Nunavut

The federal government of Canada retains legislative power over Nunavut's water. The *Nunavut Waters and Nunavut Surface Rights Tribunal Act* [248], a federal piece of legislation, established

the Nunavut Water Board, which regulates water throughout the territory by issuing licenses, while the federal departments of INAC and Health Canada oversee policy development and drinking water quality, respectively. In Nunavut, all municipalities are required to provide water to their residents, and water systems must be regularly inspected by health officials [249]. Once water permits have been approved by the Nunavut Water Board, it remains the responsibility of INAC to ensure compliance with their terms [250]. Outside of testing regulations, there are no requirements for emergency, contingency, or security plans from water or wastewater operators in the territory.

Similarly to the Northwest Territories, Nunavut has adopted a *Spill Contingency Plan* [244] that requires facilities handling hazardous or petroleum-based materials to enact emergency plans. Additionally, the *Emergency Measures Act* [251] requires every government institution and municipality to have an emergency plan and training exercises in place, though it does not specifically address water security. Unlike the other two territories, Nunavut remains dependent on the federal government for most of is water governance, and does not have substantive water security measures enacted at the territorial level.

4.6. Comparative Analysis of Territorial Policies and Legislation

Unlike their provincial counterparts, Canada's territories have varying degrees of control over their water supplies and systems. Until recently, the federal government protected and administered water (including wastewater) in both the Northwest Territories and Nunavut, allowing the INAC to create, fund, and enforce policy and regulatory bodies and Health Canada to inspect drinking water. In 2014, federal legislation covering the Northwest Territories was repealed and replaced by territorial legislation, and the Northwest Territories joined the Yukon in passing and administering its own water-related legislation. Nunavut's water supply remains under federal control as per the *Nunavut Surface Waters and Nunavut Water Rights Tribunal Act* [248], with the Nunavut Water Board approving licenses and the federal government setting regulations within the territory.

Water security legislation in Canada's north also varies greatly from territory to territory, and is regularly bolstered by support from the federal government. In addition to territorial emergency planning, all of the territories have entered into Joint Task Force North, a partnership with the federal government that aims to protect Canada's sovereignty in the north [252].

While all of the territories have relatively low populations of a similar size, they face unique challenges in providing access to and maintaining a safe drinking water supply. Chemical and oil spills, like those practiced for in Operation NANOOK, are a prominent concern for all three territories, with the Northwest Territories particularly worried about potential contamination from industrial activities in neighbouring Alberta, something it can do little to prevent [247]. Through its partnership with the Northwest Territories and Nunavut, INAC prepares an updated set of *Guidelines for Spill Contingency Planning* [244] every year, addressing water security issues specific to the north and bolstering the two territories' emergency management training. Yukon is not included in these guidelines, but has implemented robust emergency management plans through the municipal level, and has formally adopted ICS.

5. Analysis of Semi-Structured Interviews

5.1. Introduction

We completed a review of existing legislation, policy, and grey and academic literature concerning existing and emerging security standards and practices in the Canadian water sector. Our findings provided us with a general understanding of the legislative framework that governs water security, as well as some of the expectations that governments and stakeholders have with regards to future water security challenges and solutions. This section examines the views of owners and operators of water facilities across Canada, in order to capture their current practices, as well as their understanding of the water sector's needs in the coming years.

We began with a series of 12 to 17 semi-structured interviews. The interviewees were drawn from water regulators and utilities in the following numbers:

- 2-4 regulators
- 3-4 very small utilities
- 3-4 small utilities
- 2-3 medium utilities
- 2 large utilities

5.2. Structure and Frameworks

Using a series of semi-structured questions, we conducted interviews of up to 60 minutes with water facility owners, operators, and regulators. We contacted senior-level employees with managerial or executive responsibilities. The semi-structured nature of the interviews allowed us to document the perception of risk and resilience in the water sector by those in the sector, in their own words. The interviews also allowed us to use our findings from previous tasks to steer the discussions to obtain greater insights into the sector. Questions related to themes or areas of inquiry we believed to be important to the water sector.

The following themes recurred throughout both our previous reports and the questions that were received from the CWWA and other partners.

- Governance [Control Management] – practices and programs operators may have in place to prevent or mitigate risks, as well as standards set within organizations or by regulators to protect from risks. May also include specific questions about physical or cyber-security measures.
- Incident Management – practices operators follow when responding to an emergency event or realized risk. May include questions about supply chains, emergency protocols, and recovery from incidents.
- Training and Awareness – programs created to transmit knowledge to key staff members, or across an organization. May be conducted as a preventative measure, or as a response to a disaster or near miss; questions may relate to an operator's ability to learn from previous incidents.
- Business Continuity [Service Continuity Management] – procedures to ensure business continuity in the face of an emergency or disaster. May also concern long-term

operations, including business practices and their responsiveness to technological advancements, or new understandings of best practices.

- Public, Executive, and Board Engagement – procedures an operator may have in place to communicate with the public or its management, whether within an emergency situation or otherwise.

Please see Appendix D for the full list of interview questions

The interviews were also guided by Hood et al.'s Risk Regime Regulation framework, particularly their concept of a cybernetic control system. Hood et al.'s cybernetic control system has three main characteristics: information gathering, standards setting, and behaviour modification. In this sense, control means the ability to keep the state of a system within some preferred subset of all its possible states. If any of the three components is absent, a system is not under control in a cybernetic sense [256]. Information gathering is the capacity to obtain data that can be used to shape regime content. Information may be gathered actively or passively, from outside or within the system [256]. Standard setting involves establishing goals, or guidelines; in government, standards often take the form of policy. Finally, behaviour modification refers to the preferences, incentive structures, beliefs, and attitudes that shape systems – the capacity to modify behaviour of participants is the capacity to change systems. Each of our questions explored one or more aspects of a cybernetic control system within the water sector, in order to understand not only how the sector currently functions, but also in which areas improvements could be made.

The *International Risk Governance Framework* was also incorporated to categorize the risks the water sector currently faces [70]. Renn's Risk Framework divides risks into four categories: simple, complex, uncertain, and ambiguous. With *simple* risk, predicted events are frequent and the causal chain is obvious. Simple risks generate reliable data that help to inform our view about risk; we can be more confident about the extent to which the threat will materialize and the consequences of that threat. *Complex* risks exist when there is difficulty identifying and quantifying causal links between a multitude of potential causal agents and specific observed effects [66] (e.g., regular flooding). *Uncertain* risks exist where there is "a lack of clear scientific or technical basis for decision making," which "often results from an incomplete or inadequate reduction of complexity in modelling cause-effect chains" [66]. Uncertain risks can frequently generate surprises or realizations that risk modeling frameworks fail to anticipate or explain (e.g., rare natural disasters, terrorism, and pandemics). *Ambiguous* risks result from divergent or contested perspectives on the justification, severity, or wider 'meanings' associated with a given threat [66] (e.g., environmental protestors). For ambiguous risks, broad public consultation is important and solutions are usually provisional until more reliable data become available. Questions based on scenarios or specific risks will include a risk from each category, to better explore how an organization may cope with a lack of information, or different degrees of certainty about possible outcomes.

Within both of these frameworks, we explored a number of broad themes, including change, trust, culture, learning and training, relationship management, and accountability. In wide-

ranging interviews, these themes allowed us to uncover institutional attitudes and approaches to risks, in addition to specific risk-management practices.

5.3. Response Categorization

Respondents were selected based on both their geographic location and the size of community their organization served. In total, we received responses from 13 communities and two regulators. See Table 1 for a breakdown of respondents by size.

Table 2: Breakdown of interview respondents by population

Number of Interviewees	Size of Community Served (population)
4	100,000+
4	10,000 – 99,999
5	1 – 9,999

Our interview questions aimed to uncover how operators felt about risks and threats to their organizations, where they gathered information about risks, how they worked with external organizations, how they managed existing risks, and in which areas they thought they could improve. Our questions for water suppliers can be found in Appendix D and for regulators in Appendix E. These questions were meant to be open ended, designed to start a conversation or provoke thought about risk among the interviewees.

Analysis of interview responses was conducted using Nvivo transcript analysis software. Drawing on previous research done for this project, word frequency analysis, and quantitative results from the online survey, the following key themes were established:

- Standards, rules, or regulations – 459 individual references
- Staff, operators, and training – 197 individual references
- Aging infrastructure – 165 individual references
- Flooding – 123 individual references
- Cyber-security – 119 individual references

References to words, synonyms, or themes related to the above references were coded throughout all of the interview transcripts using functions within Nvivo. These were then reviewed by hand to ensure accuracy.

Nvivo was also used to determine the overall sentiment of all coded references. Sentences or sentence fragments were determined to be positive, neutral, or negative, and summarized by theme. These sentiment codes were also sampled to ensure accuracy.

Finally, Nvivo was used to pull context from individual references. The software was used to highlight references in text, and to collect frequent or typical preceding or following text from individual references to given themes. This context was then manually summarized and anonymized. As per agreements made with each interviewee, raw text from interviews could not be reproduced. Sample text or responses included in this report have been summarized or otherwise anonymized to protect the identity of respondents.

5.4. Analysis by Theme

Below is an analysis of responses by theme. Each theme was analyzed using the methods outlined in the above section.

Standards, Rules, or Regulations

There were 459 individual references to standards, rules, or regulations, including 37 mixed, 92 negative, and 45 positive references.

Frequent context for this theme ranged fairly widely, as can be seen in the sentiment ratings. Some respondents articulated difficulties in following rules and regulations set by provincial and federal levels of government because of weak communication, high standards, or frequent changes. Others noted that the standards they followed were important in maintaining the safety of the water supply, and expressed a desire to do more than the regulations required.

There were no references to any standards or regulations being too weak; all were either adequate, good, or too stringent. It was also noted that rules and regulations are developed by a variety of sources – only one respondent noted that they developed policy and standards in-house.

Frequent Context:

- Weak communication of expectations
- Frequent change in recent years
- Difficult to meet standards
- Strict – particularly following high-profile local or national contamination events
- Change in regulations without accompanying change in culture
- Creates necessary discipline
- Need more standards across the industry
- High expectations
- Heavily regulated
- Lack of understanding – why or how regulations are enforced
- Hard to meet standards, particularly with small systems
- Want to exceed regulations, to do better
- Standards and regulations are fine, more than adequate
- Set by politicians, elected officials, regulatory bodies, various agencies
- Policies created internally by an organization

Context by Size of Utility:

Utilities of all sizes were able to recognize standards kept water safe, and drove them to do better.

Smaller utilities were more likely to have issues understanding reasoning behind regulations, or to have issues communicating with regulatory bodies and government departments.

Staff, Operators, and Training

There were 197 individual references to staff, operators, and training, including 22 mixed, 62 negative, and 27 positive references.

Frequent context for this theme was largely negative. While many respondents praised their staff for their hard work and dedication, most said they had some difficulty in attracting, retaining, or training staff, whether for financial or educational reasons. Some noted that retaining staff was their utility's biggest problem, above all others discussed. There was also a general sentiment that staff function as front-line responders, and are a valuable source of information about risks.

Comments about staffing difficulties were universally shared, regardless of the size of utility responding to the interview. There was also a general sense of pride towards staff. The cost of living, regulations, certification requirements, and regional demographics were all blamed for staffing challenges.

Frequent Context:

- Involved in procedure and policy review; pro-active
- Hard to attract and retain because of training standards
- Customer service
- Seek input, participate in identifying and managing risk
- Knowledge owners; front line of defense
- Pride, sense of ownership of work
- Hard to find qualified staff
- Opportunities for better training and qualification
- Change – in regulation, standards, demographics
- Wages are standard – decent
- Cost of living is a barrier to staff retention
- Biggest problem
- Need to invest in more training and recruitment programs
- Need to decentralize decision-making and risk assessment power, involve more staff, including those on the front lines
- Staff encouraged to take on more training and certification
- Difficult to find and keep staff

Context by Size of Utility:

Training and certifications were more often a problem for small, remote, or medium-sized utilities, while staff retention was largely raised by small or medium-sized utilities, and cost of living by large utilities.

Aging infrastructure

There were 165 individual references to aging infrastructure, including 6 mixed, 12 negative, and 6 positive references.

Frequent context for this theme was less negative than expected, . While most respondents recognized that aging infrastructure is a severe threat, several noted that they had plans in place,

or that the threat was foreseeable and relatively easy to plan for. The solution to the threat was not, in all cases, increased funding; some utilities highlighted that they lacked information, expertise, or staff, but that they did have adequate funds to cover future costs. Others emphasized that they were proactively restructuring their financial systems to ensure they would be able to afford to replace their infrastructure in years to come.

Most respondents also acknowledged that aging infrastructure is a sector-wide problem that would impact everyone regardless of size. They also shared a willingness to implement creative solutions, with some pointing to efforts to collect more data and make their repairs more efficient in response to the threat of aging infrastructure.

Frequent Context:

- Budget issues, reliance on grant money, other levels of government for support
- Deferred maintenance increasing, not setting aside enough money
- Need for upgrades, to meet new standards
- Need for more information
- Need for advance planning, foresight, potential for growth
- Lack of support from federal government
- Top priority
- Lack of information, resources, funding
- Lack of capacity, capability
- Crisis arriving, soon to come
- No plan
- Grants and funding organizations provide support
- Lack of resources in small communities in particular
- Funding and human resources are lacking, not enough expertise or manpower
- Foreseeable, planned, ready to address needs
- Regular assessments, strict design standards
- Building to withstand natural disasters
- Need to collect more information
- Main way to manage risk, reviewing and replacing aging infrastructure
- Saving, setting funds aside – actively planning for future needs
- Changing risks to financial risks, rather than natural disasters, contaminations, etc.
- Nothing new being done – an old risk, everyone knows about it, nothing being done to address it
- Main risk, along with climate change
- Applying for federal and provincial funding to cover the cost
- Climate change accelerating the rate of aging infrastructure, infrastructure breakage
- Large amount of spending on infrastructure at all three levels of government
- Compounded by aging/decreasing population, decreasing water usage, declining revenues
- Requires creativity, innovation to address
- Have capital reserves in place

Context by Size of Utility:

Larger utilities were more likely to have capital reserves or financial systems in place to mitigate this risk – to be willing to talk about these kinds of measures. They were also less likely to discuss municipal budgets as a source of their funding.

Small and medium-sized utilities were likely to bring up grants, difficulties with securing and keeping funding, and their declining revenues and demographic changes (in smaller utilities in particular).

In this instance, utilities in Northern Canada were also more likely to bring up funding from territorial or federal governments in a positive light, noting that they had enough financial resources available to deal with aging infrastructure.

Flooding

There were 123 references to flooding, including 21 mixed, and 73 positive references.

Flooding was consistently seen as a minor threat to water supplies and wastewater systems, largely because it was not geographically relevant to many of the respondents. Those who had experienced flooding in the past felt that their response or plan had been well executed, and did not indicate that they were worried about further potential flooding. Respondents also frequently commented that they had included flood response plans in their emergency planning, unlike other themes explored in the interviews.

Frequent Context:

- Previous experience with floods, went well
- Network of responders available to deal with floods
- Made improvements based on actual flooding events
- Previous studies done, planning of new infrastructure to avoid floods
- Not a huge problem
- Impact on water source, not infrastructure itself
- Included in safety plans
- Unlikely in this region, area
- Have done some flood risk planning

Context by Size of Utility:

There were no discernable changes in response by size of utility.

Cyber-Security

There were 119 references to cyber-security, including 14 mixed, 39 negative, and 8 positive references.

Respondents were frequently unsure about cyber-security; several noted that it was not their area of responsibility or expertise. There was a recognition that cyber-attacks are becoming more common among utilities that had online systems, and a range of confidence in the safety of existing online networks. Some respondents also noted that threats like protestors were now more likely to be found online than in person.

Even among respondents who were unsure of their own cyber defences, there was frequent recognition that cyber-security is an emerging threat. Several respondents noted that it is often discussed at conferences or events related to water security, though there was no indication if those events caused improvements in utilities' cyber-security.

Frequent Context:

- Not relevant, plants aren't online
- Potential risks from hackers, causing environmental threats, contaminations
- Risks increasing over time – tracking in regular assessments
- Need constant change, to keep up with evolving threats
- Hard to measure
- Need more staff, more expertise to deal with threat
- Fairly protected; entire system online
- None of the system online, no potential for hacking
- Low awareness
- Protestors and outside threats more likely now on the cyber front
- Information available through the CWWA, or conferences

Context by Size of Utility:

Larger utilities were more likely to have a clear understanding of threats to cyber-security, and to be pro-actively addressing them.

Smaller utilities were often hesitant, or unsure about what potential cyber-security threats existed, or how they might impact their operations. Smaller utilities were also the only respondents to state that they operated entirely offline and thus did not face direct threats from cyber-security problems.

Medium-sized utilities were often aware cyber could be a threat, and that they do not do enough to protect themselves.

5.5. Context by Size of Utility

Sentiment Coding

Table 3: Sentiment by Size of Utility

Utility Size	Positive Coding as a percentage of coverage (average)	Negative Coding as a percentage of coverage (average)
Small	17.03%	35.36%
Medium	19.42%	40.51%
Large	25.85%	36.39%
Regulator	19.93%	35.37%

Online Questionnaire and Survey

5.6. Introduction

The purpose of the questionnaire was to collect attitudes, perceptions, and self-report data about water security and resilience from water utility organizations. The questionnaire data allowed 'benchmarks' for practice and performance to be established, as well as a 'risk profile' (see Appendix A for an example) for each participating organization.

Our questionnaire approach was informed by the measurement of safety climate, which is a risk-management technique used widely in high-reliability industries to identify safety problems before they become realized as accidents and near misses (for a review see [254] [255]).

5.7. Method

Participants completed the questionnaire online. A link to the questionnaire was emailed to participants' work email addresses by managers in participating organizations, facilitated by a covering email from the CWWA. The covering email explained the purpose of the questionnaire, reassured participants that their responses would be anonymous that the data would be treated confidentially by the researchers, and that participants would be able to access reports about the results of the questionnaire. Ideally, participants were given time during their normal working hours to complete the questionnaire, or they could complete it during their own time by accessing the link from a computer of their choice.

5.8. Participants

For the findings of the questionnaire to be reliable and valid, it was important to ensure that a representative sample of water utility organizations across Canada take part (e.g., a proportionate number of large, medium, and small water utilities). It was equally important that a representative sample of staff employed by those water utility organizations take part (e.g., senior managers/managers, engineers/technical experts, and front-line staff). This allowed for comparison of attitudes/perceptions about water security between staff groups.

To ensure that the questionnaire data are valid, slightly different versions of the questionnaire were developed for each staff group to assess different risks. For example, managers were asked about their strategic priorities for water security, whereas engineers/technical experts were asked to assess the risks associated with more technical hazards.

5.9. Content

As there is a dearth of published empirical research about security/risk resilience in water utilities, the content of the questionnaire was informed in part by topics/themes suggested by the CWWA. Also, as our questionnaire approach was informed by the safety climate literature, we drew on that literature for topic areas/questionnaire items. The following is a list of potential topic areas with a brief justification for their inclusion in the questionnaire.

Risk

Depending on their job role/expertise, participants rated the severity and frequency of a variety of hazards (e.g., physical security, cyber-security, information handling, natural hazards,

personnel). These ratings were used to construct the risk profile for each organization. Consistent with our approach for the semi-structured interviews, we will consider these risks according to Renn's Risk Framework (simple, complex, uncertain, and ambiguous).

Management Commitment

This is the most commonly identified factor in studies of safety climate and has been shown to influence employee risk-taking/safety behaviours. Management commitment has also been identified as an important factor in implementing Water Safety Plans in water utilities [253].

Attitudes/Perceptions/Self-Reported Behaviours About:

-Physical security

-Cyber-security

-Personnel (e.g., insider threats, training, awareness)

-Communication/information sharing

-Organizational interdependencies

-Trust

-Dimensions of an informed/safety culture (i.e., reporting, just, learning, and flexible cultures) [257]. This is consistent with Hood et al.'s [256] cybernetic control system (information gathering, standards setting, and behaviour modification) which is the framework used in the semi-structured interviews.

5.10. Data Retention and Access

Information provided to us throughout the course of the interviews and surveys is kept private. Only the research team at Dalhousie University has access to this information. Our publications only refer to groups, to preserve the anonymity of any respondents or interviewees; no single respondent is identified in any way in our reports or publications. All identifying information, as well as all results provided, are securely stored in an encrypted file on researchers' password-protected computers.

Survey Design and Method

The survey was developed through an iterative process between the research team and a steering group composed of CWWA members and representatives from PSC. To ensure content validity, the steering group provided details about hazards, threats, defences, and systems related to security and risk resilience by sharing documents and by providing guidance during a number of teleconferences. To ensure face validity, a pilot test was conducted.

The survey was hosted on an online platform and a link to the survey was distributed by the CWWA to its members and to non-members via email. The link to the online survey was active for 32 days for the purposes of data collection, and reminder emails about the survey were sent by the CWWA during this time to encourage participation.

Respondents

Responses were received from 352 individuals representing 139 different water utilities across all 10 Canadian provinces and two of the territories. As detailed in the main report, it was not appropriate to estimate the response rate.

The majority of respondents were male between the ages of 36 and 64 years. Just under half of all respondents were senior managers, and the majority of the rest were employed in management, operational field staff, or technical support roles.

The most responses were received from Alberta (n = 129, 37% of respondents), followed closely by Ontario (n = 114, 32% of respondents). The most responses from different water utilities was from Ontario (n = 41, 29% of participating water utilities), followed closely by Alberta (n = 36, 26% of participating water utilities).

Participating water utilities were analyzed by the size of population they service. Most of the water utilities in the sample (n = 101, 73%) service a small population (100,000 or fewer). There were 21 utilities (15%) in the sample that service a medium-sized population (100,000–500,000), and 17 (12%) that service a large population (over 500,000).

5.11. Main Findings and Recommendations

This section reports the main findings from the survey. It provides an analysis of the main findings and offers recommendations where appropriate.

Table 3: Mean Likelihood and Severity Ratings, and Resultant Risk Scores

Hazard/Threat	Likelihood Rating	Severity Rating	Risk Score
Unauthorized access to premises	.43	.62	.27
Hacking	.36	.62	.24
Flooding	.42	.57	.28
Insider threats (e.g., disgruntled/former employees)	.38	.57	.24
Loss of power	.52	.52	.30
Phishing/spear phishing/watering hole	.33	.41	.16
Earthquake	.18	.47	.11
Visitors (including visitors from foreign countries)	.38	.35	.14
Chemical release/spill	.43	.57	.27
Severe storms	.61	.62	.40
Suppliers (e.g., transportation suppliers)	.45	.45	.22
Contamination of source water (including reservoirs)	.43	.66	.30
Tornado	.34	.49	.20
Malware (e.g., viruses, worms, Trojans)	.41	.54	.24
Aging infrastructure	.64	.63	.43
Drought	.42	.47	.23
Defence/System			

External fences/barriers	.51	.48	.26
Internal locks/doors (including swipe cards)	.38	.58	.23
Patrols/check-points by security guards	.38	.40	.17
Video/CCTV	.37	.39	.16
Intrusion detection software (e.g., firewalls, anti-virus software)	.37	.55	.21
Communications (e.g., phone/radio)	.37	.48	.19
SCADA systems	.33	.65	.22
Employee ID cards	.33	.44	.17

Table 3 presents the mean likelihood and severity ratings, and associated risk scores for each hazard, threat, defence, and system. These scores are the average of all respondents' scores for an item, or the overall average for an item. It was pointed out in the 'Respondents' section of this report that the majority of respondents were from Alberta and Ontario, as was the majority of participating water utilities. Thus, these scores may be biased towards the perceptions of employees and water utilities in Alberta and Ontario, but this is not necessarily problematic as there were not any prior expectations about regional differences.

As can be seen in Table 3, the highest risk score, 0.43, was for aging infrastructure, followed closely by a risk score of 0.40 for severe storms. The lowest risk scores were 0.14 for visitors and 0.11 for earthquake.

It is more conventional to plot likelihood and severity ratings on a 2*2 grid in order to see the relative position of various hazards and threats to each other more easily. Such a plot is called a 'risk matrix' or a 'risk profile'. The mean likelihood and severity ratings from Table 3 are displayed in this way below in Figure 9.

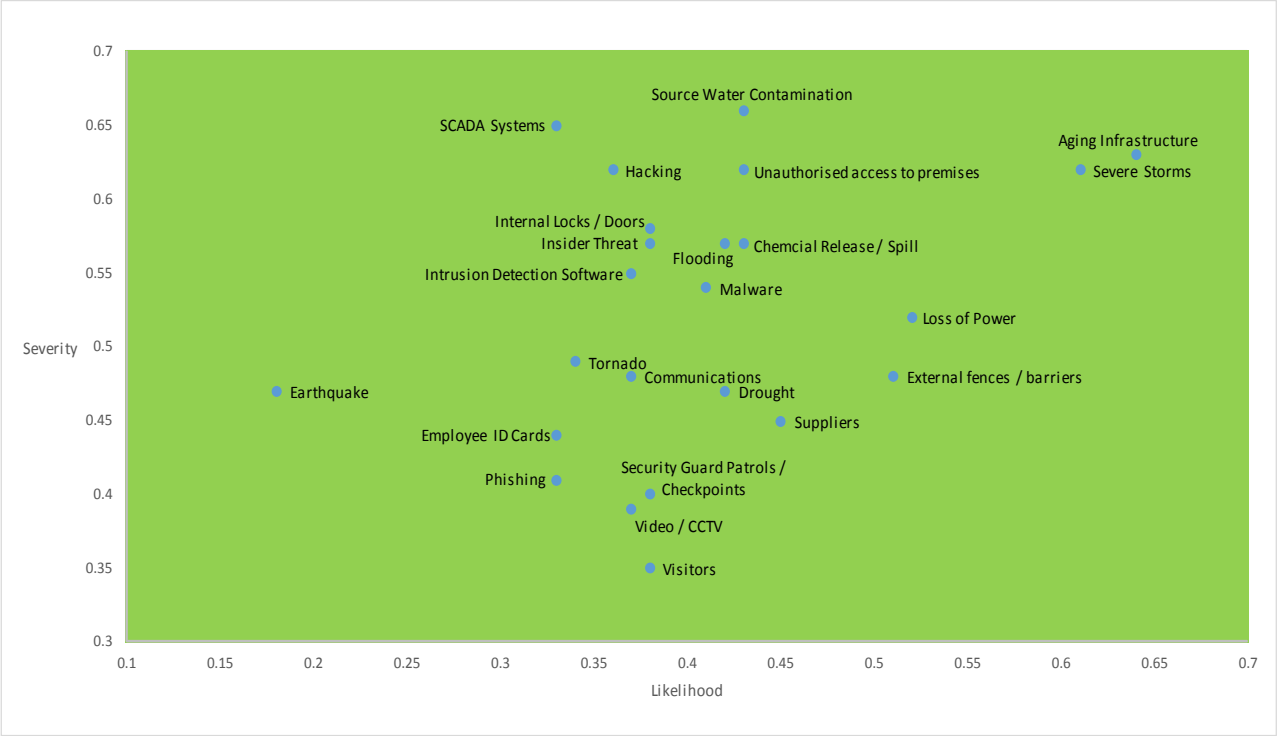

Figure 9: Mean Likelihood and Severity Ratings

As can be seen in Figure 9, aging infrastructure and severe storms occupy the upper-most right-hand section of the risk profile, with mean likelihood and severity ratings all in excess of 0.60. This suggests that aging infrastructure and severe storms should be a high priority for risk management. Loss of power also occupies the upper right-hand section of the risk profile, but with mean likelihood and severity ratings of just over 0.50. This suggests that loss of power should be a medium priority for risk management.

Other hazards, threats, defences and systems were given high (i.e., greater than 0.60) severity ratings but low (i.e., less than 0.50) likelihood ratings. They are: SCADA systems, hacking, source water contamination, and unauthorized access to premises. This suggests that they should be a medium priority for risk management.

Internal locks/doors, insider threats, intrusion detection software, malware, flooding, and chemical release/spill were given relatively high severity ratings (i.e., greater than 0.50 but less than 0.60) but low (i.e., less than 0.50) likelihood ratings. This suggests that they should be a medium priority for risk management, albeit at the lower end.

Lastly, it should be pointed out that one defence, external fences/barriers was given a relatively high (i.e., greater than 0.50 but less than 0.60) likelihood rating but a low (i.e., less than 0.50) severity rating. This suggests that it too should be a medium priority for risk management, albeit at the lower end.

Figure 9 presents data for the 24 hazards, threats, defences, and systems rated in the survey. By visual inspection alone, it is difficult to discern any risk categories or coherent structure in terms of how the survey respondents perceived risk. Thus, an exploratory factor analysis was

conducted using the mean risk scores in Table 3. It yielded a five-factor solution, which was interpreted as 'Five Perceived Risks to Water Security'. These perceived risks are: physical access, cyber-related, water supply, other uncertain risks, and infrastructure-related.

The results of the factor analysis are presented in Appendix G. The first factor that emerged was physical access, comprising six items: unauthorized access to premises, external fences/barriers, internal locks/doors, security guard patrols/check-points, video/CCTV, and employee ID cards. The second factor was cyber-related, comprising five items: hacking, phishing/spear phishing/watering hole, malware, intrusion detection software, and SCADA systems. The third factor was water supply, comprising three items: chemical release/spill, source water contamination, and drought. The fourth factor was other uncertain risks, comprising four items: earthquake, visitors, suppliers, and tornado. The fifth factor was infrastructure-related, comprising three items: loss of power, severe storms, and aging infrastructure. It should be noted that three items (flooding, insider threats, and communications) did not load onto any of these five factors. This suggests that respondents perceived the risks associated with flooding, insider threats, and communications to be different somehow from the 'Five Perceived Risks to the Water Security'.

For each of the 'Five Perceived Risks to Water Security', likelihood and severity scores were calculated for each respondent by averaging together the respective, constituent items, as per the results of the factor analysis (e.g., the likelihood score for infrastructure-related was calculated by taking the average of the likelihood ratings for loss of power, severe storms, and aging infrastructure). Risk scores were then calculated by multiplying respective likelihood and severity scores. Table 4 displays the overall mean likelihood, severity, and risk scores for the 'Five Perceived Risks to Water Security.' Infrastructure-related risks yielded the highest risk score, and other uncertain risks yielded the lowest risk score.

Table 4: Mean Likelihood, Severity, and Risk Scores for the 'Five Perceived Risks to Water Security'

Risk	Likelihood	Severity	Risk
Infrastructure-related	.59	.59	.38
Water Supply	.43	.57	.27
Cyber-related	.36	.56	.22
Physical Access	.40	.49	.21
Other Uncertain Risks	.34	.44	.17

The mean likelihood and severity scores from Table 4 are displayed in a 2*2 plot in Figure 9. Infrastructure-related risk is the only risk to fall in the uppermost right-hand section of the risk profile with mean likelihood and severity scores both just under 0.60. This suggests that infrastructure-related risk should be a medium-high risk management priority. Water supply yielded a high (greater than 0.50) severity score but a low (less than 0.50) likelihood score, suggesting it should be a medium priority for risk management.

To compare the 'Five Perceived Risks to Water Security' to each other, a Repeated-Measures Analysis of Variance (ANOVA) was conducted. The results of the ANOVA found that overall there were significant differences between the five risk scores; $F(4,1404) = 168.57$, $p < .001$.

Further pairwise comparisons revealed that: 1) the risk score for infrastructure-related risks was significantly higher than the other four risk scores, 2) the risk score for water supply was significantly higher than those for physical access, cyber-related, and other uncertain risks, but as mentioned was significantly lower than the risk score for infrastructure-related risks, 3) the risk score for other uncertain risks was significantly lower than the other four risk scores, and 4) there was not any difference between the physical access and cyber-related risk scores.

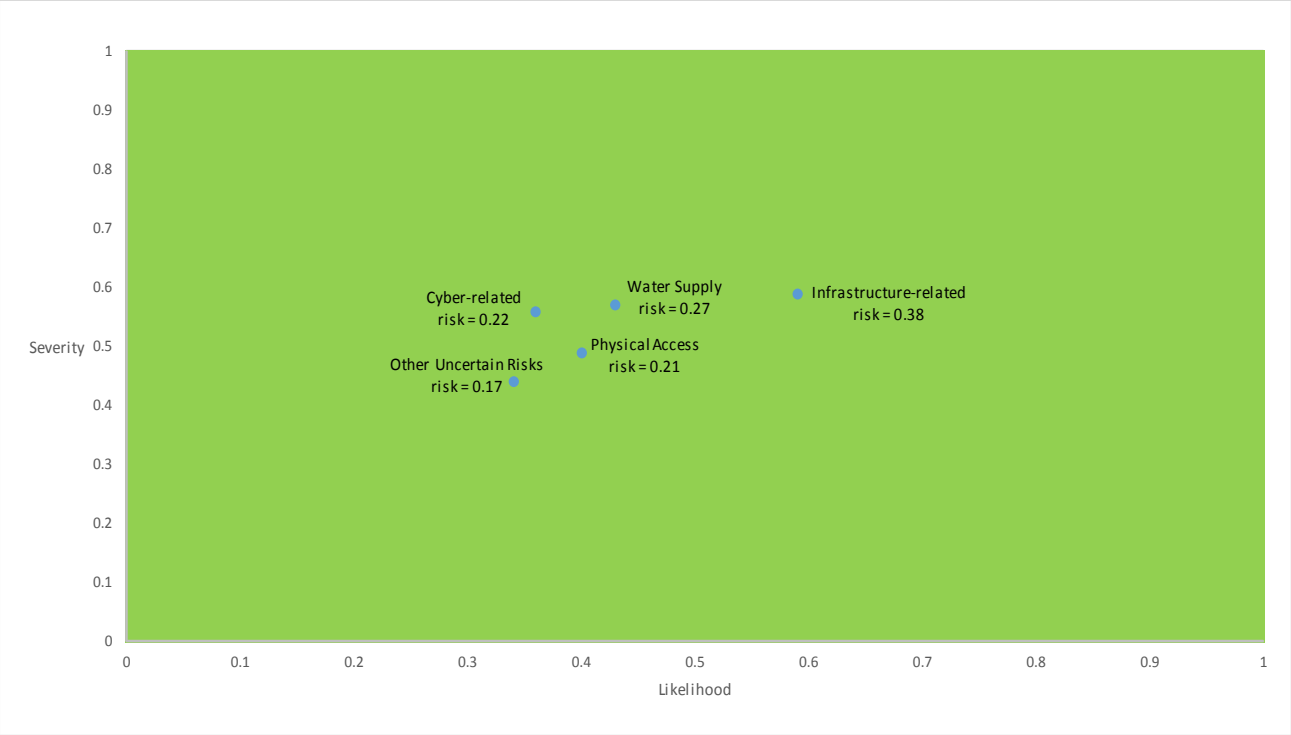

Figure 9: Five Perceived Risks to Water Security

Analyses suggest that employees from water and wastewater utilities that service large populations perceive more risk for physical access, cyber-related, and other uncertain risks than do employees from water utilities that service small populations. Another important finding is that senior and non-senior managers have shared perceptions about the risks to water security, apart from a small difference in risk perception for physical access. These risk scores are valid in that they form the basis for water utility employees' risk acceptance and security-related behaviours. Any disparity between objective risk data (as measured by the number or theoretical estimates of adverse events) and these perceived risk scores could be addressed through improved risk communication. Risk profiles by size of population serviced by a water utility, and by senior managers and non-senior managers are located in Appendix J.

Using Renn's classification of risks, infrastructure-related, water supply, and physical access were considered complex risks, while cyber-related and other uncertain risks were considered uncertain risks. Renn suggests that there should be different risk management plans for complex and uncertain risks. Complex risks involve many variables but operators typically have some experience with them and some reliable data to help them understand the likelihood of such risk events and how they might reliably reduce the exposure level. On the other hand, uncertain risks

are those for which there are few reliable data and operators typically lack experience with them. The likelihood that uncertain risks will manifest themselves is not necessarily low; rather, it is unclear. The next stage of our research will bring together multiple sources of data to consider how these risks can be managed as part of a more comprehensive framework.

6. Sector-Specific Workplan

6.1. Introduction

This section presents an overview of existing vulnerabilities in the Canadian water sector, and outlines potential goals and objectives to aid in mitigating these risks. It also outlines an implementation plan, as well as an exercise plan to test and validate actions taken.

It follows ISO 31000 standards, particularly 4.3, Design of Framework for Managing Risk (ISO 31000:2009). It established the general environments in which the risk is present; they have also established key trends in the water sector, as well as the Canadian water sector's internal context, in accordance with item 4.3.1. In establishing a risk governance framework, this section will put forward a rationale and objective in managing risk, in accordance with item 4.3.2. The section will also suggest concrete actions and policies that the CWWA and/or Canadian water sector could adopt in order to meet these objectives.

Item 4.3.4 of ISO 31000 also requires that risk management be embedded in all of an organization's practices and processes. The second recommendation, for a cultural shift within the sector, will aid in achieving this goal. As per ISO 31000 standards, all of the proposed actions in this section will need to be regularly reviewed for efficacy, updated, and re-communicated throughout the organization. The introduction of a risk management plan, or the adoption of these recommendations into an existing risk management plan would be the first step in an evergreen process of monitoring, evaluation, re-assessment, and adjustment.

The legislative and policy review conducted in September 2016 identified climate change, natural disasters, and growing water needs as some of the risks facing the water sector. It also provided an overview of each province's and territory's water governance frameworks, including required communication with the public, emergency planning and protocols, and the involvement of the private sector in water delivery and testing. Interviews conducted on the basis of this research found that standards and regulations, operators and training, aging infrastructure, flooding, and cyber-security were the most common risks raised. The online survey confirmed these findings, establishing five perceived risks to water security among respondents: infrastructure, water supply, cyber-security, physical access, and other uncertain risks.

6.2. Goals

Following the ISO 31000 framework, this report's recommendations for a risk management framework provide a whole organization approach, serving as policies that can be embedded into organizational processes (ISO 31000:2009). Based on previous research, interviews, and the online survey, we recommend that the water sector, through the CWWA or any other overarching structure: develop a constructive learning environment, develop codified risk practices, and increase transparency and public education.

Interview subjects offered varied assessments of the severity of the risks listed above. While some felt that they were adequately prepared for cyber threats, flooding, climate change, or had excellent staff retention, others indicated that they struggled in some or all of these areas, often severely. Our recommendations seek to draw on the knowledge that already exists within the

water sector to ensure that best practices are shared across all operators and utilities in a timely and accessible fashion.

We further recommend that information about risks be shared with the general public, as well as members of the Canadian water and wastewater sector. While interview respondents were asked to assess threats from external actors, they were more likely to note that irate customers, rather than any kind of protesters, were their primary concern – and that proactive public education and awareness was their chief tool in solving the problem. More information on public education and risk tolerance is provided below.

When asked what they would do with an extra day to work per month, most interview respondents said that they would spend it learning about or planning for risks. Facilitating the transfer of knowledge between existing utilities, and providing a better understanding of risks and how to develop plans to manage them would meet the needs of these interviewees. A majority of respondents also indicated a strong willingness to learn from other utilities and colleagues in the sector. A formal approach to this process will ensure that that all utilities can access the knowledge that already exists in their networks.

6.3. Small versus Large Utilities

As outlined in the summary and analysis of the interviews conducted, smaller utilities expressed less anxiety about risks, compared to their larger counterparts. Many of the small utilities interviewed noted that they had not considered specific risks, or areas of risk management; others indicated that they felt they did not have the time or resources to properly assess given risks, or that they were lacking in expertise. There is a lack of reliable data regarding the risks facing small Canadian water utilities, making it difficult to verify if smaller utilities do face fewer or less severe risks than their larger counterparts.

The recommended actions below should take into consideration the potential difference between small and large utilities. While we cannot verify that smaller utilities are less prepared to respond to risks, or face fewer risks than other utilities, there was a general willingness to learn from other utilities among respondents from small utilities, while many larger utilities noted that they either already do or are willing to provide support, resources, and training to those in their region or network.

6.4. Mitigation Actions

Below is an overview of our suggested goals, as well as recommended mitigation actions to achieve them.

- Adopt a risk categorization framework: Renn's *International Risk Governance Framework*. Categorize, understand, and respond to risks based on what we know about the them.
- Create a constructive learning environment within the water and wastewater sector by: creating a knowledge commons for the sector, empowering water organizations to share and seek information (including aggregate vulnerability information through PSC's

Regional Resilience Assessment Program (RRAP)) about the risks they face, and to learn from organizations facing similar risks.

- Develop codified risk practices: adopt standards like ISO 31000 to ensure that risk practices are formal and accessible to all organizations within the sector.
- Increase transparency and public education: consider broader sharing of risk information, including aggregate RRAP data, with stakeholders including emergency management organizations and P/T entities to increase knowledge of specific vulnerabilities within organizations with a role to play in the resilience of the water sector.

Adopt a Risk Categorization Framework

Renn's Risk Framework has guided our research and report, proving easily adaptable to the risks that the Canadian water sector faces. Developed by IRGC, the framework divides risks into four categories, based on knowledge available about the risks [66]. The state of knowledge about the risk then determines the course of action in the risk governance process.

Adopting Renn's Risk Framework would provide a clear and internationally recognized framework through which the Canadian water sector could evaluate not only the risks that it faces, but also the type and quality of information available about them. Below is a summary of the frameworks' four types, as well as a brief study of how each could be implemented.

Risk Types

The framework identifies four types of risks: Simple, Complex, Uncertain, and Ambiguous. Though they share characteristics, they are qualitatively different and should be treated accordingly. The online survey found five perceived risks: Infrastructure-related, Water Supply, Cyber-related, Physical Access, and Other Uncertain Risks.

According to Renn's framework, infrastructure-related, water supply, and physical access risks are complex risks because they are all driven by complex relationships among a wide range of variables that are difficult to quantify and understand. Risks to the water supply, for example, could include source water contamination, droughts, or chemical releases, presenting a variety of triggers for the risk. In our survey, complex risks were ranked highly on the risk register, though respondents tended to be more familiar with these risks. Respondents' solutions for the risks were arguably more straightforward because of this pre-existing knowledge, as well as the associated reliable data available. The existing familiarity with these selected complex risks mitigates some of the threat they pose, reducing reliance on scientific consensus in dealing with the risks as operators rely on their own established best practices instead.

Renn's framework would classify cyber-related risks as uncertain risks because of a lack of knowledge available about the risk itself. In this case, cyber-related risks in particular are likely to be considered uncertain because they are relatively recent developments in the water and wastewater sector. Uncertain risks like cyber-security threats are also unpredictable and potentially unavoidable. They require that operators be able to adapt their systems or reverse critical decisions once the risks have come to pass, as information about the risk may only become available at that point.

Ambiguous risks, include political risks and values conflicts were mentioned very infrequently by both interview and survey respondents, and yet are the most likely to raise significant conflict for respondents. Interview respondents generally indicated that ambiguous risks like environmental protestors rarely, if ever, occurred. If serious values conflicts did arise, as has happened in Canada most recently with proposed pipelines, risks would need to be managed through discourse and consensus-building among stakeholders.

Complex Risks

Complex risks are "often associated with major scientific dissent about complex dose-effect relationships or the alleged effectiveness of measures to decrease vulnerabilities [66]. They require that organizations act on the best available expertise to increase their ability to absorb risks. Organizations may alter their day-to-day operations to build the ability to absorb complex risks as they occur, increasing their robustness or buffer capacity.

Complex risks included in the survey included infrastructure-related risks (e.g., aging infrastructure, loss of power, and damage due to storms) and water supply risks (e.g., source water contamination, chemical release/spill, and drought), and physical access (e.g., unauthorized access, breach of external barriers and internal locks/doors, breach of security guard check-points and CCTV, and ID cards).

In Renn's framework, appropriate tools for managing or mitigating complex risks are those that build an expert consensus, bringing together people with experience or knowledge of the risk and drawing on their expertise to determine the best course of action. Solutions may include meta analyses or scenario construction to properly use available knowledge [66], or additional safety factors, built-in redundancy, or improved coping capacity to prevent complex risks from having a significant impact on an organization when they do occur. The framework highlights that relevant internal staff from the organization as well as external experts, to ensure a full understanding of both the risk and the solution [66].

Once implemented, solutions or mitigation plans for complex risks would have measurable impacts over time. Actions to reduce leaking systems, for example, would produce a noticeable reduction in water loss and costs savings if successful. These actions would also improve the overall robustness of the system. While these types of risks are introduced because of their complexity, and the requirement for outside expertise, they may also be modeled and can produce quantifiable results.

Kahneman argues that there are two basic conditions for acquiring a skill: 1) an environment that is sufficiently regular to be predictable, and 2) an opportunity to learn these regularities through prolonged practice [259]. Risk assessment is a skill and, like all skills, development of expertise is slow because expertise in a domain is not a single skill but a large collection of mini-skills.

Complex risks are examined largely on the basis of expert opinion and formal modelling. As many complex risks are regularly occurring (e.g., spring flooding), with sufficient experience, people can become expert risk assessors of complex risks as they meet Kahneman's two basic conditions for skill acquisition. Similarly, expert opinion may not be successful in mitigating uncertain risks because uncertain risks are not predictable enough to produce adequate learning

environments. Simulating these types of environments through tools like knowledge commons could provide a solution to this challenged, as outlined below.

Uncertain Risks

With uncertain risks, "knowledge is either not available or unattainable due to the nature of the hazard...knowledge acquisition may help reduce uncertainty" [170]. Uncertain risks require precaution-based and resilience-focused strategies. To combat uncertain risks, organizations must be able to reverse critical decisions when risks materialize, and must establish a capacity to withstand surprises. Uncertain risks are unpredictable, though they may be deterred by identifying particular vulnerabilities within the organization. Risks in this category included in the survey include cyber threats, natural disasters, and those acting with malicious intent, including insider threats.

Addressing uncertain risks involves using tools to estimate the potential for risk, either by containing parts of a system that may be prone to risks that cannot be prevented, or by attempting to eliminate as many potential causes of risks as reasonable while recognizing that the potential for risk will remain. A system that increases resilience will avoid high vulnerability, allow for flexible responses, and will be prepared for adaptation once risks do occur [66].

As in complex risks, staff from the organization and external experts should be included in risk planning or mitigation efforts. Uncertain risks also require that stakeholders be consulted, including industry representatives and groups that could be directly affected by a risk. These actors would participate in reflective and evaluative risk assessments, seeking to understand what the potential impacts of a risk may be, in addition to determining how likely the risk is to come to fruition [66].

We expand on our suggestion to create a constructive learning environment below. It would be one possible response to aid in reducing uncertain risks, bringing together staff, experts, and stakeholders to exchange information about risks and determine how likely they are for a given organization. Performance metrics for this action could include a survey of users of the learning environment, to evaluate whether they feel it is productive, or to determine how frequently they use it, and how often it is able to solve their questions. A more constructive learning environment would also increase the available data pool for low-probability risks, create more effective responses to uncertain events, and provide better access to expertise concerning uncertain risks. This could be measured either through interviews or a survey, to assess organizations' resilience and adaptive capacity. Equally, greater participation by the water sector in RRAPs may also lead to increased learning about uncertain risks and 'best practice' responses from across the sector.

Ambiguous Risks

Ambiguous risks are those in which the information available is either disputed or interpreted differently by stakeholders within society; this may be caused by conflicting values of what should be protected or reduced in order to address the risk [66]. These risks require predominantly discourse-based strategies that resolve conflict through internal consensus, eliminating the conflicting values to simplify the risk to be solved.

Ambiguous risks included in our interviews and previous reports included fracking and environmental protestors; respondents largely did not see environmental protestors as a threat. Those who had had experience with protestors found information sharing and consensus building to be the best methods of resolving the threat, de-escalating protests by providing additional information to customers or members of the public in order to achieve consensus.

As referenced above, ambiguous risks are best solved through discourse-based solutions that focus on conflict resolution and create consensus. These require that stakeholders be included in the risk management process, and that they communicate between themselves. Performance metrics would include a decrease or successful resolution of conflicts; with the ambiguous risks examined in this study, this could include fewer protests or complaints about a service. Performance metrics can also focus on processual matters, including how often the key stakeholders meet to share views.

As evidenced in our literature and policy review, ambiguous risks within the water sector seem to be growing, stemming in part from the environmental movement. These risks include debates over balancing commercial water use with environmental protection, as well as over energy resource extraction, particularly fracking, against maintaining the quality of drinking water. These are growing debates in Canada, but were not raised by our interview respondents. The literature and policy review found that most of these topics were being discussed at the provincial and federal levels, and were predominantly being resolved through legislative means in the absence of any clear societal consensus [209]. While these risks certainly pose a threat to individual organizations, the responsibility for managing them appears to currently rest with other actors. Some of these emerging trends may develop into uncertain, rather than ambiguous risks as consensus is achieved – for example, a consensus to allow fracking near a water supply would resolve the conflict, but would create a potential threat to the water supply.

Create a Constructive Learning Environment within the Water Sector

Based on Douglas and Wildavsky's work on the same topic, Hood refers to four organizational types: hierarchical, egalitarian, individualist, and fatalist. He defines egalitarian organizations as those that have local, communitarian, and participative organizations; authority resides with the collectivity [256]. A majority of respondents to both our interviews and online survey indicated that the sector as a whole has strong egalitarian tendencies; respondents indicated that they are open and willing to share information with their counterparts in other organizations, and that they do not see themselves as being in direct competition with these other organizations.

Egalitarian organizations exist in non-competitive sectors, and will share information and learn from each other. According to Hood, in these sectors there is little difference between the views held by employees at the top and bottom of the organization, where top managers and front-line workers are likely to share the same understanding of potential risks; the online survey confirmed this was the case for the water sector.

While these organizations also tend to be willing to share information within their sector, they tend not to be outwardly transparent beyond the sector, which can be a challenge for the purposes of democratic governance. Equally challenging, in a country like Canada, egalitarian

organizations may also share information with other water organizations when in fact the experiences across the country are quite different. There is, for example, considerable variation in risk exposure based on geography, size, or other local characteristics; this makes it potentially difficult to establish best practices across the country.

Egalitarian organizations, as well as respondents to our interviews, indicated that they prefer to learn from 'one of their own,' facilitating knowledge sharing but making gathering knowledge from outside experts more difficult. New and developing threats, like cyber-security within the water sector, require that the sector actively seek out expertise and share it internally, across organizations of all sizes. Group sharing and learning is also a necessity, in addition to online posting. Many respondents to the interviews indicated that in-person conferences were a primary source of new information, while face-to-face engagement provides heightened accountability.

Create a Knowledge Commons for the Water Sector

Adopting a formal risk framework and distinguishing risks based on the knowledge and quality of data available would enable organizations create to risk management plans appropriate to the risk. It would also aid in determining which type of information or expertise is required, facilitating the use of a knowledge commons for the water sector.

The water sector in the US has developed a WaterISAC, to facilitate information sharing between organizations and coordinate responses to risks. We recommend adopting a similar online structure in Canada, to provide regular online training as well as information sharing between organizations.

Many of the interview subjects expressed a clear interest in learning from other water service providers, and were open to cooperation not only with other organizations but bodies like the CWWA and PSC. These organizations would be ideal providers of training, while groups, like provincial regulators, that appeared at times to have tense relationships with organizations, would be less likely to be successful.

Developing a water ISAC could benefit small utilities in particular, by ensuring a regular flow of knowledge to equalize the resources available to certain organizations. Informal information sharing and training opportunities were evident throughout our interviews, but were available only on a sporadic basis, depending on the organization and its relationship with other local utilities. Further surveys of ISAC users could be done to establish the usage and usefulness of the tool, as well as any associated decreases in risks posed to the organizations.

Aggregate RRAP data can also help achieve this goal. RRAPs are intended to facilitate the exchange of information, communicate standards, and nudge people to improve performance while at the same time protecting individual facilities from having their vulnerabilities disclosed outside their organization. While individual assessments can help a specific facility improve its resilience (but cannot be widely shared), anonymized and aggregate data from all facilities can and should be shared with relevant stakeholders including water associations, emergency management organizations at the municipal and P/T level, and other relevant F/P/T entities.

RRAPs are also conducive to egalitarian dynamics, providing collective assessments and encouraging organizations both to match the level of safety or security that exists across their network and potentially to reach out to organizations they know to be more advanced for expertise and guidance. RRAPs would also provide clear metrics by which to track the progress of individual organizations.

Develop Codified Risk Practices

As outlined in the summary of interviews, many of the respondents were not comfortable discussing risk management, stating that they had not yet given thought to a particular risk or management strategy, or that they did not have formal plans or policies in place. Some respondents also appeared to be unfamiliar with industry risk management plans, referring exclusively to their own risk management policies rather than to regional, provincial, or federal frameworks to govern risk.

A significant proportion of respondents indicated that most of their learning opportunities about risk came from on-the-job experience. While these respondents may not be confident in discussing formal risk management strategies, they nevertheless have valuable accumulated experience and knowledge in managing risks that is likely reflected in their practices, without being formalized.

The practice of informal knowledge exchanges is particularly problematic in areas with high staff turn-over, a risk identified as a top priority for a number of respondents, particularly in smaller communities and in the North. Developing codified risk practices would ensure that organizations with high staff-turnover would have a greater degree of institutional memory and would better enable knowledge sharing between organizations. These practices would both draw from and aid in adhering to local, provincial, and federal guidelines, as well as established best practices from other organizations. The ISO 31000 provides a potential framework for developing these kinds of codified risk practices, allowing organizations within the sector to harmonize their existing practices using a consistent approach.

Increase Transparency and Public Education

As outlined above, increased transparency and public education could aid in resolving ambiguous threats. It could also encourage collective accountability at the organizational, group, community, or regional level by ensuring that organizations are accountable not only to the public but also to others within the water sector. This would require some level of disclosure and reporting to the public, a trend that the legislative and policy review has already begun in many provinces. Organizations that have already implemented measures towards this goal have evaluated their success through customer satisfaction surveys as well as customer engagement levels, noting that the public tends to view water and wastewater organizations more favourably after public education campaigns [109].

6.5. Next Steps

When considering complex risks, there is a tendency to focus on expert opinion. As examples of ambiguous risks above demonstrate, it is also important to understand the public’s opinion of and tolerance for given risks.

Opinion on the state of the Canadian water sector is divided; there are strong movements representing environmental concerns, including fracking, coupled with strong resistances to rate or tax increases, even if necessary to ensure the quality of the water supply and sewage treatment. It is difficult to determine the magnitude of the risk posed by these attitudes without more empirical data. While we can discuss the consequences of failures, we do not know their probability, and thus cannot reliably measure the risk. Further study of other stakeholders in the industry, as well as the public, would help to determine the potential for this risk.

Our study had staff estimate the probability of events occurring. While their expert opinion is a foundation for risk assessments, it should be confirmed by performance data available in the public domain about failures and risks as they have occurred. Industry-wide data, pooled from members of the CWWA, would provide a clearer understanding of the magnitude of given risks, uncertain risks in particular. This additional research would further enrich this study, and ensure that resources are appropriately allocated towards the most severe or likely risks.

Appendix A: Risk Profile Sample (Questionnaire)

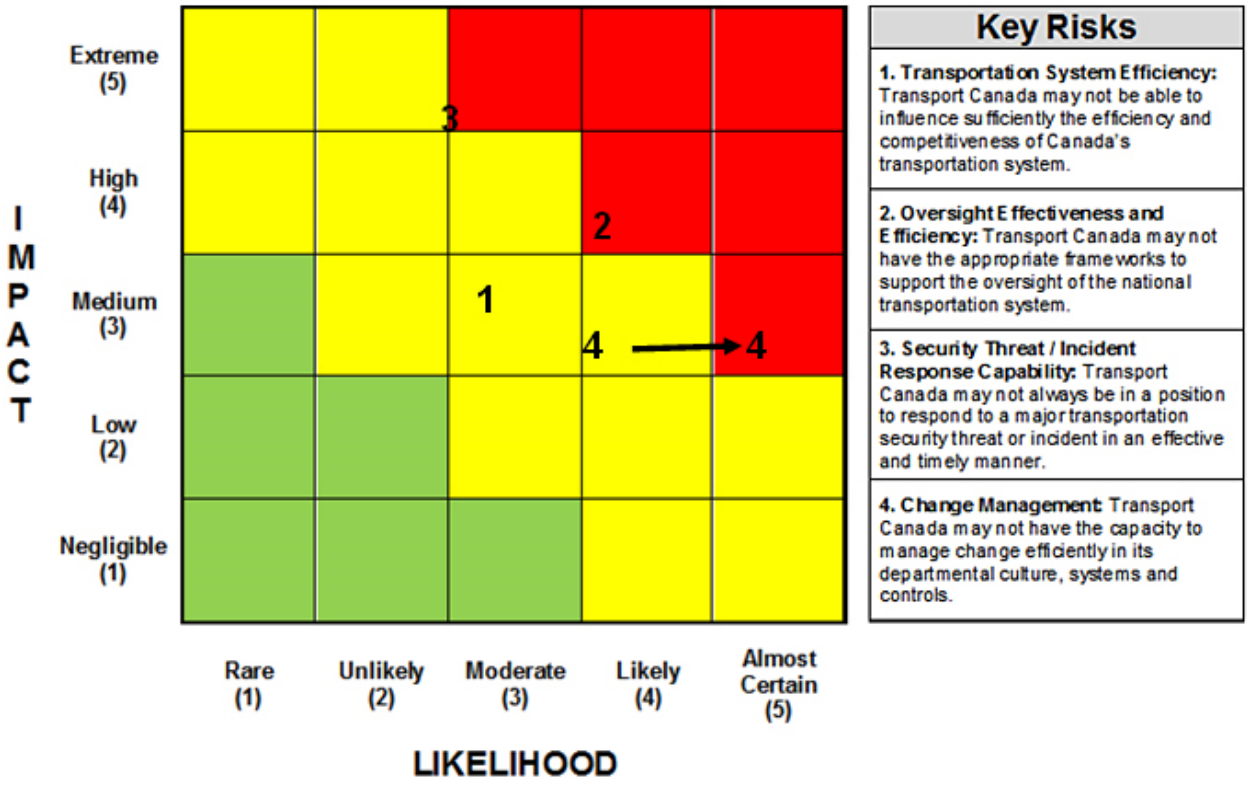

Figure 1: Transport Canada's Corporate Risk Profile (as revised in February 2012) [258]

Appendix B: Letter of Introduction

To whom it may concern,

The MacEachen Institute for Public Policy and Governance has partnered with the CWWA to research water security and safety in Canada. As a result, we are conducting a number of interviews with operators and regulators in the Canadian water sector. You were chosen as one potential interview subject, and we hope that you will be able to participate.

The research and interviews are being led by Dr. Kevin Quigley, Director of the MacEachen Institute at Dalhousie University. Our interviews are designed to take a half hour to an hour to complete. If you are able to participate, we are able to schedule an [in person/telephone] interview at your convenience. All information collected in the interviews will be kept anonymous, and we will not share any identifying information in our reports or publications.

Results from the interviews will help us to better understand the needs and priorities of water facility operators across Canada. Through the course of our research, and in these interviews, we hope to uncover best practices, effective policies, and security measures that can be shared with other water facility operators, in order to improve the overall security of the Canadian water sector.

We will follow up with you to schedule an appropriate time to contact you. If you have any further questions about the interview, or about our research, you can contact Dr. Quigley at kevin.quigley@dal.ca.

We hope to hear from you soon.

Sincerely,

Kevin Quigley, PhD
Director, MacEachen Institute for Public Policy and Governance
Dalhousie University
kevin.quigley@dal.ca
902 494 3782

Appendix C: Confidentiality Letter

To whom it may concern,

Thank you for agreeing to participate in our survey of Canadian water operators and regulators. This interview will form a key part of our research, enabling us to better understand the current needs and practices of the Canadian water sector.

In this interview, we would like to hear your thoughts and observations on safety and security practices and governance within your organization. The questions are intentionally quite broad. I am using the questions to guide our discussion but you should feel free to provide the information you feel is most relevant to the topic.

We adhere to strict research protocols throughout all of our research. I will send you a copy of my notes to allow you to comment on its contents and comment on its accuracy; we request that you provide any comments within one week from the interview. The information you provide will help us in our research, which will likely be published, in a report to the sector, as well as in academic journals and professional reports. All interviews are confidential. The transcript will only be seen by the lead researcher and research assistants, who have signed confidentiality agreements and are aware that all interviews are confidential. Your identity will not be revealed without your written consent. You can end this interview at any time, and your participation in this study is entirely voluntary.

This research is supported by Dalhousie University and the Canadian Water and Wastewater Association.

If you have any questions or concerns regarding your participation in this study, you may contract gwendolyn.moncrieff-gould@dal.ca, or kevin.quigley@dal.ca.

Sincerely,

Kevin Quigley
Director, MacEachen Institute for Public Policy and Governance
Dalhousie University
kevin.quigley@dal.ca
902 494 3782

Appendix D: Operator Questions

How is the water sector changing? What opportunities and threats does this pose?

What does your organization do well when it comes to managing risk? What could it do better?

Which risks cause you the greatest anxiety, and why?

Where do you get information about risks?

What arrangements (e.g., processes, committees, policies) do you have in place for managing risk? How well do they work?

Can you list examples of previous learning opportunities about risk within your organization? What did you learn? How did you learn?

To what extent do you depend on external organizations to fulfill your organizational mandate? What systems do you have in place for managing external relationships?

What standards (e.g., rules and policies) do you follow in managing risks? How effective are they?

Follow up; can you list the strengths and weaknesses of each set of standards and behaviours? Do these include laws, business continuity plans, supply chain management, public reporting and training standards?

I am going to list a series of risks. Score each on a scale of 1 to 10. 10 means you have a very robust plan, you are confident you have limited exposure, and, if exposed, the consequences would be limited. 1 means you do not have a plan, risk is high, and consequences would be serious. The rating is not an exact science but an impression; it is a way to communicate your overall impressions of the risk management plans and practices in place. Once you have rated the risk exposure, take a minute to explain your rationale.

1. Aging infrastructure
2. Flooding
3. Cyber
4. Insider threat
5. Environmental protesters
6. Source-water protection

What would you do with an extra day a month if you have to spend it on improving risk management?

What would you like to see come out of this report?

Appendix E: Regulator Questions

How is the water sector changing? What opportunities and challenges does this pose for regulators?

What does your organization do well when it comes to regulating risk in the water supply? What could it do better?

Which risks to the water supply cause you the greatest anxiety, and why?

How do you collect information about risks to the water supply?

What arrangements (e.g., processes, committees, policies) do you have in place for managing risk? How well do they work?

Can you list examples of previous learning opportunities about risk to the water supply? What did you learn? How did you learn?

To what extent do you depend on external organizations to fulfill your organizational mandate? What systems do you have in place for managing external relationships?

What standards (e.g., rules and policies) do you follow in managing risks? How effective are they?

I am going to list a series of risks. Score each on a scale of 1 to 10. 10 means you are confident in the manner in which risks are being addressed, and if there were a failure you would be confident in the response. 1 means that you do not have confidence in the manner in which the risks are being addressed, and you are concerned that if there were a failure, the response would be inadequate or you do not have a plan; The rating is not an exact science but an impression; it is a way to communicate your overall impressions of the risk management plans and practices in place by water service providers working with regulators. Once you have rated the risk exposure, take a minute to explain your rationale.

1. Aging infrastructure
2. Flooding
3. Cyber
4. Insider threat
5. Environmental protesters
6. Source-water protection

What would you do with an extra day a month if you have to spend it on improving risk management of the water supply?

What would you like to see come out of this report?

Appendix F: Summary of Risk Ratings

Below is a summary of responses to the final question of the interview. Responses are not an objective assessment of the likelihood of a given risk; rather, they represent a respondent's impression of the severity of the risk.

Size	Aging Infrastructure	Flooding	Cyber	Insider Threat	Environmental Protestors	Source Water Protection
100000+	8	8	9	7	8	
100000+	7	6	5	7	8	8
100000+	7	9	9	8	8	8
100000+	8	8	7			
10000-99999	5	6	7	4	8	6
10000-99999	7	7	9	9	10	5
10000-99999	6	8	8	8	8	5
10000-999999	3	8	8	8	7	4
1-9999	4	7	9	9	10	
1-9999	6	4	4	2	9	
1-9999	7	7	5	7	9	
1-9999	7	8	4	8	8	6
1-9999	5	5	8	1	9	8
Minimum	3	4	4	1	7	4
Maximum	8	9	9	9	10	8
Average	6.153846154	7	7.076923	6.5	8.5	6.25
Average (100000+)	7.5	7.75	7.5	7.333333333	8	8
Average (10000-99999)	5.25	7.25	8	7.25	8.25	5
Average (1-9999)	5.8	6.2	6	5.4	9	7

Appendix G: Results of Exploratory Factor Analysis

Rotated Component Matrix[a]

	Component				
	1	2	3	4	5
risk_unauthorised	.606	.238	.271		.227
risk_hacking		.819			
risk_loss_power					.820
risk_phishing		.714		.208	
risk_earthquake			-.262	.489	
risk_visitors	.416			.625	
risk_chemical_spill	.304		.565	.375	
risk_storms			.325	.453	.566
risk_suppliers	.204		.452	.597	
risk_source_water_contam		.211	.727		
risk_tornado			.240	.599	
risk_malware		.841		.262	
risk_aging_infrastructure			.328		.662
risk_drought			.643		.258
risk_external_barriers	.760				.239
risk_internal_locks_doors	.794				
risk_patrols_guards	.772			.265	
risk_video_cctv	.772	.240			
risk_intrusion_detect_software	.333	.701	.200		
risk_SCADA	.268	.601	.444		
risk_ID_cards	.570	.427	.248	.213	

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 9 iterations.

Appendix H: Risk Profiles by Size of Population Serviced by a Water Utility

Table J1: Mean Risk Scores for the 'Five Perceived Risks to Water Security' by Size of Population Serviced

Risk/Population Size	<50K	50K-100K	100K-200K	200K-500K	500K+
Infrastructure-related	.35	.40	.40	.47	.37
Water Supply	.23	.32	.27	.31	.28
Cyber-related	.17	.22	.25	.25	.24
Physical Access	.17	.23	.23	.25	.23
Other Uncertain Risks	.13	.17	.18	.22	.19

Table J2: Mean Risk Scores for the 'Five Perceived Risks' for Senior Managers (n = 157) and Non-Senior Managers (n = 195)

Risk	Senior Managers	Non-Senior Managers
Infrastructure-related	.37	.38
Water Supply	.25	.28
Cyber-related	.20	.23
Physical Access*	.19	.22
Other Uncertain Risks	.16	.17

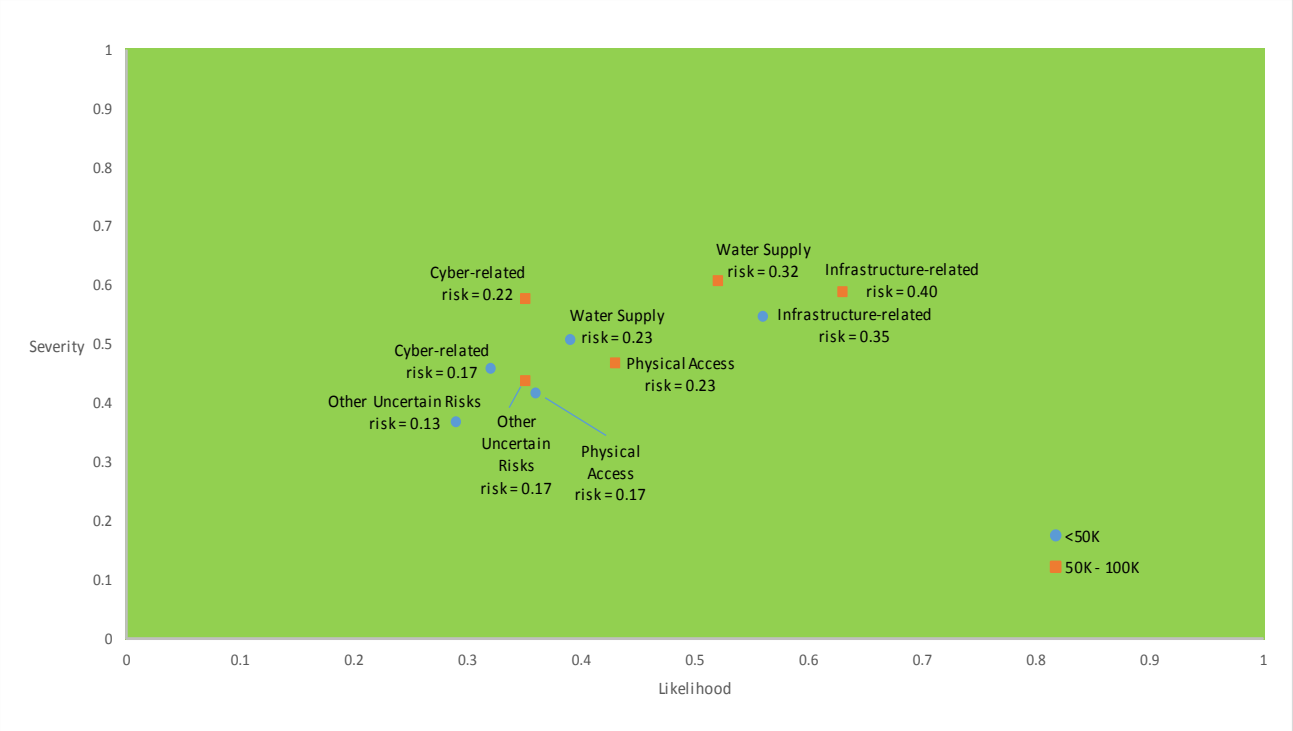

Figure J1: Five Perceived Risks to Water Security – Small Population Serviced

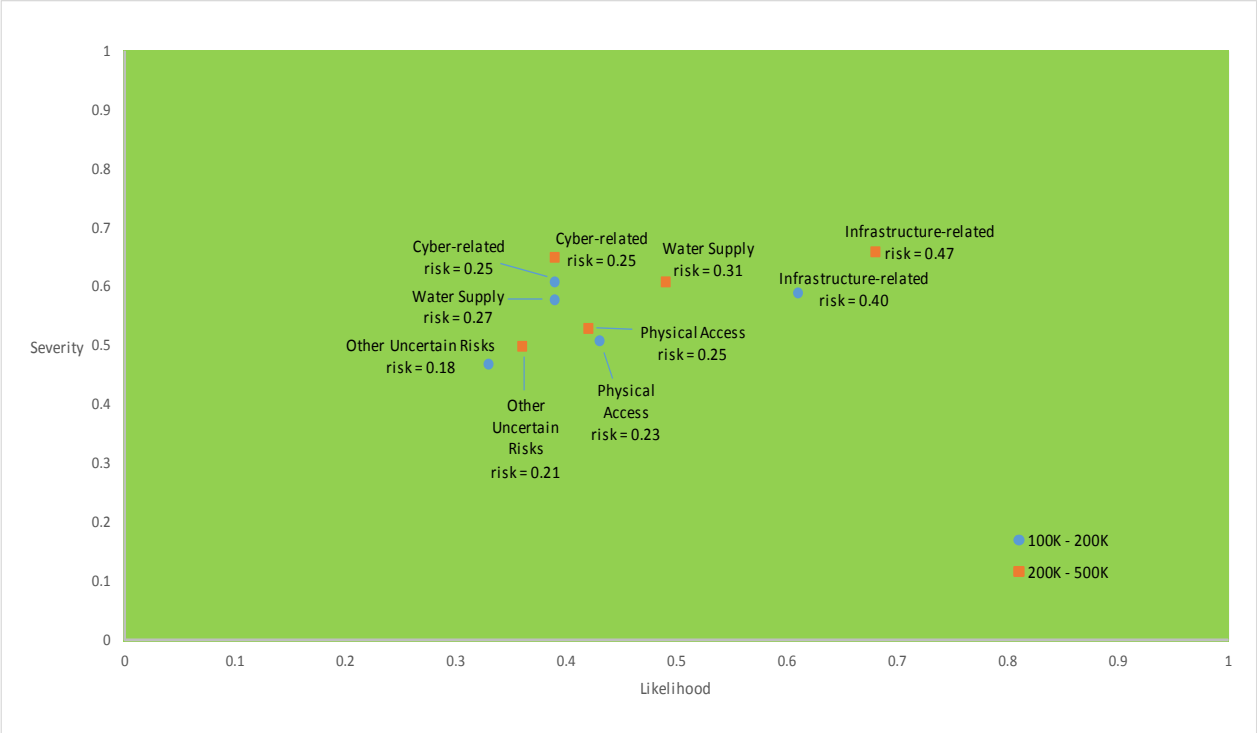

Figure J2: Five Perceived Risks to Water Security – Medium Population Serviced

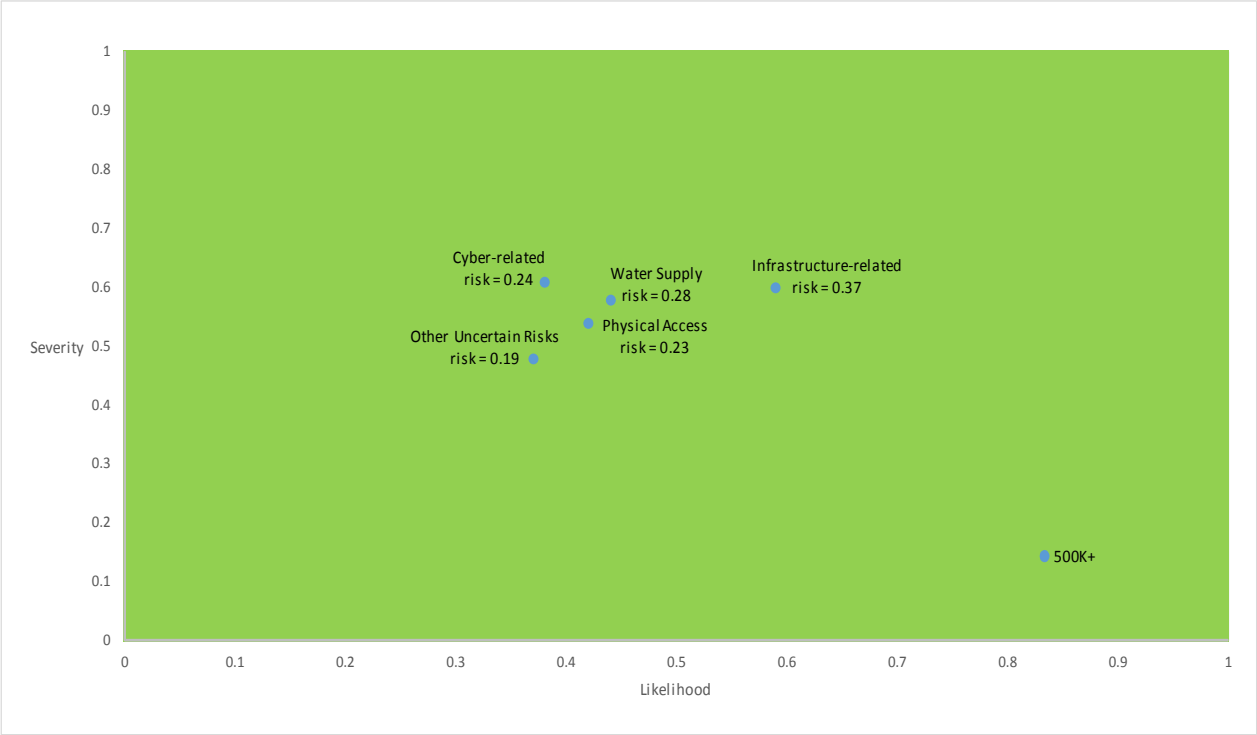

Figure J3: Five Perceived Risks to Water Security – Large Population Serviced

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Addendum: Water Sector – Cyber Threat Landscape

The following section was produced by Public Safety Canada, in conjunction with the CWWA, as an addendum to the above report.

Water Sector – Cyber Threat Landscape

This analysis is being included to provide a summary of the general threat landscape regarding the water sector and the cyber threats it is facing. It has been developed using open-source documents from both Canada and the United States.

What is the Water Sector?

The water sector is a highly integrated, multi-faceted, and complex sector. It encompasses various critical services such as the water supply for industrial and commercial industries, potable sources for consumption, and wastewater treatment and removal. These services are essential for preserving the health, safety, security, and economic well-being of Canadians.

What are the Cyber Systems in use by the Water Sector?

Computer networks and systems play a particularly vital role in maintaining the effective operations of the water sector. If these systems are disrupted or rendered inoperative they can have potentially catastrophic results for everything that depends on water. The sector relies on multiple types of process control systems to monitor and control continuous and repetitive functions within the production process. This includes: numerous upstream and downstream processing systems, communications infrastructure, and distribution networks that require continuous monitoring and maintenance.

As with other critical infrastructure sectors, the water sector is facing new challenges related to the rapidly expanding domain of cyber-security. Rapid technological development is putting new pressures on organizations and, as a result, many may find it a challenge to protect against.

The water sector utilizes computerized processes and control systems to efficiently run operations. These systems, like all computer networks, are vulnerable to a wide variety of threats, including hacking, intrusions, viruses, data alteration, and data loss.

Why is the water sector particularly vulnerable now?

Every CI sector displays some characteristics that render it vulnerable to certain kinds of attacks or a particular set of threats. The combination of these threats and vulnerabilities result in specific risks to a sector.

Vulnerabilities can contribute to risks in several ways: 1) vulnerabilities can increase the probability of an incident occurring against a specific asset; 2) they can increase the possibility of an asset being compromised or disrupted by an incident or attack; and, 3) they can increase the severity and/or impact of an incident.

The following two (2) characteristics are generally recognized as being the principle vulnerabilities for the water sector:

Reliance on SCADA, PCS, and ICS

The water sector depends on SCADA, Process Control Systems, and ICS to successfully carry out its primary business functions. These systems allow for the monitoring of source water, treatment processes, and delivery to end users. Reliance on these systems poses many challenges as these systems can be particularly vulnerable to all manner of cyber-attacks.

Over the last 15 years many critical infrastructure sectors began integrating their ICS and SCADA systems with the internet of things (IoT) or other remote administration devices. The business demands of the 21st century made it necessary to integrate ICS and SCADA systems to networks so that operators could perform their tasks remotely[1]. For example, smart water meters have been deployed across residential neighborhoods and treatment plants to monitor water usage or check for signs of contamination. These devices communicate with one another over the internet to monitor and compare information and route it back to a central database for analysis.[2] By integrating IoT devices throughout their facilities and connecting them to their ICS and SCADA networks, owners and operators have provided hackers and criminal avenues of access to these previously inaccessible systems.

Research studies uncovered that 220,558 ICS components can be accessed from the internet on 188,019 hosts throughout 170 countries[3]. It was noted that the most widespread types of available components were Industrial network devices which included: industrial routers; industrial gateways; programmable logic controllers (PLC); and, SCADA systems[4]. While individual water facilities use multiple types of components and devices, generally speaking, PLC and ICS systems form a significant portion of the control systems in the water sector across Canada.

Supply Chain Management

Drinking water systems throughout Canada are highly distributed by design with interlocking components that include: water supply systems (rivers, aquifers, lakes, wells, dams, and groundwater), water treatment, distribution, and control systems. The sector also relies on numerous interconnected supply systems such as filtration plants, reservoirs, wastewater facilities, and pumping stations before water is supplied to consumers at large. It is vital to ensure these upstream systems are as secure as their larger counterparts as all are susceptible to both physical and cyber based attacks. This however can prove to be a daunting task as many

smaller providers do not possess the financial resources or technical knowledge as their larger counterparts.

The New Cyber Reality: The Internet of Things

There has been significant growth in the development and proliferation of internet accessible devices over the past 15 years and this trend is expected to continue reaching an estimated 34 billion devices by 2020.[5] Of particular note is IoT. The IoT is an ever evolving system where an increasing number of electronic devices are being connected to the internet. Devices such as smoke detectors, radios, home appliances, sensors, etc., now have the ability to access the internet and communicate with each other.

The IoT allows objects to sense, detect, and communicate with each other across network infrastructures. It is the integration of computer based systems into physical objects. When many of these smaller objects are linked together they form the basis of what is known as 'cyber-physical systems'.[6] Examples of cyber-physical systems currently in operation include: smart grids, and auto-pilot functions for aircraft. At the extreme, cyber physical systems can even become fully autonomous with no need for human operators and rely solely on sophisticated algorithms and related IT networks and infrastructure e.g., self-driving vehicles.

This new cyber reality increases efficiency by minimizing human interactions with systems and components, however, a whole new set of vulnerabilities are created. For example, a consequence of this emerging system is that if not properly protected, these IoT devices have the potential to be compromised by all types of internet based threats. Cyber criminals can leverage these new access points to gain entry into larger information technology (IT) and operational technology (OT) systems. Presently, many of these IoT devices have poor security features or security features that are not properly activated. In some cases owners may neglect to change the default security settings or password protections. This simple oversight can easily allow these devices to become infected and become part of a larger BotNet.[7]

Recent compromises of devices and assets via the IoT include; Fiat Chrysler having to recall 1.4 million vehicles after it was shown they could be controlled remotely; medical devices such as insulin pumps and x-ray machines being compromised and their operating systems reprogrammed, Smart TV's being infected with malware and used to gather personal information, and a large scale DDOS attack against the DNS provider Dyn via internet connected devices such as IP cameras, printers, and baby monitors.

IoT and the Water sector

The water sector is dependent on its network of ICSs to maintain and manage water flows for cities and communities across Canada. Many of their related SCADA systems were originally designed under the assumption that they would be physically isolated or air gapped, thus creating

the situation where unauthorized access was assumed to be difficult if not impossible.[8] Many of these systems as a result, do not have basic user or operator security controls installed.

In addition, many older ICS and SCADA systems found in the water sector can be upwards of 30 years old.[9] As such, they can be prohibitively expensive or overly complicated to retrofit to include modern security and protective measures. As a result, IoT devices can be used as a gateway to obtain access and control of these previously isolated systems.[10]

Previous Cyber-Based Attacks on the Water Sector

Opportunities for malicious cyber based attacks against organizations are increasing and the water sector is not immune. In the United States, DHS lists cyber events as one of the most significant risks facing their water sector.[11] In 2015, in the United States alone, 25 water utilities reported cyber incidents to ICS-CERT.[12] Many other attacks however can go unreported or even undetected and those reported for the water sector have the potential to be damaging to both the environment and public health. The following represents a snap shot of some high profile attacks that have been directed towards the water sector in the last 15 years.

- In 2001, a disgruntled employee from a SCADA software vendor hacked into an Australian wastewater treatment plant and released 260,000 gallons of raw sewage into local rivers;[13]
- In 2006, a foreign based hacker successfully infiltrated a water treatment plant in Pennsylvania in order to distribute Malware;[14]
- In 2013, in Rye, New York, a control dam which operated pumps and disinfected drinking water was breached via a hacker seeking information about the dam's operating system;[15]
- In 2016, a water treatment plant referred to only as 'Kemuri Water Company' was breached by hackers who proceeded to alter the level of chemicals used to treat tap-water. The attackers were able to gain access because the water company relied on an outdated server from 1988 to run their IT network.[16]

Such incidents serve to demonstrate that these types of problems are only going to increase over the coming years. Hackers, cyber criminals as well as security organizations are taking note of current vulnerabilities in IoT devices. They are starting to view them as relatively easy routes for attacking or gaining access to an organization and its critical IT or OT systems. In some cases these IoT or other mobile devices can be challenging for incident response staff to properly secure.[17] In many cases these devices are installed without the organizations' IT department being informed.

Non IoT-based Attacks

While the IoT represents the latest frontier for criminals to conduct cyber based attacks, many of the more traditional cyber based scams and attacks simply take advantage of the human operators behind the computer screen.

These more traditional breaches succeed due to poor security habits and lack of basic security awareness of people and organizations. With all cyber based attacks, the human factor still remains the weakest link in the security chain. These types of cyber-attacks rely primarily on social engineering techniques and take advantage of the fact that people can be convinced, manipulated, or otherwise duped into acquiescing to the desires of the attacker.

The following examples only represent a fraction of all the types of non IoT cyber based attacks currently in-play. However, they represent some of the most common methods perpetrators use to compromise systems.

Social Media

Recently, social media sites such as Facebook, Twitter, Instagram etc., have become ubiquitous and many people maintain personal and professional accounts with these organizations. These sites can prove useful for criminals to obtain information that can later be used to gain access to company networks. People tend to post personal information to these social media which can then be leveraged in numerous ways. For example, an individual may post pictures to a social media site detailing their vacation. That information can be downloaded and used as part of an identity theft campaign. A hacker is able to download and then email those photos to people within the victims' company thereby potentially tricking them into thinking it's coming from the individual on vacation. This technique easily provides the hacker a believable cover story and method to request other information or documents.

Phishing

Standard exploits using email still remains one of the primary tools to gain access to systems. Approximately 190 billion emails are in circulation every day and represent the easiest route for cybercriminals to gain access to systems.[18]

Phishing attacks are typically large and not directed at anyone in particular. This type of attack saturates users with numerous emails promoting any number of web sites or products that appear to come from a friend, acquaintance or other reliable source. It is the internet equivalent of receiving junk mail. Eventually a user may click on one of the emails either because something finally caught their interest or they did so accidentally. They are then directed towards a web site where they might be prompted to provide personal information, credit card details or other information.

Alternatively, a phishing email may trick the individual into opening an attached file which contains malicious code. The attachment in question is usually camouflaged as an invoice, meeting invitation, or even a funny picture. These types of attacks have the potential to do serious harm as many people lack the proper training and awareness to spot the indicators of such attacks. Typically, an attacker may use an email address that looks very similar to a legitimate one. For example, by placing letters 'r' and 'n' next to each other and using a different font, one can mimic the letter 'm'. This can trick the victim into thinking they are receiving an email from 'Microsoft' when in fact it's coming from 'Microsoft'. Phishing campaigns have generally been increasing over the last few years due to improved methods to target victims. These campaigns abuse information obtained via social media sites and tend to be associated with larger ransom ware campaigns[19]. Through this type of attack hackers can remain anonymous and off-the-shelf software to conduct these campaigns continues to be readily available.

Spear Phishing a.k.a Targeted Attack

Spear phishing or targeted attack campaigns have been growing in popularity particularly due to the fact that they are proving to be very successful. This technique typically involves weeks or even months of research and reconnaissance combined with superior social engineering skills on order to deceive the target. These attacks are directed against very small groups of people, a specific organization, or even a single individual in order to deceive them into divulging sensitive information or providing access to their organizations' systems. The attack is specifically tailored towards that target and can be very convincing to the point where compromise is virtually guaranteed.

As a first step, the hostile actor identifies and amasses as much information as possible about the victim. This can be done through public channels such looking up email and contact details through online directories or acquiring information that has been posted to public forums. As previously mentioned information can be easily obtained by going through the intended victim's social media accounts. Once enough information has been gathered, the attacker can then create an attack plan that targets the vulnerabilities they have uncovered through their research.

One of the more common spear phishing attacks against executives in larger corporations is sometimes referred to as "We're Being Sued". Through their research, the attacker uncovers which law firm the company employs. They then proceed to fake an email from that law firm warning of pending legal action against the organization. Attached in the email is a document outlining the details of the impending litigation. However, embedded in that document is malicious code or software that gets deposited into the companies' network once the individual opens the attachment.

Another common method for successful spear phishing attacks is the use of "watering holes". Through their research, the attacker may uncover which web sites are frequented by the organization or individual. If the web site is small and inconsequential, the attacker may compromise that web site knowing that their target will eventually visit and thereby gain access

via that route. When the individual goes to that website they can compromise their systems because the attacker has introduced malicious code into the site. The malicious code might be hidden in a link or file on the site the attacker is fairly confident the target will click. In other cases the malicious code will be downloaded automatically when the target visits the site.

Advanced Persistent Threat (APT)

A sub-category of targeted attack that also exists is referred to as the Advanced Persistent Threat (APT). This type of attack is usually beyond the means of individual hackers or even dedicated cyber criminals. APTs are usually conducted by state-level actors and are sometimes indicative of foreign government espionage activities. Such attacks are considered extremely difficult to defend against due to the resources dedicated and technical sophistication of the attackers. These types of attacks tend to be long term and include detailed and in-depth reconnaissance of the target. They rely on stealth and covertness while extracting information for as long as possible without arousing suspicion.

Challenges in Securing IT systems

Securing IT systems is by no means an easy task. Many companies employ numerous types of computer systems each with their own specific security protocols or operating standards. As such, it can be challenging to find solutions that address all their vulnerabilities. Similarly, unique challenges exist for securing ICS and SCADA systems as they tend to be much older systems and require specialized or unique security measures than those for typical business enterprise based systems. For older ICS and SCADA systems, up to date patches may not even exist and thus companies have limited options for securing them.

In addition, many companies do not fully disclose or report on the full extent of data breaches to their systems[20]. They are reluctant to do so for fear that publicly releasing such information will be damaging and will negatively impact their reputation with investors and customers. As such it can be difficult to obtain complete data on the types of breaches occurring to specific systems or sectors.

Securing IT systems to match the organization's perceived level of risk can be an expensive endeavor. Many organizations may simply view it as a costly and unnecessary undertaking that serves to only lower their overall return on investment. Smaller organizations face even more daunting obstacles than their larger counterparts. Small businesses have nowhere near the financial capital to invest in securing their systems. Even if they do invest it must be accomplished in an even more cost effective manner. Small operations sometimes have one employee responsible for securing all the various IT functions within the organization. In many cases it may not even be that individual's primary function within the organization. For such situations, it is difficult for one person to have complete knowledge and understanding of every aspect of their organizations' IT network and operating procedures. This lack of resources and dedicated employees can sometimes lead to systems being improperly secured.

Incident Response and Best Practices

Cyber threats will continue to evolve and will pose even greater challenges for organizations who fail to take adequate measures to protect themselves. Organizations should strive to ensure their systems are up-to-date with the newest patches and bug fixes as well as to maintain a secure backup system. Further, organizations should endeavor to provide training and awareness programs to all employees so that they can be kept up-to-date of the latest threats and the response plan to mitigate against it. While no defensive posture will guarantee complete cyber-security, there are resources available that can aid in mitigating many common cyber threats.

Canadian Cyber Incident Response Centre (CCIRC)

CCIRC is Canada's computer security incident response team. It is mandated to coordinate a national response in the event of significant cyber incidents. They also serve as the main point of contact for owners and operators of Canada's critical infrastructure when they need to report a cyber-incident. They also function as the national coordination centre for the prevention and mitigation of cyber events. CCIRC achieves this providing authoritative advice and support and coordinating information sharing and event response. Detailed information on CCIRC and how to contact them in the event of an incident can be found at the flowing link:

https://www.publicsafety.gc.ca/cnt/ntnl-scrt/cbr-scrt/ccirc-ccric-en.aspx. CCIRC acquires all its data via its stakeholders and clients, international CERT partners, open source and commercial feeds, news reports, and intelligence partners. This information is compiled to produce actionable cyber threat information which is distributed to critical infrastructure partners.

Cyber-security Frameworks

In addition to the services offered by CCIRC, there also exist numerous cyber-security practices, guidelines and framework documents. Most are open source and owners and operators can make use of them to better secure their operations and cyber systems from attacks. For example, the *Process Control System Security for the Water Sector*[21], published by the American Water Works Association provides advice and step-by-step instructions that water sector owners and operators can implement within their facilities. It includes advice and plans on how to develop organization wide security frameworks, disaster recovery plans, steps to secure vital cyber systems, or access control practices. While it is a U.S. publication, many of the practices they recommend can be applied to Canadian facilities.

Also available is the National Institute of Standards and Technology, Cyber-security Framework (NIST CSF).[22] The voluntary framework consists of standards, guidelines and best practices for critical infrastructure sectors owners and operators to consider when developing cyber-security practices for their organizations. The document is designed to offer many recommendations that can be implemented, but owners and operators may pick and choose those practices that best fit their specific business operations.

While no individual framework provides complete solutions to the seemingly infinite variety of cyber-risks they, nonetheless offer a common base-line approach for organizations achieve a minimum level of cyber-security. Ultimately, individual organizations should adopt whatever cyber-security practices they feel best conforms to the size and scope of their organization. With these resources at hand, water sector owners and operator should find enough information in order to properly develop for their organization a robust and comprehensive strategy to protect themselves again cyber-attacks.

Cyber Vulnerability Assessments

As noted in the report above, PSC's RRAP conducts field-based vulnerability assessments to identify and measure vulnerabilities for Canada's critical infrastructure owners and operators, including in the water sector. The Canadian Cyber Resilience Review (CCRR) is a non-technical assessment tool that measures an organization's ability to manage cyber risk to its critical services against ten broad domains found in the NIST CSF.[23] Participants in the CCRR obtain scores for each domain and are provided with comparison scores for peers in the water industry and other critical infrastructure sectors, including US facilities. Vulnerabilities are clearly identified and resilience enhancement options are provided by Public Safety. Participants are provided an overall Maturity Indicator Level between 0 and 5, with progression between indicator levels representing the degree to which cyber-security practices and goals are not only performed, but meet planning and standards requirements, are properly resourced and managed, are monitored and controlled, and are consistent across the organization.

While specific conclusions cannot be disclosed in a public report due to the sensitivities regarding site-specific vulnerabilities, some general findings include:

- Since inception in 2013, 12 water facilities, including water treatment plants and wastewater treatment plants, have undergone CCRRs.
- The facilities assessed included water systems serving populations ranging in size from 12,000 to over 1,000,000 in six provinces.
- The average Maturity Indictor Level for these water facilities was 0.55 out of 5.00, indicating that cyber-security practices range from "incomplete" in some of the domains to "minimally performed" in others.
- No single domain, however, reached higher maturity indicator levels, where practices adhere to common standards, cyber activities are properly resourced and managed, and so on.
- The water sector score of 0.55 was below the all-sector average of 0.97.
- Domains scoring the lowest marks included Situational Awareness, Training and Awareness, and Service Continuity Management.

As noted in the report above, recommendations for the water sector include creating a knowledge commons, empowering water organizations to share and seek information, and increasing transparency and public education. The RRAP's CCRR helps to meet these objectives both at the facility level (where individual owners and operators gain better understanding of their cyber

vulnerabilities) and at the sector level (where aggregate RRAP data could be used to reshape PT entities' targeted actions to help enhance the cyber-security of Canada's water sector).

Conclusion

The cyber threat landscape is continuously and rapidly evolving. Criminals are finding new and more efficient ways to gain unauthorized access to systems and information. While the water sector may not be perceived to be the most targeted sector, it remains vulnerable to all the various threats that currently exist. As computer technology continues to advance and becomes increasingly integrated into older systems, the more challenging it will be for organizations to secure each and every point of entry. It is imperative that organizations renew their focus on cyber-security and make genuine efforts to prioritize the safety and security of their networks going forward.

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