WATER SECURITY
SECURITY GUIDANCE
SGD DOCUMENT

WATER SECURITY GUIDANCE DOCUMENT

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PART 1 SECTION 1
DEFINING AND ASSESSING WATER SECURITY

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WATER SECURITY GUIDANCE DOCUMENT
PART 1 SECTION 1
DEFINING AND ASSESSING WATER SECURITY

ABSTRACT

The section introduces the project, outlining the concept of water security, including how it is defined and the genealogy of the term. Current approaches to measuring and assessing water security are outlined, along with a guide to using this Guidance Document.

THIS SECTION IS BASED ON THE FOLLOWING JOURNAL ARTICLES AND POLICY REPORTS:

Cook, C. and Bakker K. (2011). **Water Security: Debating an emerging paradigm.** Global Environmental Change, 22(1): 94 - 102. http://dx.doi.org/10.1016/j.gloenvcha.2011.10.011

Dunn, G. and Bakker, K. (2011). **Fresh Water-Related Indicators in Canada: An Inventory and Analysis**. Canadian Water Resources Journal Vol. 36(2): 135-148.

Norman, E.S., Bakker, K and Dunn, G. (2011). **Recent developments in Canadian Water Policy: An emerging water security paradigm**. Canadian Water Resources Journal Vol. 36(1): 53-66.

Emma Norman with Karen Bakker, Christina Cook, Gemma Dunn and Diana Allen (2010). **Water Security: A Primer**. Vancouver, BC: UBC Program on Water Governance. http://www.watergovernanace.ca/wp-content/uploads/2010/04/WaterSecurityPrimer20101.pdf

Dunn, G. and Bakker, K (2009). **Canadian Approaches to Assessing Water Security: an Inventory of Indicators** (Policy Report). Vancouver, BC: UBC Program on Water Governance. http://www.watergovernance.ca/PDF/IndicatorsReprtFINAL2009.pdf

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BACKGROUND: KEY ISSUES AND CONTEXT

Fresh water-related issues are of growing concern throughout Canada, both in terms of quality and quantity:

- According to Environment Canada, one quarter of all Canadian communities have experienced water shortages since the mid-nineties.
- Water quality in more than one thousand rural communities is as bad as or, in some cases, worse than many developing countries. In 2007 alone, there were 1766 boil water advisories across Canada in small towns, cities and townships, some of which had been in place for more than 5 years. A further 93 were in place in First Nations communities (Eggerston 2008).
- Some ecosystems are showing signs of stress due to compromised water quality and declining water levels.
- These issues will be affected by global climate change impacts (the full scope of which is still unknown).

There are multiple stressors that result in water insecurities. Many water management approaches fail to link water quality and quantity together, both in terms of human health and aquatic ecosystem health. Furthermore, often there is inadequate consideration and assessment of risks to water. Disparate water management challenges demand a broad integrative approach that accounts for multiple stressors and cumulative effects. We suggest that the concept of water security, broadly defined, is one promising approach to sustainable water governance.

PURPOSE OF THE GUIDANCE DOCUMENT

The purpose of this Water Security Guidance Document is to:

a. Define the concept of water security, and document multiple perspectives on this concept (*Part I*)
b. Present methods for small water system managers to assess potential risks to water security (*Part II*)
c. Present possible responses to these risks, focusing on governance-based strategies (*Part III*)

INTENDED USERS

This Water Security Guidance Document has been developed for small communities to assess risk to water security in their watershed, but many of the concepts and issues are applicable at larger scales. The Water Security Guidance Document contains a broad range of information for both experts and non-experts. Intended users include, but are not limited to: community watershed groups, citizen environmental committees, water managers, municipal water policy and decision makers, aggregate mining industry officials, source water protection groups, provincial water planners and watershed groups, health authority officials and water suppliers.

FORMAT OF THE WATER SECURITY GUIDANCE DOCUMENT

The Water Security Guidance Document comprises three parts:

Part 1 – Concepts: *Part I* introduces the concept of water security, outlining multiple perspectives on water security, and current approaches used to assess water security.

Part 2 – Assessing Water Security (Measuring Risk): *Part II* comprises step-by-step guides to applying each component of the water security assessment framework including risk assessment, vulnerability scoring, current status, and groundwater quality mapping. Although these tools can be used independently, they can also be applied in combination, depending on the needs and resources of the community. It is important to note that these concepts are deeply interconnected, and together form a comprehensive assessment of overall water security. Indeed, the *Water Security Risk Assessment (Section 2)* is strongly tied to the *Water Security Status Indicators (Section 4)*. The *Vulnerability Scoring Method (Section 3)* is a component of overall *Water Security Risk Assessment (Section 2)*. Likewise, *Mapping Groundwater Contamination (Section 5)* is a component of *Water Security Status Indicators (Section 4)* illustrating methods to spatially represent data.

Part 3 – Managing Water Security (Adaptive Governance): *Part III* outlines some approaches developed during the project for water managers to manage risk to water security. It includes *Fostering Good Governance Practices (section 6)* and *Boil Water Advisories Protocol (section 7)*.

Appendix A: Gives an overview of the project including research team and project partners.

Appendix B: Lists all project-related outreach activities (including peer reviewed journal articles, policy reports, conference and workshop presentations, and advisory roles).

Table 1: The Water Security Guidance Document (2012)

Part I: Water Security (Concepts)	
	Overview of the Guidance Document
	Defining and Assessing Water Security
Part II: Assessing Water Security (Application)	
Section 2	Water Security Risk Assessment (WSRA)
Section 3	Water Security Risk Scoring Method
Section 4	Water Security Status Indicators (WSSI)
Section 5	Mapping the Likelihood of Groundwater Contamination
Part III: Managing Water Security (Governance)	
Section 6	Working Towards Water Security: Fostering Good Governance Practices Through Adaptive Management
Section 7	Boil Water Advisory Protocol

Appendices: Ancillary Material	
Appendix A	Project Overview
Appendix B	Complete List of Water Security Project Publications

DEFINING WATER SECURITY

Water security is an emerging concept, which has gained increasing attention over the past five years. For example, in 2009, the World Economic Forum described water security as "the gossamer that links together the web of food, energy, climate, economic growth and human security challenges that the world economy faces over the next two decades" (World Economic Forum 2009, 5). In this Guidance Document we define water security as "sustainable access on a watershed basis to adequate quantities of water, of acceptable quality, to ensure human and ecosystem health". This definition sets baseline requirements for water resources management in a watershed on a continuous basis; there must be access to adequate quantities of acceptable quality of water for both humans and the environment.

Water security takes a broad look at all demands placed upon a watershed, including quality, quantity (including climate change and allocation), aquatic ecosystem health, human health, risk and adaptive governance. Water security demands a greater priority for water. As such, it is a broad concept of integrated water management that balances resource protection and resource use. It is important to measure water security because this approach examines the watershed as a whole. Setting a goal of water security could enable decision-makers to effectively assess and mediate between conflicting demands for water use and minimize potentially adverse impacts from land and water management practices.

Water security-related issues have been of growing concern in Canada over the past decade. Well-publicized water contamination incidents in Walkerton (Ontario), North Battleford (Saskatchewan), and Kashechewan (Ontario) have alerted Canadians to public health issues related to water quality (Butler 2008; O'Connor 2002; Parr 2005). At the federal level, reports from the National Water Resources Institute (Environment Canada) and the Senate on increased threats to water have attracted renewed attention to water issues (Environment Canada 2001, 2004; Senate of Canada 2005).

Canada is not alone in dealing with water quality and water quantity concerns. Water, by its very nature, presents managers with three issues that are difficult to resolve: (1) competition between users of water resources; (2) vertical coordination of the multiple levels at which water is used and managed; and (3) the mismatch between geopolitical and administrative boundaries, on the one hand, and hydrological boundaries on the other.

These issues flow, in part, from the fact that water is a multi-purpose resource, with multiple sets of users operating at different scales. In turn, this creates competing uses and diverse views of stakeholders within the policy debate. For example, cities sit within watersheds, and the water within cit-

ies is often the subject of competing claims both upstream and downstream: industrial, tourism, amenity, residential, agricultural, and resource (e.g., hunting and fishing) uses. The debate over the Oak Ridges Moraine (north of Toronto) is one such example, of which there are many across the country.

CONCEPT OF WATER SECURITY: GENEALOGY OF THE TERM[1]

Despite increased concern about water-related issues, no common definition of water security exists. Indeed, use of the term water security has increased across a wide range of disciplines in the last decade. Figure 1 illustrates the trend of steadily increasing frequency of use of the term "water security" in academic, peer-reviewed journals.

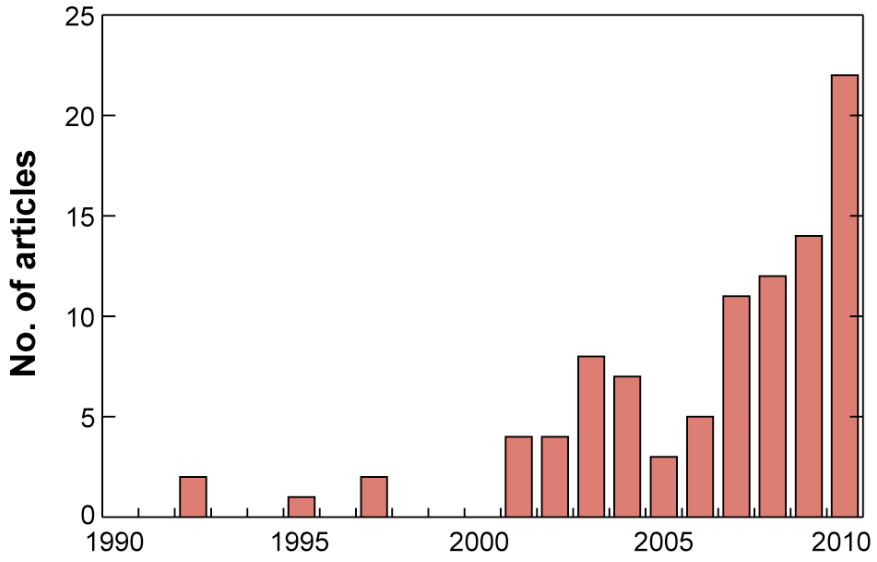
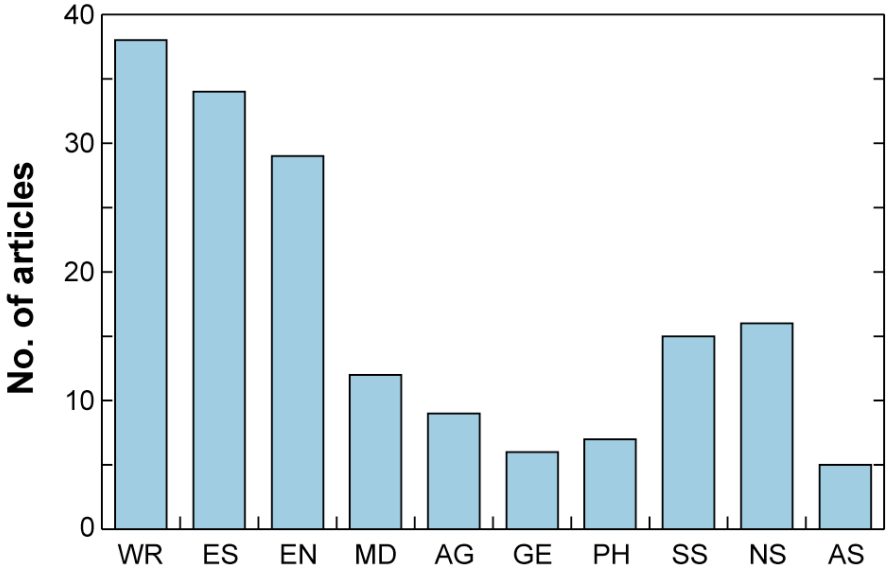


Figure 1: Articles containing the term "water security" in the academic literature (1990 – 2010). Source: Web of Science database

The analysis also illustrates the diversity of disciplinary approaches currently characterizing academic research on water security. Figure 2 indicates that a wide range of disciplines use the term "water security".

[1]The section comprises excerpts from "Water Security: Debating an emerging paradigm" by Christina Cook and Karen Bakker. Global Environmental Change (in press). Reproduced with permission from Elsevier Ltd.



WR=Water Resources;
ES=Environmental Studies, Sciences, and Ecology;
EN=Engineering (Civil, Environmental, Chemical, Multidisciplinary);
MD=Geosciences, Multidisciplinary sciences;
AG=Agriculture, Agronomy;
GE=Geography;
PH=Health (Public, Environmental, Occupational);
SS=Social Science (International Relations, Law, Planning and Development, Anthropology, Area Studies, Ethics, Economics, Operations Research and Management Science, Sociology);
NS=Natural/Physical Science (Biology, Computer Science, Fisheries, Food Science, Limnology, Biodiversity Conservation, Social Science, Tropical Medicine, Plant Science, Parasitology);
AS=Meteorology and Atmospheric Sciences

Figure 2: Disciplinary grouping of articles containing the term "water security" (1990 – 2010). Source: Web of Science database

Another salient finding of our analysis is the variability of scales at which water security is defined and measured. Scale is critical in assessing water security because of the scalar variability of hydrology, as illustrated by a recent study (Vörösmarty et al. 2010). The global focus of that study is useful for inter-country comparisons; however, the relatively coarse spatial resolution of the study hides significant variability in water security. In Canada, for example, which is classified as "water secure", decreasing water availability in the Prairie region is a growing concern, and long-term water quality issues in Aboriginal communities have been well documented (Phare 2009).

In general, the definitions of water security used in the 1990s were linked to specific human security issues, such as military security, food security and (more rarely) environmental security. Then, at the Second World Forum in 2000, the Global Water Partnership introduced an integrative definition of water security that considers access and affordability of water as well as human needs and ecological health. Since then, a variety of a scholars and policymakers have taken up the term and given it various meanings, with some developing discipline-based definitions and others advancing an integrative,

interdisciplinary approach. Within this diverse literature, four interrelated themes dominate the published research on water security: water availability; human vulnerability to hazards; human needs (development-related, with an emphasis on food security); and sustainability.

Water security is an overarching conceptual framework that articulates the desirability of balancing competing land and water-use practices, much like Integrated Water Resource Management (IWRM). We argue in favour of an integrative and broad framing of water security for four reasons. First, a broad framing of water security is complementary to IWRM, as both imply the need to integrate water quantity and quality, in addition to ecosystem and human health concerns. 'Narrow' approaches to water security may move away from the integrative approach central to IWRM, which implies the need for robust governance processes to mediate the trade-offs between different stakeholders, scales, and uses of water. Second, a broad and integrative approach may be more analytically robust, because it is more comprehensive. Definitions of water security that focus solely on water quality, for example, are likely to miss water quantity-related concerns, which also affect secure access to water. Third, water security provides a means to respond to recent calls for a "clear vision or direction about a desired end state for a catchment or river basin" (Mitchell 2006, 52). In other words, water security provides a framework, which lends itself to a 'vision', which is normatively goal-oriented (insofar as security implies a particular state). We suggest this is positive because it focuses attention on the end goal (water security) rather than the process of "integrated management" (as has been the case with IWRM). Fourth, the use of the term 'security' implies thresholds (below which water is insecure)—which may be of use in situations where monitoring and enforcement have been lacking. With thresholds in place, stakeholders and regulators must ensure water meets some agreed upon minimum standard, and water security may lend (at least discursively) greater priority to doing so, as explored below.

Operational definitions of water security are also, our analysis indicates, likely to vary geographically. Specific definitions of water security have emerged in regions where particular water security concerns are acute. Our review of research on water security in Australia, China, and the Middle East and North Africa illustrates these regional specificities where disciplinary framings have taken a particular focus. In Australia, well known as the world's most arid continent, water security has been defined predominantly as a concern of water availability (quantity) to be addressed by the national and state governments through a variety of mechanisms, as detailed in A National Plan for Water Security (Government of Australia 2007, 2010). In China, the industrial and populous north is considered highly water insecure (Xia et al. 2007). Here, water security research often has a combined focus on both availability and pollution. In the Middle East and North Africa region, the focus is on sharing a scarce resource amid increasing demand in an unstable geopolitical climate. One article defines water security as having "[A]vailable and secured enough quantities of fresh water to meet normal/rationing demand under emergency situations until water production facilities are constructed or rehabilitated" (Al-Otaibi and Abdel-Jawad 2007, 301).

ASSESSING WATER SECURITY

Currently, indicators are one of the most commonly used methods for water security assessment, as they enable the synthesis of large amounts of complex information to be presented in a simplified format that can be easily understood. However, indicators are static, presenting a snapshot in time of current status; risk or future status is not included. The risk due to deterioration of quality and quantity over the longer term is an important issue. Accordingly, this Guidance Document addresses both current and future risk related to water (in)security.

ASSESSING RISKS TO WATER SECURITY

An important element of water security is the likelihood that the water source may become deteriorated in some way and have some impact on human or ecosystem health. Deterioration is viewed both in terms of quality and quantity. Risk to water quality and quantity associated with current land use practices, changes in land use, climate change, or changes in water demand, can be evaluated by considering these various stressors.

The risk assessment itself encompasses several elements. For example, within a groundwater quality context (chemical), the intrinsic susceptibility of an aquifer can be mapped using information on the soils, geology, water table depth, etc. using a variety of established methods (See Part II, Section 5). The threat of contamination (such as application of fertilizer or sudden release via a spill) or the threat due to overuse and the associated uncertainty of occurrences must be taken into account (See *Part II, Section 3*), leading to an overall vulnerability of the resource. Risk analysis, however, also requires some estimate of consequence, such as the cost to replace a water supply well, or the cost to the public health care system if people get sick. To assess water quality risk, one first needs to know the hazard the chemicals present pose, their quantities, and whether they could have an impact on human health if humans were exposed to them. Second, one needs to know the likelihood that the chemicals would be released (i.e., how are they stored?). Third, one needs to know how easily those chemicals could enter the aquifer and contaminate it – this is determined by the properties or intrinsic susceptibility of the aquifer. Fourthly, one needs to know the pathway the contaminant might take to the water source. Finally, one needs to consider the potential consequences of the hazard threat and susceptibility pose to water quality. A similar type of analysis could be done for surface water sources. The *Water Security Risk Assessment (WSRA)* method presented in this document (*Part II, Section 2*) provides spatial indicators of risk by mapping attributes of the built and natural environments.

Water quantity risk assessments are more difficult to tackle because not only is information on the current supply and demand needed, but also projections are needed about how that ratio might change in the future. Whilst projections for future use can be made, a supply assessment is difficult because of natural climate variability and climate change. In fact, climate change and variability are wild cards that can potentially impact both water quantity and quality.

ASSESSING CURRENT WATER SECURITY STATUS

Current approaches for determining whether a water source measures up to a baseline (minimum standard or threshold) are often based on indicators. Indicators play an important role, enabling us "to take complex scientific and social data to provide a simplified, quantified and communicated expression that anyone can understand" (US EPA 2008). There are many indicators of water quality, but fewer indicators of water quantity (particularly demand in relation to supply), as our indicator inventory determined (Dunn and Bakker 2009, 2011). Indicators are static in that they describe how water measures up at some instant in time. Target and baseline values play an important role in the use of indicators, as these help define changes in policy and action. As such, indicators need to be tracked over time (ideally through continuous assessment) to determine improvements, or declines against baselines or thresholds. The integration of the results from monitoring and assessment into the decision-making process could ultimately help move communities closer to water security. *The Water Security Status Indicator (WSSI) assessment method (Part II, Section 4)* is a new approach, which offers communities a process by which to assess their current water security status. The WSSI assessment method provides practitioners with a framework to select water quality and quantity indicators related to ecosystem and human health.

MANAGING RISKS TO WATER SECURITY: A GOVERNANCE-BASED APPROACH

Managing Water Security *(Part III)* presents a governance-based approach to managing water security risks. An adaptive governance approach focuses on the process by which the information from water security status and risk assessment is absorbed, decisions are made and implemented, and decision makers are held accountable in the development and management of water resources and the delivery of water services. This place-specific governance approach promotes strategies that are sensitive to feedback (both social and ecological) and are oriented toward system resilience and sustainability. In *Part III, Section 6 Fostering Good Governance* we outline and define an adaptive management approach and provide examples of steps communities can take to implement "good governance" practices with the aim of achieving water security. In *Part III, Section 7 Boil Water Advisory Protocol* we present a step-by-step guide for government regulatory officials and water suppliers involved in the decision to issue and rescind boil water advisories.

Practicing good governance is crucial for communities to achieve water security and an adaptive governance approach can facilitate this. Succinctly defined, adaptive governance is a methodological approach to resource management, whereby policies are implemented as experiments and learning is integral to resource stewardship. Adaptive governance formalizes a "learning by doing" approach that can link science and policy. It entails three overlapping activities: participation of stakeholders; policy-development; and monitoring and enforcement. Risks and changes to ecosystem health and human health are monitored and assessed over time. Policies and decision-making processes are then adapted over time, creating a closed (and hopefully virtuous) feedback cycle.

SUMMARY

Our research findings suggest the importance of a broad and integrative approach to water quality and quantity, which incorporates human health and aquatic ecosystem health. We specifically suggest that the assessment of current water security status needs to be combined with the assessment of risks, and the results incorporated into an adaptive governance framework, which formalizes a flexible "learning by doing" approach that can respond to changing conditions. In facilitating this integration the concept of water security is worthy of consideration for both research and policy strategies in support of sustainable water governance.

GLOSSARY OF TERMS

Adaptive Management, a systematic process for continually improving management policies and practices by learning from outcomes of operational programs.

Aggregate Extraction Site, (may include pit or quarry) is a land from which unconsolidated or consolidated aggregate is being or has been excavated. Aggregate materials include: gravel, sand, clay, earth, shale, stone, limestone, dolostone, sandstone, marble, granite, rock or other prescribed material.
Source: Aggregate Resources Act, R.S.O. 1990, c. A.8.

Aquifer, an aquifer is a water-bearing layer underground.

Aquitard, the layer of geological material that prevents or inhibits the transmission of water to or from a confined aquifer. Source: Ontario Drinking Water Source Protection documents: http://www.sourcewaterinfo.on.ca/content/spProject/glossary.php.

Assessment Framework, a methodology, strategy, or approach to analyzing a system.

Boil Water Advisory, public notifications of drinking water quality that are primarily used as temporary, precautionary measures to protect the public from possible waterborne illnesses.

Community, can be broadly defined. In this project we often refer to a small municipality as a 'local community'.

Confined Aquifer, an aquifer overlain by a low permeability layer (saturated and usually under (artesian) pressure).

End-user, a person or persons that would use a particular product.

Goals, often more qualitative and desire-based (for example the ability to swim or canoe in a river without it being full of algae or smelly).

Good Governance (water), the democratization of water management decision-making e.g., participatory, census-oriented, accountable, transparent, responsive, effective and efficient, equitable and inclusive, and following the rule of law (Norman et al. 2010; Bakker 2002).

Governance (water), water governance is the process by which water resources and services are organized and managed. This includes not only laws and regulations, but the entire range of political, organizational and administrative processes involved in managing the water supply: from the time when communities articulate their interests, and that input is absorbed, to the time when decisions are made and implemented, and decision makers are held accountable for the development and management of water resources and the delivery of water services (Norman et al. 2010; Bakker 2002).

Hazard, these may be quantity-related (such as contaminants) or quantity-related (such as large water extraction volumes).

Indicator, a univariate or absolute number, statistic or parameter. Tracked over time, an indicator can provide information, often related to a trend on the condition of a phenomenon and have significance extending beyond that associated with the properties of particular statistics (Dunn and Bakker 2009).

Index, a multivariate, aggregate or complex number that incorporates a number of components. An index is often comprised of a number of indicators and expressed as a numerical scale (e.g., 1-100). It is a composite reflection that can enable, for example, two cities to be compared (Dunn and Bakker 2009).

Indices, plural of index, or indicator.
Note: Despite their different meanings, the terms "indicator", "index" and "indices" are often used interchangeably. Frequently indicator is used as a catchall term that may include indices, performance measures, report cards, benchmarks and objectives. The concept of indicators is loosely inferred when monitoring status, trends and conditions. In this Guidance Document we use the term indicator as an umbrella term for both indicator and index.

Intrinsic (Aquifer) Susceptibility, a relative measure of natural susceptibility. For an aquifer it is a relative measure of the ease with which a contaminant, introduced at the surface, will move from the surface down into an aquifer.

Loss, loss is the economic, environmental or health consequence associated with the deterioration of a water resource (either in terms of its quality or quantity).

Objectives, quantitative, science-based targets often specific to a particular variable.

Orthophotograph, an aerial photograph from which distortions due to camera tilt and ground relief have been removed. An orthophoto has the same scale throughout and can be used as a map to measure true distances.
Source: adapted from ArcGIS glossary.
(http://support.esri.com/en/knowledgebase/GISDictionary/term/orthophotograph)

Participatory Governance, focuses on deepening democratic engagement of citizens in the processes of governance with the state. The idea is that citizens should play a more direct role in public decision-making or at least engage more deeply with political issues.

Raster, a raster data type is, in essence, any type of digital image represented by reducible and enlargeable grids.
(http://en.wikipedia.org/wiki/Geographic_information_system#Raster)

Risk, a function of vulnerability and loss.

Risk Assessment, the identification, assessment, and prioritization of risks.

Stakeholder, a person (or persons) with vested interest in an issue.

Unconfined Aquifer, is exposed at surface, meaning that the permeable materials comprising the aquifer are not protected by a cover of lower permeability materials that can act as a barrier to entry to contaminants introduced at surface.

Vulnerability, the potential for damage caused by various hazards (e.g., contamination, over use), offset by the natural protection provided by the physical (unaltered or altered) system.

Water Security, sustainable access on a watershed basis, to adequate quantities of water, of acceptable quality, to ensure human and ecosystem health.

Watershed, every waterway lies within a watershed. A watershed (also known as a "catchment" or "drainage basin") may be defined as a geographical area in which surface waters flow towards one destination. Surface watershed boundaries (or "divides") follow the highest ridgelines around the stream channels and meet at the lowest point of the land where water flows out of the watershed. Water flows in two different directions on either side of the divide. Ground-watersheds may not coincide with surface-watersheds. Watersheds may be small, representing a single tributary within a large system or quite large, covering thousands of kilometers. Watersheds can extend across borders, engaging multiple scales of governance.

Watershed-scale, an arbitrary scale of analysis constructed around a 'watershed'.

LIST OF ACRONYMS

ALR – Agricultural Land Reserve
AVI – Aquifer Vulnerability Index
BC MoE – British Columbia Ministry of Environment
BMP – Best Management Practices
BWA – Boil Water Advisory
CA – Conservation Authority
CCME – Canadian Council of Ministers of the Environment
CCME WQI - Canadian Council of Ministers of the Environment Water Quality Index
CDWQG – Canadian Drinking Water Quality Guidelines
DEM – Digital Elevation Model
EC – Environment Canada
Eh – Reduction Potential
EMS – Environmental Monitoring System
GIS – Geographic Information Systems
GRCA – Grand River Conservation Authority
GVWD – Greater Vancouver Water District
HC – Health Canada
HRS – Hazard Ranking System
IWRM – Integrated Water Resources Management
LA 21 – Local Agenda 21
MAL – Ministry of Agriculture and Lands
MENA – Middle East and North Africa
MHO – Medical Health Office (Ontario) or Medical Health Officer
MNR – Ministry of Natural Resources
NAICS – North American Industry Classification System
NGO – Non-Governmental Organization
PTTW – Permit To Take Water
PWN – Private Well Network
SCDM – Superfund Chemical Data Matrix
SFU – Simon Fraser University
ToL – Township of Langley
UBC – University of British Columbia
UoG – University of Guelph
US EPA – United States Environmental Protection Agency
WAI – Water Availability Index
WHO – World Health Organization
WSAF – Water Security Assessment Framework
WSRA – Water Security Risk Assessment
WSSI – Water Security Status Indicators

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WATER SECURITY GUIDANCE DOCUMENT

PART 2 SECTION 2
WATER SECURITY RISK ASSESSMENT (WSRA)

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ABSTRACT

The Water Security Risk Assessment (WSRA) framework considers the hydrologic components of the watershed (surface water and groundwater) and the quality and quantity of these water sources. To demonstrate how such a framework could be implemented, a groundwater quality risk assessment methodology is presented and tested within the Township of Langley, British Columbia. Risk is defined as a function of vulnerability (aquifer susceptibility and hazard threat) and contamination consequence. Aquifer susceptibility reflects the relative ease with which contaminants introduced at surface can contaminate an aquifer. Conduits (wells) increase susceptibility by providing a short-circuit 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.

JOURNAL ARTICLES RELATED TO THIS TOOL INCLUDE:

Simpson, M.W. Allen, D.M. (in review) **Assessing Risk to Groundwater Quality Using an Integrated Risk Framework**. Submitted to Water Resources Management (September 2011).

THESIS RELATED TO THIS TOOL INCLUDE:

Simpson, M.W. (in prep). **An Integrative Approach to Assessing Water Security** (Provisionary Title). MSc Thesis, Department of Earth Sciences, Simon Fraser University.

WATER SECURITY GUIDANCE DOCUMENT

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BACKGROUND: KEY ISSUES AND CONTEXT

The assessment of water security requires both the evaluation of current status of water quality and quantity through the use of indicators (refer to *Part II, Section 4 Water Security Status Indicators*), and an assessment of **risk** to water owing to uncertainty in foreseeable future events that may negatively impact water quality or quantity. Although risk principles and methodologies are well documented for natural disasters such as landslides and earthquakes (Birkmann 2006), comprehensive risk assessments are seldom applied to water-related issues. Methodologies to assess one component of risk, namely **vulnerability**, are in use for both surface water and groundwater (Ontario Ministry of Environment 2004) and others are currently under development (e.g., Banting and McBean 2011; *Part II, Section 3 Water Security Vulnerability Scoring Method*). However, risk assessment must consider both the likelihood of consequence (i.e., vulnerability) and the magnitude of the consequences (i.e., **loss**). Thus, Risk is defined as a function of Vulnerability and Loss.

$$\textbf{RISK } (R_H) = \textbf{Vulnerability } (V_H) \textbf{ x Loss (L)} \quad [1]$$

The Water Security Risk Assessment (WSRA) framework is based on the principles of risk assessment methodology. The risk assessment framework considers the hydrologic components of the watershed (surface water and groundwater), together or separately, depending on the driving issues and practicalities (e.g. data availability, knowledge). The risk assessment framework also considers water quality and quantity, together or separately, for similar reasons (Figure 1). It may be impractical or unnecessary (in some cases) to assess risks to each hydrologic component and its respective attributes (quality and quantity), although *integrated management of these two water sources is ultimately necessary.*

Figure 1: Hydrologic components of the watershed (surface water and groundwater) and their attributes (quality and quantity)

The risk assessment framework itself provides *spatial indicators of risk* by mapping attributes of the built and natural environments, ideally, at a watershed scale. These include:

1. the intrinsic susceptibility of the source, the natural water supply;

2. natural and anthropogenic pathways for water movement (e.g., low topography leading directly to streams, wells as conduits);

3. the hazard threat (either in terms of natural or anthropogenic contamination or threat from over use of water).

The framework incorporates some measure of probability or likelihood of occurrence, such as a spill, entry of agricultural contaminants into an aquifer or surface water course, or reduction in water quantity due to climate change. The uncertainty of these events must be taken into consideration. In addition, the framework incorporates some measure of consequence or loss:

4. socio-economic hardship related to having to seek a replacement water source, human health, or aquatic ecosystem health.

The risk assessment may be used in a general way (encompassing a range of contaminants) or tailored to a specific contaminant of concern. In a tailored assessment of water quality, the assessment would be focused on a particular contaminant (e.g., chemical or pathogen) to determine: the susceptibility of the system; the presence of pathways; the hazard threats; and the loss or consequence all relative to that contaminant alone.

PURPOSE OF THE FRAMEWORK

This Water Security Risk Assessment (WSRA) framework is an indicator method of current risk level, based on the attributes of the natural and built environments. It can be adapted to consider either or both groundwater and surface water, and either or both water quality or quantity, depending on the driving issues and practicalities (e.g. data availability, knowledge).

This document focuses specifically the Groundwater Quality Risk Assessment methodology – one component of the Water Security Risk Assessment (WSRA) framework. Approaches can be adapted to assess risk to surface water quality, surface water quantity, and groundwater quantity by following the basic steps, but altering the representation of the spatial indicators of risk.

INTENDED USERS

This tool is primarily aimed at community watershed groups, citizen environmental committees, water managers, and municipal water policy and decision-makers. The approach can be adapted to the available data and the level of expertise in the use of Geographical Information Systems (GIS).

DESCRIPTION OF FRAMEWORK

The Water Security Risk Assessment framework defines **risk** based on two fundamental components: vulnerability and loss (Equation 1 on page 3). **Vulnerability** is the potential for damage caused by various hazards (e.g., contamination, over use), offset by the natural protection provided by the physical (unaltered or altered) system. **Loss** is the economic, environmental or health consequence associated with the deterioration of a water resource.

A STEP-BY-STEP GUIDE TO APPLYING THE RISK ASSESSMENT FRAMEWORK

Table 1: Summary table outlining the fundamental steps to apply the Water Security Risk Assessment Framework (WSRA)

Step	
1	Define the Scope and Scale of Assessment
2	Assemble an Assessment Team
3	Prepare Information Required to Assess Risk
4	Assess Water Source Susceptibility
5	Complete a Hazard Inventory
6	Assess the Potential Consequences
7	Assess Current Risk Status
8	Develop Mitigation Strategy

STEP 1 – DEFINE THE SCOPE AND SCALE OF ASSESSMENT

Depending on data and resources available, the geographic extent of the assessment area may differ from the area of interest. Areas lacking the most basic data may need to be removed from the assessment area. For data-rich areas, it may be possible to assess risk at a higher level of resolution (e.g., parcel by parcel) compared to data-poor areas.

The scope of the assessment will be based on the aspects of water that are important to the specific community. For example, the primary concern may be the preservation of drinking water supply or the protection of aquatic habitat. Depending on the primary concern, the scope of risk assessment may change.

STEP 2 – ASSEMBLE AN ASSESSMENT TEAM

Identify the team members from within the assessment area. These should include parties involved in monitoring water-related issues and land-use planning; decision-makers (for example watershed groups, municipal sectors, provincial representatives, as well as private and public sectors); and stakeholders (industry, agriculture, medical, commercial, residential, First Nations, etc.). It is important that all decision-makers be identified and included at the outset of the process, in order to successfully identify information needs and facilitate well-informed decisions. A breadth of stakeholder involvement will

increase the accuracy at which the risk assessment inputs (e.g., hazards) can be quantified.

STEP 3 – PREPARE INFORMATION REQUIRED TO ASSESS RISK

There are three major components of risk, each with its own unique data requirements (see steps 4, 5 and 6).

1. Susceptibility
2. Hazard Potential
3. Consequences

The level of detail possible will be largely determined by the data that are available. Depending on the resources allotted to the project, it may be possible to collect data specifically for one portion of the risk assessment. For example, a chemical hazard inventory can be completed using data that are readily available, or a parcel by parcel survey can be completed in order to compile an accurate chemical hazard assessment.

The complexity of the analysis will depend not only on the available data, but also on the expertise and skills of the assessment team. For the approach described here, a GIS was used to spatially map indicators of risk. Spatial coverages of indicators of risk are converted to raster for calculations. Use of a GIS is ideal; however, simple hard copy maps with annotations or overlays can also be used.

STEP 4 – ASSESS WATER SOURCE SUSCEPTIBILITY

Water source susceptibility is determined by measuring intrinsic aquifer susceptibility and the impact of conduits on that susceptibility. Intrinsic susceptibility provides a relative measure of the natural susceptibility of a water source (surface water body or aquifer) to contamination or over use. For a surface water body, this may include physical attributes of the land surface and subsurface (e.g., natural drainage pathways both on the ground surface and groundwater discharge areas), the climate of the area, which determines the water supply, etc.

INTRINSIC AQUIFER SUSCEPTIBILITY:

For a groundwater quality risk assessment, the intrinsic aquifer susceptibility provides a relative measure of the ease with which a contaminant, introduced at surface, will move from surface down to an aquifer. Many aquifer susceptibility methodologies are in use. Common methods include DRASTIC (Aller et al. 1987) and AVI (Van Stempvoort et al. 1993). The methodology chosen should ideally be based on the characteristics of the assessment area; however, data availability may limit the choice of assessment method. Some common susceptibility methods are included in Table 2.

Table 2: Common Intrinsic Susceptibility and Vulnerability methods

Method	Assessment	Reference
Aquifer Vulnerability Index (AVI)	Intrinsic Susceptibility	Van Stempvoort et al. (1993)
DRASTIC	Intrinsic Susceptibility	Aller et al. (1987)
GOD	Intrinsic Susceptibility	Foster (1987)
DRASTIC-Fm	Intrinsic Susceptibility	Denny et al. (2007)
Ontario MoE Source Water Protection	Vulnerability	Ontario MoE (2004)
Water Security Vulnerability Scoring Tool	Vulnerability	Banting and McBean (2011: *Part II, Section 3*)
BC Wellhead Protection Toolkit	Vulnerability	BC Ministry of Environment, Lands and Parks (2000)

To assess **intrinsic susceptibility**, possible input parameters should be compiled, including soil properties, surficial and bedrock geology, aquifer recharge rate, aquifer hydraulic conductivity, depth to water, and topography. For many regions of Canada, soils maps, surficial geology maps, and topographic maps (digital elevation models or DEMs) are readily available as spatial datasets that can be downloaded from data providers free of charge (e.g., Land and Resource Data Warehouse BC; Province of British Columbia 2011). Aquifer-related properties, such as aquifer hydraulic conductivity, aquifer recharge rate, and depth to water are often only available through targeted studies conducted at the local scale (e.g., consulting reports, government or university studies). In British Columbia, a map-based aquifer classification system was developed by the BC Ministry of Environment, Lands and Parks (now BC Ministry of Environment) to identify, map and categorize aquifers using data from the provincial water well database (Kreye et al. 1994). To date, over 800 aquifers in

BOX 1 - Assessing Susceptibility with limited data:

Where data are limited, to the extent that a commonly used intrinsic aquifer susceptibility method cannot be completed (as presented here), a more basic assessment can be completed, ideally by someone with knowledge of hydrogeology and/or soil science. For example, a soils map in combination with a map of topography can be used to roughly outline areas of high intrinsic aquifer susceptibility (permeable soils, low slope) and low intrinsic aquifer susceptibility (impermeable soils, high slope).

Conversely, where advanced methods are possible (e.g., time of travel derived from numerical models), the results can be similarly utilized. Whether using a defined methodology (e.g., Table 2) or mapping susceptibility in a general way, the assessment needs only be reclassified using a scale of 1-10 (low to high intrinsic susceptibility).

The *Water Security Vulnerability Scoring* method (*Part II, Section 3*) presents a specific case of aquifer vulnerability.

BC have been classified (BC Ministry of Environment 2011). Aquifer polygons, aquifer classification, and various aquifer properties are available for certain aquifers in the province.

Some source water protection methodologies in use today include hazard mapping as part of the assessment process. For example, both Ontario's Source Water Protection process and BC's Wellhead Protection Toolkit include an inventory of potential contaminants and, therefore, these methods assess *vulnerability*, rather than *intrinsic susceptibility*. The assessment methodology tested by Banting and McBean (2011; Part II, Section 3) is a vulnerability assessment. Where vulnerability is assigned using one of these methods (Table 2) they too can be included in this WSRA, by reclassifying *vulnerability* using a 1-10 scale and including an assessment of *loss* (Equation 1).

CONDUITS:

Mines, open pits, or boreholes into the subsurface, including geotechnical and water wells provide pathways through which a contaminant from the surface can move directly into a deep aquifer. By acting as a bypass, these features, referred to as *Conduits*, increase the natural intrinsic susceptibility of an aquifer at the local scale. An inventory of potential conduits within the study area must be completed. The level of threat provided by the conduit is then established. For example, well construction properties (e.g., presence of a well cap) can be used to determine the probability that a particular well could act as a conduit (Simpson et al. in review). A conduit's level of threat is classified using a scale of 1-10; where no conduits exist, a score of 0 is given.

Conduits increase the susceptibility of an aquifer. Therefore, the combined aquifer susceptibility is the intrinsic susceptibility plus the conduit score (maximum of 20):

$$\textbf{Aquifer Susceptibility } (S_A) = \textbf{Intrinsic Aquifer Susceptibility } (S_I) + \textbf{Conduit } (C) \quad [2]$$

STEP 5 – COMPLETE A HAZARD INVENTORY

Areas of high *susceptibility* are seldom at real risk without a source of contamination. Therefore, it is necessary to include an inventory of potential hazards. Hazards may be quality-related (such as contaminants) or quantity-related (such as large water extraction volumes).

CONTAMINATION HAZARDS

The *threat* represented by each hazard source is qualified based on factors specific to the chemical(s) (toxicity and environmental fate), its potential magnitude (onsite quantity and spatial extent), and the probability that each will be released to the environment:

$$\textbf{Chemical Hazard Threat } (T_H) = \sum \textbf{(Chemical Intensity (CI) x Quantity (Q) x Extent (E) x Probability (P))} \quad [3]$$

where,

$$\textbf{Chemical Intensity} = \textbf{(Toxicity + Environmental Fate) / 2} \quad [4]$$

Quantity = Relative volume of point or non-point source contaminant;
Extent = Spatial footprint of area exposed to threat of contamination; and
Probability = Likelihood of hazard threat occurrence

A detailed and thorough hazard inventory would involve detailed onsite investigations throughout the study area. However, this task would be extremely time consuming. A hazard inventory can be most readily completed using data that are already available:

1. Records (e.g., permits, licenses, etc.) for operations of interest, such as landfills, gas stations or hazardous waste storage facilities.

2. Utility pipelines, such as sewer, oil and gas are often mapped accurately and readily available.

3. Land use data are also often available and can be used to map potential hazards, based on the typical hazards found on a particular land use type.

Assumptions made while compiling the hazard inventory can be confirmed through site investigations or aerial photographs.

Once a hazard is identified, it is analysed further to determine the relative hazard threat (Equation 3).

Chemical Intensity: Using data compiled by the Ontario Ministry of Environment (2004), each contaminant is first assigned a toxicity and environmental fate (each on a scale of 1-10). The chemical intensity of each contaminant is then calculated using Equation 4.

Quantity: The quantity stored or used on each parcel must be estimated (scale of 1-10) by persons with local knowledge of common practices or using other available data.

Probability: The likelihood/probability of release to the environment must be ranked (1-10). This probability is based on several factors, such as the level of spill response in the area, legislative requirements of storage and use of contaminants, as well as local or industry best management practices (BMPs).

Extent: The extent is the spatial footprint of contamination. The extent of potential release is expressed as a percentage of the land base being analyzed (e.g., manure spreading over 80% of a parcel of land is assigned a level of 8). Where a point source is mapped over the entire expected extent of contamination, an extent rating of 10 is assigned.

Evaluating the factors of quantity, extent and probability heavily relies on accurate data or a high level of local knowledge. Depending on the level of available information, the contaminants can be assessed by group (e.g., agricultural waste) or by individual contaminant (e.g., nitrate, pathogens, etc.) and/or generalized by operation type (e.g., dairy farms) or by individual operations.

STEP 6 – ASSESS THE POTENTIAL CONSEQUENCES

Loss is the consequence of the resource becoming deteriorated either in terms of its quality or quantity. This factor has environmental, human health and economic consequences; one or more indicators can be used for this assessment. The choice of indicator should be based on the values of the community,

but may be limited by data availability and resources. From a human health perspective, for example, an analysis of the number of people affected by contamination could be used. Where ecosystem health is of primary concern to a community, aquifers with high degrees of connectivity to surface water, where that surface water is deemed important, may be assigned a higher level of contamination consequence. From a financial perspective, the replacement costs or economic impacts due to contamination or water supply loss can also be used to assess consequence. Once a community decides the loss factor that is important, it must be assessed spatially using a standard methodology. Some examples are included in the example application, below. Once the loss is assessed, the consequences are reclassified by importance using a 1-10 scale.

STEP 7 – ASSESS CURRENT RISK STATUS

The determination of risk in this step is described within the context of contamination of a groundwater system. Using the results of Steps 4 and 5, the vulnerability of the groundwater system is first calculated using Equation 5.

$$\textbf{Vulnerability } (V_H) = \textbf{Aquifer Susceptibility } (S_A) \times \textbf{Hazard Threat } (T_H) \quad [5]$$

These results should highlight areas where potential contaminants exist and areas where the physical system is prone to contamination. These areas are, therefore, the most vulnerable to groundwater contamination. The results of this step need to once again be reclassified using a 1-10 scale.

Although groundwater may become contaminated, where there is no consequence (as defined by the values of the community), there is no risk. Therefore, the vulnerability above must be combined with the loss analysis using Equation 1.

Following the calculation of risk, the final results are reclassified with a 1-10 scale.

The overall Groundwater Quality Risk Assessment calculation is shown in Figure 2.

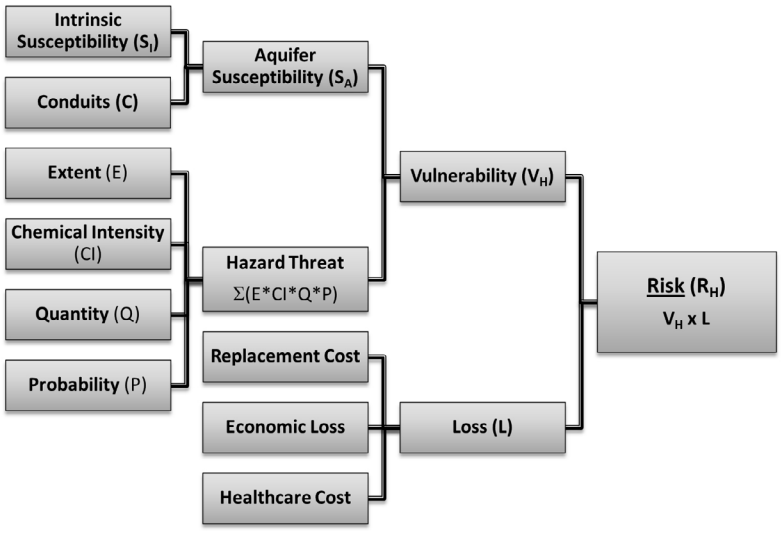


Figure 2: Groundwater quality risk assessment methodology

STEP 8 – DEVELOP MITIGATION STRATEGY

Although this **risk assessment** is an indicator method of current risk level, it can also be used as a planning tool. Apart from chemical intensity and intrinsic aquifer susceptibility, the input variables of this methodology are not static. One of the strengths of this method is the ability to analyse the components individually in order to reduce the overall exposure to risk by increasing resistance and capacity. In order to efficiently make changes toward a reduced risk exposure, it is common to use back-casting. This involves working backwards from a 'desired future state' to determine the changes in laws, policies, behaviour and management practices needed today to achieve the goal of water security.

The **vulnerability assessment** highlights areas where a high hazard value is located over a susceptible aquifer or, in the case of a surface water body, in a contributing area for surface runoff, drainage, or groundwater discharge. Each contaminant can then be matched with a management strategy, either regulatory (e.g. greater enforcement of existing environmental law, new laws) or non-regulatory (e.g., adopting best management practices or BMPs), in order to reduce contaminant quantities, extents or probability of release in certain areas. Regulatory examples may include mandating secondary containment of storage facilities, nutrient management plans, septic system maintenance or spill response plans, to name a few. Non-regulatory efforts, such as increased education of the public and industry, may also reduce the likelihood of contamination. Higher standards for the construction, management and closure of potential conduits, such as wells or mines, would reduce aquifer susceptibility. Each of the above is an example of means to increase resistance, thereby reducing vulnerability.

The **Loss analysis** is a planning tool that enables a community to reduce risk by strategically increasing their capacity. For example, areas prone to a high loss potential should be considered for increased monitoring efforts. As well, contingency response plans could be developed for use in the event of contamination. For example, municipal water lines could be extended into vulnerable areas as a backup supply, or filtration systems might be developed and used on an as needed basis.

Through changes to resistance and capacity, a community's **vulnerability**, **loss** and, subsequently, overall exposure to **risk**, can be strategically reduced over time.

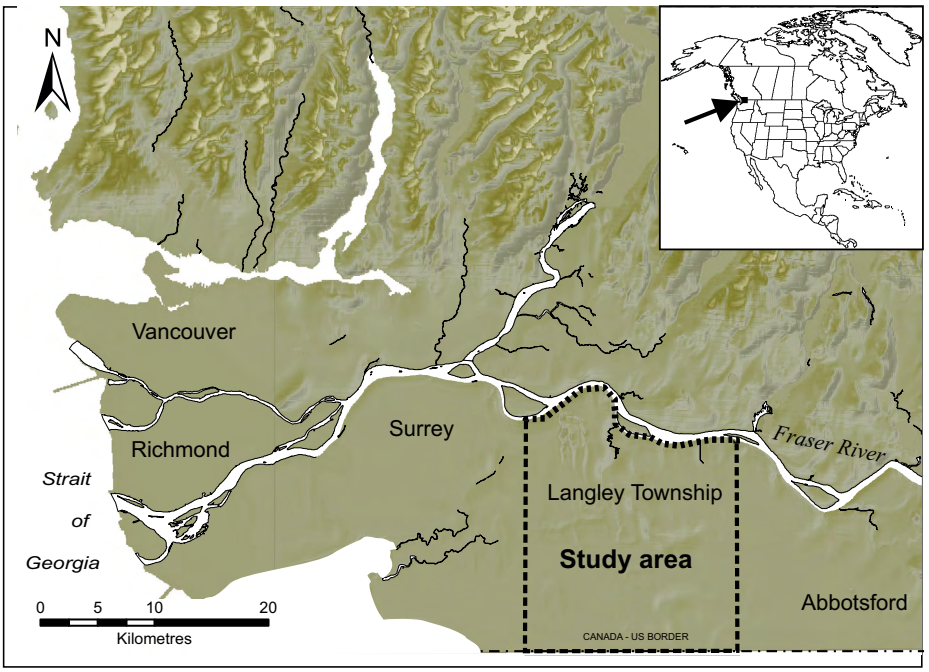
APPLICATION OF THE GROUNDWATER QUALITY RISK ASSESSMENT METHOD

The Groundwater Quality Risk Assessment method (one component of the Water Security Risk Assessment (WSRA) framework) was applied to the case study community, Township of Langley, BC. The focus on groundwater quality in this example is a result of the high dependency of the community on groundwater as well as the variety of land uses that may host contaminants. The WSRA framework is designed to facilitate communities using indicators that suit their values and data availability.

STUDY AREA

The Township of Langley (the Township or ToL), is located 45 kilometres east of the City of Vancouver, in the Lower Fraser Valley, southwestern British Columbia (Figure 3). Historically, a highly productive agricultural community, the Township is experiencing considerable urban growth; the current population of approximately 100,000, is expected to grow to 165,000 by 2026. Today, much of the rural area is serviced by approximately 7,600 private wells; the more urbanized areas are serviced by the municipal system. Nearly all agricultural activity is sustained through private wells and accounts for over $200 million in annual farm sales (Statistics Canada 2007). The municipal system relies on 18 production wells in addition to surface water[1] from the Greater Vancouver Water District (GVWD). Overall, approximately 80% of residents use groundwater for their water needs; therefore, the overall social and economic health of the Township is highly linked to groundwater. Nitrates sourced from agricultural fertilizer and septic systems are known to negatively impact groundwater quality throughout the Township (Carmichael et al. 1995).

Figure 3: Map of the case study area. Township of Langley shown in the Lower Fraser Valley, British Columbia.



STEP 1: DEFINE THE SCOPE AND SCALE OF ASSESSMENT

To adequately test the WRSA framework, the scale of application was set as the entire municipality, thereby capturing a wider breadth of physical and social characteristics. This scale was thought feasible as the resolution of the available data did not vary spatially.

[1] GVWD water is sourced from surface watersheds in the mountains to the north of the City of Vancouver – remote from the study area. Water is piped to the Township.

The resources devoted to this project were not sufficient to complete a parcel by parcel hazard inventory. Therefore, land-use data were used to infer the likely location of potential contaminant threats. In doing so, the resolution of the assessment was set at the scale of individual parcels.

The majority (~80%) of water used for both agriculture and potable uses is sourced from local groundwater. If the groundwater were to decrease in quality, the Township would need to develop or obtain replacement water sources, a potentially costly proposition. This means there is a significant potential financial consequence if the resource is contaminated. Therefore, financial loss was included as part of the loss assessment. The Township contains critically important fish habitat, including approximately 700 kilometres of fish-bearing streams and numerous wetlands. Groundwater contamination, negatively impacting freshwater ecosystems, is a reported concern of the community. However, given a lack of information on the interconnectedness of groundwater and surface water, this aspect of risk was beyond the scope of the case study.

STEP 2: ASSEMBLE AN ASSESSMENT TEAM

As a groundwater-dependent water purveyor, as well as a local government that makes decisions related to land use, the Township itself was viewed as a necessary partner for this assessment. Township staff provided input on values and issues as well as data. With agriculture being a large part of the Township's economy and community, the Ministry of Agriculture and Lands (MAL) was also identified as a key partner. Both MAL staff and industry representatives from various agricultural sectors (e.g., poultry producers, berry, etc.) were identified as stakeholders and sources of information including data on potential losses and typical hazard quantities and extents. The Ministry of Environment has several roles within the Township, including monitoring water quality, regulating wells construction and closure, and providing data and expertise related to the hydrogeology of the study area.

STEP 3: PREPARE INFORMATION REQUIRED TO ASSESS RISK

The risk framework was best completed within a GIS, and compiling necessary, GIS-ready, data was crucial. Intrinsic aquifer susceptibility had been previously assessed (Golder & Associates 2005) and the Township supplied these spatial maps. Data for potential conduits (wells) are collected and archived by the BC Ministry of Environment; these data are freely available from the provincial geographic information warehouse, GeoBC. BC Assessment authority provided the land-use data, necessary for the inventory of potential hazards; MAL provided more detailed land-use data for within the Agricultural Land Reserve (ALR). The Township provided other GIS data (e.g., municipal water and sewer service areas) that were necessary to infer other possible hazards (e.g., onsite sewage disposal) and losses (e.g., areas on wells vs. water utility). Finally, the Township provided data on municipal capture zones (Golder & Associates 2004).

STEP 4: ASSESS AQUIFER SUSCEPTIBILITY

Golder & Associates (2005) completed a Township-wide intrinsic aquifer susceptibility mapping project, using the Aquifer Vulnerability Index (AVI) method (Van Stempvoort et al. 1993). AVI is simple to use and requires only two parameters: the thickness and hydraulic conductivity of each layer above the aquifer. The Intrinsic Aquifer Susceptibility is calculated as the sum of the hydraulic resistance, c, for each layer:

$$\mathbf{c} = \sum \mathbf{(d/K)} \quad [6]$$

where,

d = layer thickness [Length], and
K = hydraulic conductivity [Length]/[Time].

The hydraulic resistance is calculated on a well by well basis, and a map is generated by contouring the results.

The man-made conduits which represent the biggest threat to groundwater quality are the estimated 8,000 to 9,000 wells that have been drilled in the Township over the last century. The magnitude of the susceptibility-increase these wells represent depends on the depth of the well; however, the probability that the well will act as a conduit depends on the well construction and location characteristics. Each well is assessed based on Table 3 and the overall score for each well within a 50m x 50m grid cell is summed. The score for each cell is added to the AVI value to yield an overall Aquifer Susceptibility (Figure 4).

Table 3: Rating scheme for assessing the level of Conduit threat provided by a well

Construction	Score	Characteristic
Prescence of a well	0	No well present on the property
	1	Well present on the property
Effective surface seal	0	Good seal installed
	1	Adequate seal installed
	2	Seal installed but characteristics are unknown or are not ideal
	3	Seal not installed
Well cap cover	0	Watertight cap installed
	1	Adequate cap installed
	2	Inadequate/no cap installed
Likelihood of ponding around the wellhead	0	Ponding is unlikely
	1	Ponding is probable
	2	Ponding is highly likely
Abandoned	0	Well in use or closed
	2	Well likely abandoned and in disrepair

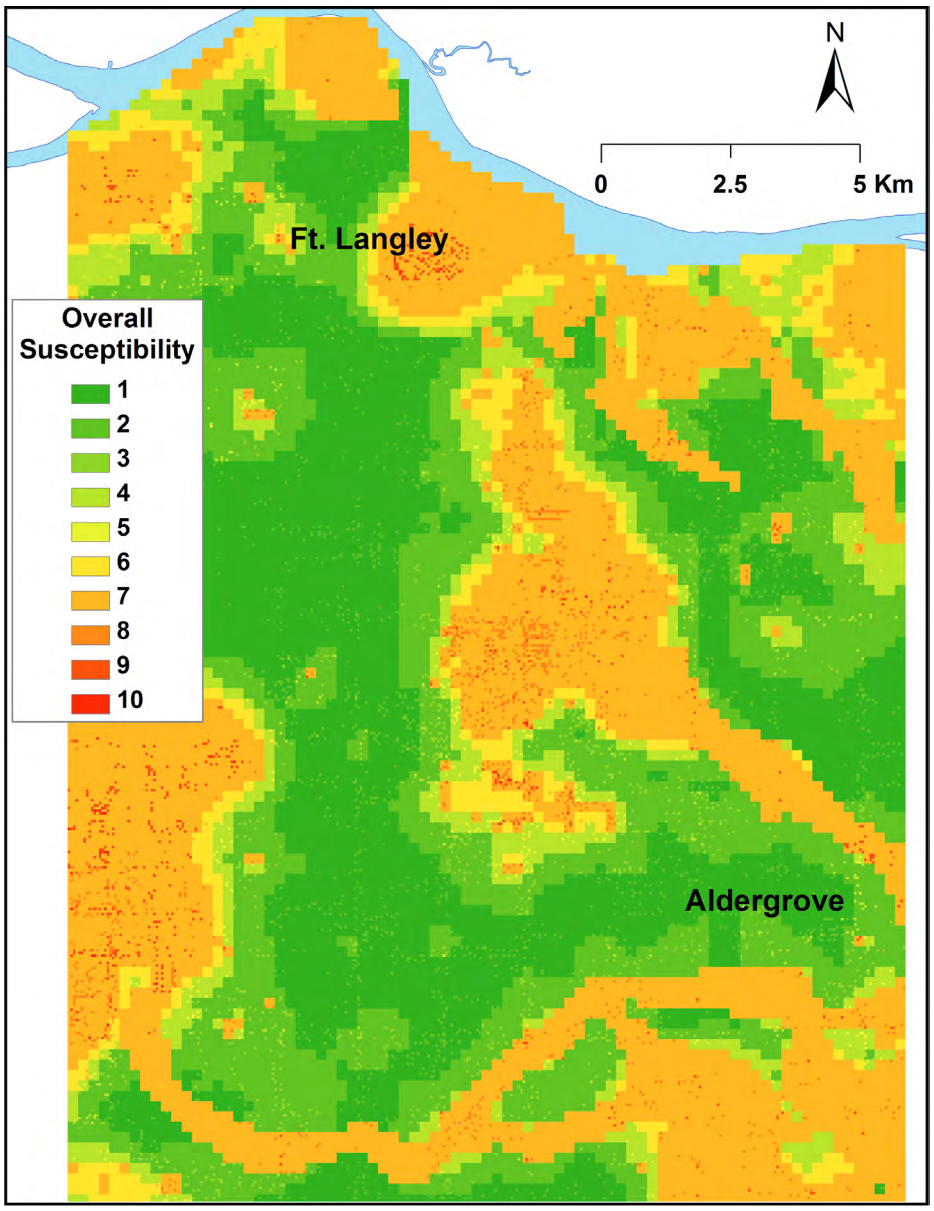


Figure 4: Aquifer Susceptibility map

STEP 5: COMPLETE A HAZARD INVENTORY

Detailed chemical hazard information was not available for the study area; therefore, land-use data, which are readily available, were used. Land-use information was classified into the North American Industry Classification System (NAICS). These data are used to populate each parcel with the typical contaminants found on the land use type (U.S. Environmental Protection Agency 2004). Using these assumed hazards, the threats were assessed as per Step 5 of the WSRA framework. Using a custom Microsoft Access database, the quantity and probability of release were assessed by chemical group for each land-use type. These were combined with the chemical intensity and extent using Equation 3, to calculate a hazard threat score for each parcel, followed by a reclassification using a 1-10 scale (Figure 5).

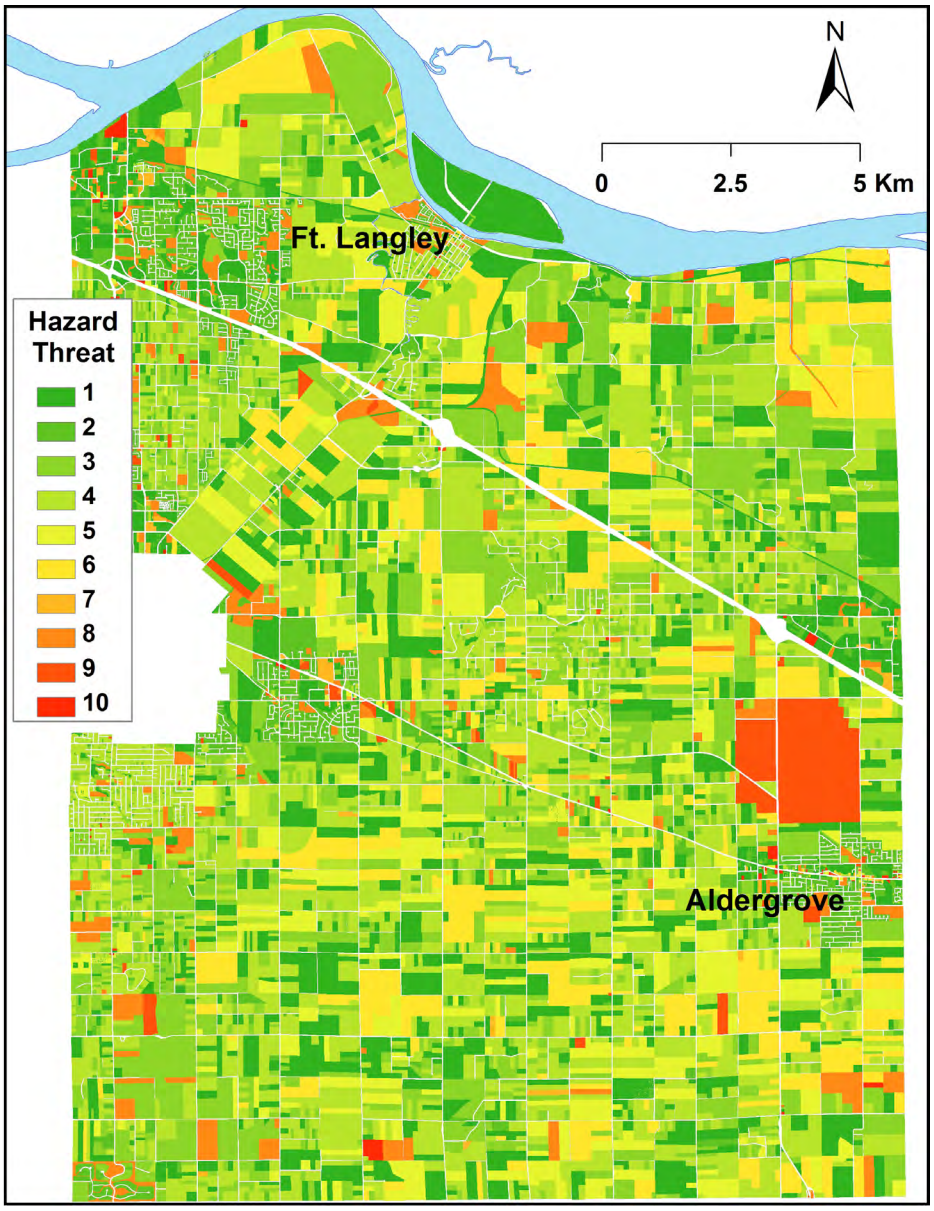


Figure 5: Hazard Threat Assessment

STEP 6: ASSESS THE POTENTIAL CONSEQUENCES

There is a large potential financial consequence if the groundwater resource is contaminated. Two major areas of financial loss are included in this assessment: 1) losses related to the replacement of potable water (both private and municipal systems) and 2) economic losses incurred by the community following the closure of a water intensive business (agriculture).

Private water systems using groundwater were assigned a dollar value consequence based on the cost of replacing their well with the least expensive option. This included drilling a new well (where the geology allows), hooking up to municipal water, or importing water. The municipal supply in the Township is also partially reliant on groundwater; loss of use of municipal produc-

tion wells requires the utility to purchase more water from a regional purveyor (GVWD). This increased cost of purchasing water is assessed to properties within the municipal well capture zones (Golder & Associates 2004).

Without a viable water source, agriculture, which represents over $200 million in economic revenue (Statistics Canada 2007) within the Township, would not be sustainable. The majority of water used for agriculture within the Township is sourced from groundwater. A new, deeper well would provide a relatively inexpensive alternative, where the geology allows. However, where this is not possible it is assumed that the farm would no longer be able to operate in the same manner. In order to assess the economic impact (to the surrounding community), the farms are assigned a loss based on the annual revenue generated by the business. Detailed farm-by-farm income was not available; average farm income (dollars/acre) for different crop types were used from readily available sources (US Census 2007).

The total potential loss was the combination of replacement cost and economic loss; the final loss assessment is reclassified using a 1-10 scale (Fig 6).

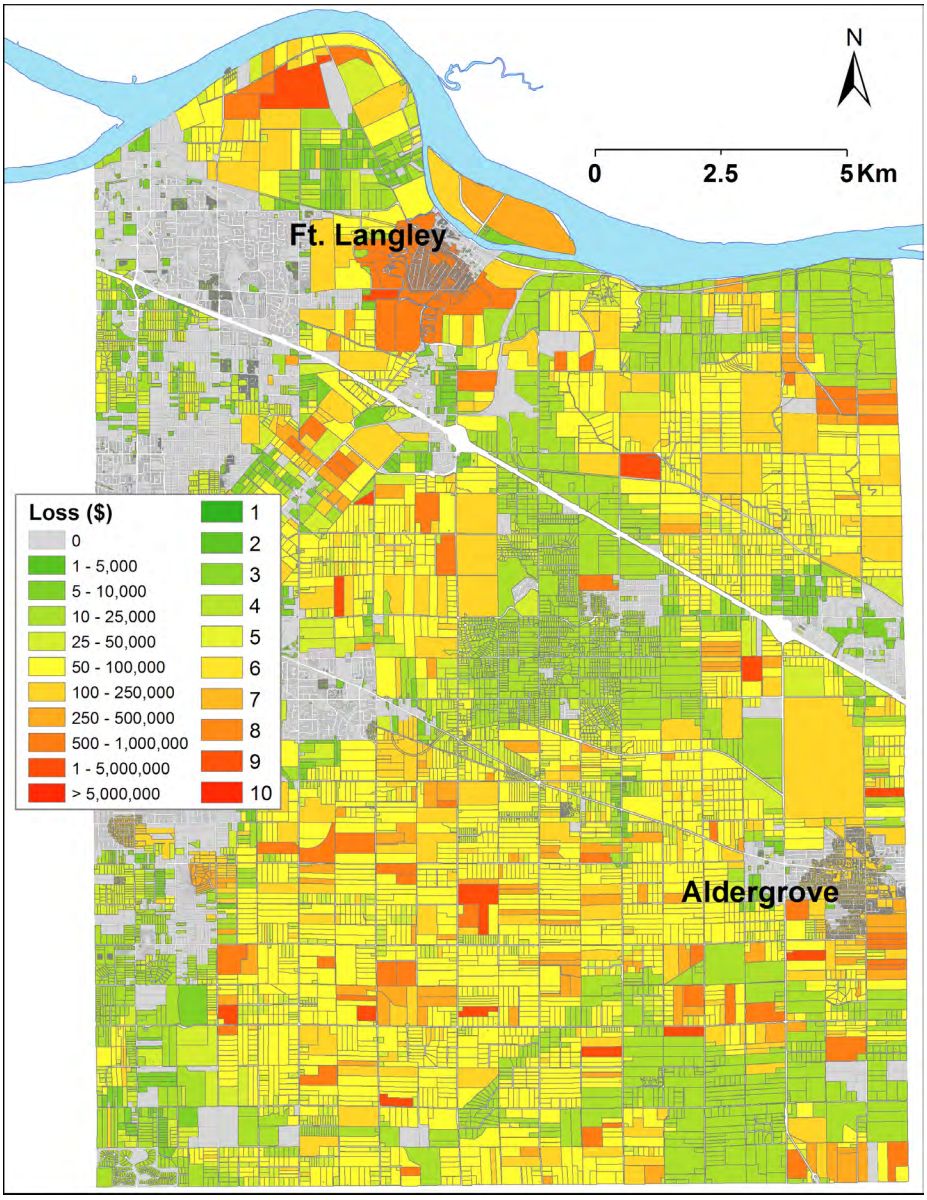


Figure 6: Total Loss in $'s; Total Loss for the base case reclassified using a 1-10 scale

STEP 7: ASSESS CURRENT RISK

With the susceptibility and hazard assessments complete, *vulnerability* was calculated using Equation 5 (Figure 7). The final step is the calculation of overall Risk using Equation 1 (Figure 8).

The results show high risk scores in areas where moderate to high scores were achieved in all three major indicators of risk: susceptibility, hazard, and loss. A notable area of high risk is south of Aldergrove, where high value agriculture is occurring far from municipal services over portions of the unconfined and susceptible Abbotsford-Sumas aquifer. Another high risk area is in and around Fort Langley, where a highly susceptible aquifer is tapped by a high density of wells; the highest producing Township production well is located in this aquifer.

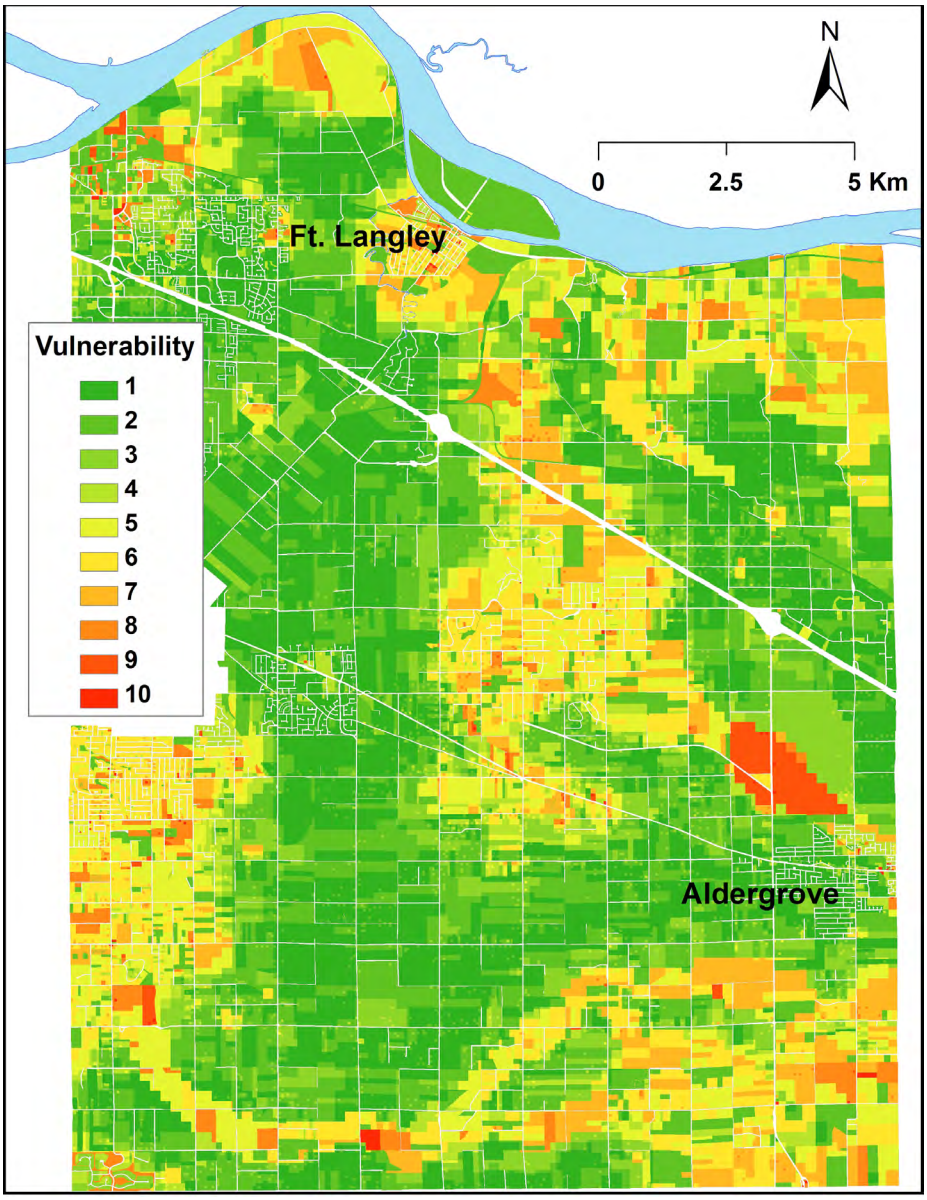


Figure 7: Vulnerability Assessment results

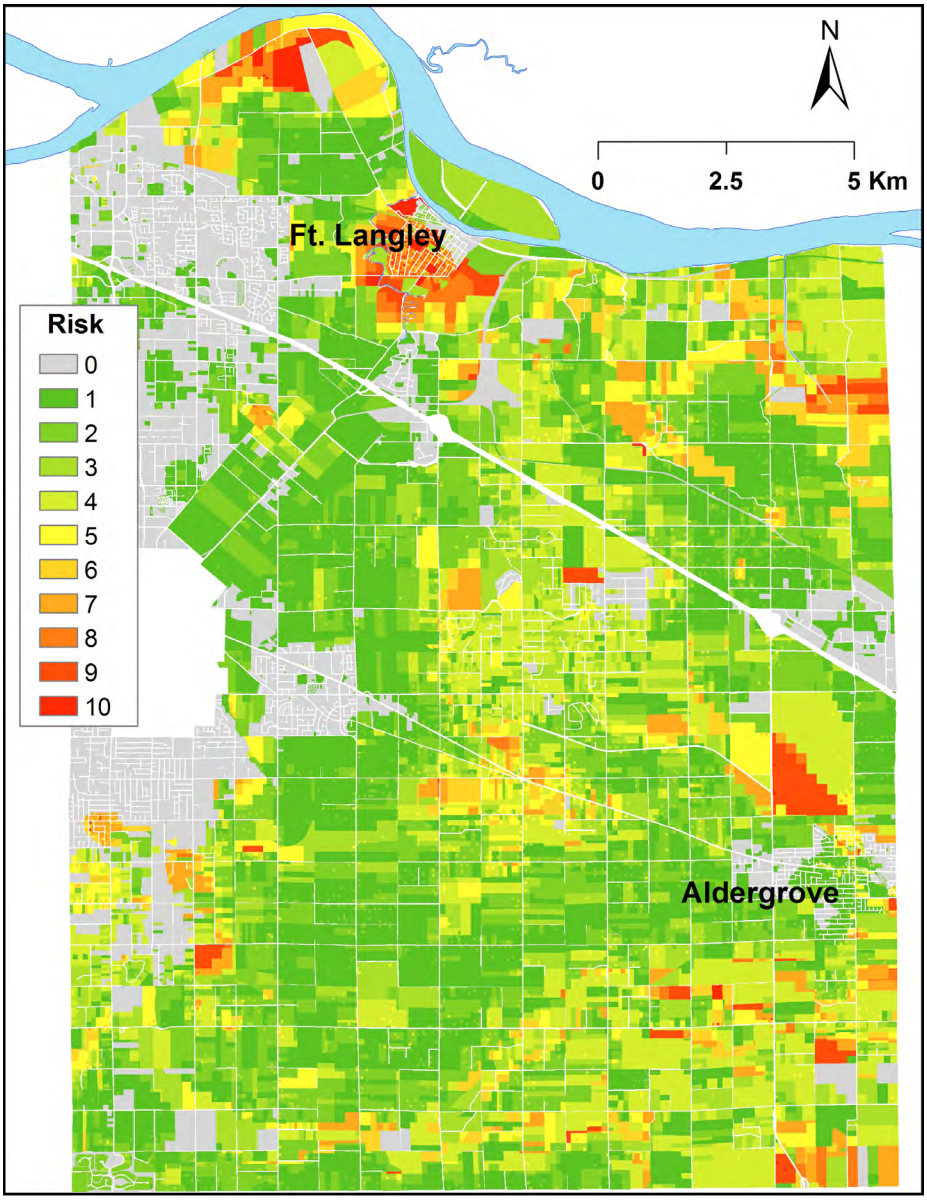


Figure 8: Final Risk results

STEP 8: DEVELOP MITIGATION STRATEGY

With areas of high risk identified, it is possible to look at the components (susceptibility, hazards and loss) individually to reduce risk exposure by increasing resistance or building capacity.

Intrinsic Aquifer Susceptibility is a static indicator; however, conduits may be dynamic (change over time). A high density of what are believed to be abandoned wells in and around Fort Langley, has a high potential to augment susceptibility because these wells may act as conduits. Management options to address this include education of well owners in the area and increased compliance and enforcement of well closure requirements. Parcels of high vulnerability (i.e., high hazard threat in areas of high aquifer susceptibility)

could be managed differently. For example, chemical storage in vulnerable areas could be subject to legislative requirements of secondary and tertiary containment. Homeowners in areas of high septic density (biological threat via pathogens – not assessed here through chemical intensity) could be the focus of an education campaign regarding septic maintenance. In the future, municipal planners could consider aquifer susceptibility when planning or changing land-use.

The potential consequence (i.e., loss) assessment can be used to direct increases in capacity. Given the high losses that could occur near municipal production wells (notably Fort Langley and south of Aldergrove) and irrigation wells of high value crops (e.g., poultry, berries), these areas should be subject to increased monitoring efforts. The municipal water utility may increase capacity by constructing backup wells to be used in the event of contamination. Further, the utility may increase its capacity by extending water infrastructure into urban areas where deeper aquifers do not exist and by sizing municipal water lines to handle agriculture use, if necessary.

The WRSA framework is intended as a planning tool. A critical component of a comprehensive risk assessment is *adaptation*, i.e., having plans in place to link the findings back to behavioural change. Through changes to resistance and capacity, a community's *vulnerability*, *loss*, and subsequent overall exposure to *risk*, can be strategically reduced over time.

Engagement of stakeholders is also an essential component of the Water Security Risk Assessment framework. Continued buy-in from citizenry and policy-makers through civic engagement and general awareness of water-related issues are critical for linking assessment to change. Stakeholders also provide valuable local knowledge and access to data sources. Both of these are necessary in order to accurately locate and assess hazards within the study area. The loss assessment, besides requiring a certain level of information and expertise, also relies on stakeholder values in order to determine what components (e.g., ecosystem loss vs. financial loss) to use as indicators of loss.

RECOMMENDATIONS AND FURTHER AREAS FOR RESEARCH

Ongoing research at Simon Fraser University aims to further develop the Water Security Risk Assessment (WSRA) framework through the incorporation of methodologies for assessing risk to groundwater quantity. The research also aims to validate the index-based risk approach presented here by comparison with a process-based groundwater flow and transport model.

Research is needed to develop surface water quality and quantity risk assessment methods that build on the overall WSRA framework. Ideally, both hydrologic components (surface water and groundwater) and their respective attributes (quality and quantity) should be evaluated at a watershed scale to implement a WSRA.

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WATER SECURITY GUIDANCE DOCUMENT

PART 2 SECTION 3
WATER SECURITY VULNERABILITY SCORING METHOD - EVALUATING CONSEQUENCES RELATED TO ANTHROPOGENIC DISTURBANCE

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WATER SECURITY GUIDANCE DOCUMENT
PART 2 SECTION 3
WATER SECURITY VULNERABILITY SCORING METHOD

ABSTRACT

This section of the Water Security Guidance Document outlines the necessary steps to apply the Water Security Vulnerability Scoring method. 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. This is a general screening tool, which can be used to assess vulnerability related to a variety of natural infrastructure and contamination issues, in urban and rural settings. The methodology is applied to an aggregate extraction site in the Grand River Watershed in Ontario, and presents an example of how changing land use may change pathways.

THESIS RELATED TO THIS SECTION:

Banting, Cassandra. (in prep). **Development and application of a risk scoring method for aggregate mining extraction sites within the Grand River Watershed**. (Provisionary title). MASc Thesis, School of Engineering, University of Guelph.

WATER SECURITY GUIDANCE DOCUMENT

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BACKGROUND: KEY ISSUES AND CONTEXT

Calculating risk to groundwater and surface water, both in terms of water quality and quantity, represents a useful means to prioritize issues for municipal water management. The purpose of this Vulnerability Scoring method is to assess the impacts of degradation of natural infrastructure or the use of anthropogenic infrastructure changes that may influence pathways of a contaminant source to impact the water supply system. The basis of the methodology follows the Hazard Ranking System (HRS), an approach used by the Environmental Protection Agency (EPA) to evaluate contaminated sites and the threat posed to people and/or sensitive environments.

The vulnerability score is only one component of a comprehensive risk assessment, since it does not include consequence or loss (for a comprehensive risk assessment method refer to *Part II, Section 2 Water Security Risk Assessment*). The method presented herein focuses on the vulnerability portion of risk assessment, to quantify relative vulnerability. This type of vulnerability assessment is especially important in Ontario, to fulfill the requirements of the Clean Water Act, 2006, S.O. 2006, c.22. The Act constitutes the province's framework for planning and implementing source protection (refer to *Part III, Section 6*, Text Box 1). Conservation authorities are leading the planning process for source protection, including the development of assessment reports that determine vulnerable areas where contaminants may migrate toward drinking water intakes or wellhead protection zones. This Vulnerability Scoring tool is used on a much smaller scale than source water protection plans and permits focus on a particular land-use issue.

This Vulnerability Scoring method uses three components to determine a vulnerability score: the transmission pathway, the contaminant source characteristics, and the target groups affected by the contamination. It also looks at three pathways: groundwater, surface water overland flow (or runoff), and groundwater to surface water. The groundwater migration pathway is described by the potential movement of contaminants within the groundwater to nearby wells and includes surface water moving to the groundwater. The surface water overland flow pathway is described by the potential movement of contaminants on the surface, or near the surface, which can travel on the ground surface to nearby bodies of water. The groundwater to surface water pathway describes the potential migration of a contaminant source from the groundwater into surface water, which occurs when aggregate material is extracted and the removal of surface materials creates a migration pathway.

PURPOSE OF THE METHOD

The purpose of this method is to supplement decision-making in all levels of government, particularly at the watershed and municipal scale. It can be used to assist communities in decision-making on projects that may alter the natural landscape. The principles of this tool can be applied to other uses and purposes, and is not restricted to evaluation for an aggregate pit. Alternate uses of the HRS methodology are primarily focused on assessing the relative threat that sites (areas where hazardous substances are located) with actual or potential contaminant release pose to humans or sensitive environments. For example, communities dealing with old landfills that need remediation

may find the HRS methodology useful. The tool can also be adapted for use in wellhead protection planning where a site vulnerability assessment is needed, as Hathhorn and Wubbena (1996) discussed. Since aggregate mining is a highly contentious issue within the Grand River Watershed of Ontario, the case study demonstrates the principles in application to this particular type of land-use activity.

INTENDED USERS

This method is intended for community water groups, aggregate mining industry officials, water managers, municipal water policy and decision-makers, source water protection groups, provincial water planners and watershed groups.

DESCRIPTION OF METHOD

The Vulnerability Scoring method uses three pathways: groundwater migration, surface water flow to groundwater migration, and groundwater to surface water migration. A score for each of these pathways is calculated as a function of three components: likelihood of release to the transmission pathway, characteristics of the contaminant sources, and targets (people or sensitive environments), which may be impacted by a contaminant release. The tool uses a 'bin' methodology where data fall into relevant categories and then are scored accordingly. This bin methodology allows for rapid assessment. The tool uses an additive-multiplicative algorithm to combine system parameters using simple or weighted sums and multiplication of the parameter scores.

The likelihood of release or transmission score is calculated using factors such as contaminant containment type, and depth to groundwater. The contaminant source characteristic component requires information about the types of chemicals present, and their associated toxicity and chemical quantity values. The target component is based on the population using nearby wells for drinking water or other uses, or using surface water as drinking water. The groundwater and groundwater to surface water pathways also evaluate the risk to human food chain threats, if applicable, as well as sensitive environments, including protected wetlands.

The Vulnerability Scoring method can be used for a range of environmental issues, which relate to changes to the natural landscape. The tool uses a structured analysis approach for scoring sites by assigning values to factors that relate to risk, based on the conditions at the site. This tool can be used as a screening tool to evaluate how altering the natural infrastructure may alter the relative threat posed by a contaminant to certain pathways. When completing a risk assessment, such as the Water Security Risk Assessment approach (outlined in section *Part II, Section 2* of this Guidance Document), two crucial steps are mentioned: step 4 – assessing intrinsic susceptibility, and step 5 - completing a hazard inventory. This tool addresses both intrinsic susceptibility and hazard inventory in steps 3 –(transmission and likelihood of release) and 4 (contaminant source characteristics) by quantifying susceptibility and different hazards. The scoring tool methodology allows the user to input specific variables into a score that then gives a relative vulnerability value that can guide the user in decision-making and priority-setting.

A STEP-BY-STEP GUIDE TO APPLYING THE VULNERABILITY SCORING METHOD

Table 1: Summary table outlining the fundamental steps of risk scoring

Step	
1	Define the Scope and Scale of Assessment
2	Prepare the Required Data
3	Transmission and Likelihood of Release
4	Contaminant Source Characterstics
5	Targets
6	Assess the Potential Consequences of the Vulnerability Score

STEP 1 – DEFINE THE SCOPE AND SCALE OF ASSESSMENT

The first step in applying the tool is to specify the study area. The scale of the project must be large enough to include the site under investigation (e.g., an aggregate extraction site), the nearby contaminants (which may produce a contamination event) and the elements of the site that may operate as a transmission pathway to nearby groundwater wells or water supply intakes. Although the scale can vary, a larger study area will produce greater variation in data. As such, limiting the assessment area to one particular site (e.g. an aggregate extraction site) at a time is recommended. Furthermore, the HRS methodology typically recommends a 6.5 kilometre buffer around the site of investigation so that drinking water supply wells and intakes that are in close proximity to the study area are taken into account in the assessment.

The Vulnerability Scoring method considers three pathways: groundwater migration, surface water overland flow, and groundwater to surface water migration. Using a matrix, shown in Table 2, the contaminant pathways warranting attention can be identified. First, each contaminant is specified and related to a pathway; then each pathway is evaluated separately. This first step in the assessment determines the likelihood that a contamination event will occur within the delineated region through that specified pathway.

Table 2: Potential Contaminant Pathways

	Ground water transmission	Surface Water Overland Flow Pathway	Groundwater to surface water				
		Drinking Water Threat	Human Food Chain Threat	Environmental Threat	Drinking Water Threat	Human Food Chain Threat	Environmental Threat
Chemical X							
Chemical Y							
Chemical Z							

STEP 2 – PREPARE THE REQUIRED DATA

Each potential pathway requires different source, transmission and receptor group data. Table 3 outlines the factors related to each component and pathway of the site score and indicates the type of data required. (Since this is not a complete risk assessment approach, data relating to loss is not used in this methodology. However, comprehensive risk score, including vulnerability and loss, can be achieved by using the framework outlined in *Part II, Section 2: Water Security Risk Assessment*.)

Table 3: Data Required for Vulnerability Scoring Method

	Contaminant Source Type	Transmission	Targets/Receptor
Groundwater	- toxicity - mobility - chemical quantity	- containment factor - net precipitation - depth to aquifer - travel time (based on conductivity and thickness of hydraulic layer)	- nearest well - water used for resource purposes - wellhead protection zone
Surface Water Overland Flow	- persistence - toxicity - chemical quantity - bioaccumulation - ecotoxicity	- drainage area - surface soil group - rainfall/runoff value - distance to surface water - potential for flooding (design/construction) - flood frequency	- nearest water intake - resources
Ground Water to Surface Water	- toxicity - mobility - persistence - ecotoxicity - bioaccumulation - chemical quantity	- containment - net precipitation - depth to aquifer - travel time factor	- surface water intake - water used for resources - sensitive environment - human food chain

Within the original hazard ranking system (HRS) framework, the EPA has supplied a chemical data matrix that provides substantial quantities of the contaminant data, such as toxicity, mobility, persistence, and bioaccumulation potential. These values may also be calculated using first principles. The HRS methodology evaluates three measures of toxicity in a tiered approach that uses acute data only when the other data are not available. The three measures are: cancer slope factors; reference doses for non-carcinogen effects for chronic exposure; and, acute toxicity using the lethal dose or lethal con-

centration at which fifty percent of experimental animals die. The methods are outlined in detail in the HRS Final Rule (EPA 1990).

Geographic data are commonly available as public geographic spatial datasets, which can be viewed and manipulated in a Geographic Information System (GIS). Depth to aquifer, travel times, well locations, and distances between sources of contamination and receptors, such as nearest intakes or wells are commonly available. These GIS maps are often provided to the public by the local municipality, the conservation authority, provincial levels of government or other special interest groups. In Ontario, Source Water Protection documents provide many applicable data. For contaminant specifics, site studies may need to be conducted to determine the location and types of nearby potential chemical hazards.

STEP 3 –TRANSMISSION AND LIKELIHOOD OF RELEASE

The likelihood of a chemical being released to a pathway is an essential part of calculating the vulnerability score. If there is minimal chance of transmission or likelihood of release of the chemical, then the overall score will be low.

Table 4 summarizes the components for calculating the transmission component of the vulnerability score for groundwater pathway, as an example. The reclassification values are determined through a series of steps outlined in the HRS Final Rule (EPA 1990). Their magnitude is a function of the chemical characteristics or the variable being examined. This method controls the relative importance of each of the pathway factors.

The **Likelihood of Release** is the higher of the **Observed Release** or **Potential for Release**, where:

Potential for Release = Containment x (net precipitation + depth to aquifer + travel time) [1]

An **Observed Release** occurs if the measured concentration of the hazardous substance is significantly above background levels, and if that concentration can be reasonably attributed to the site (as determined by a team of experts having conducted site investigations). However, if there have been no observable releases recorded in previous monitoring or if a comprehensive site investigation cannot be completed, then the scoring will be completed using the **Potential for Release**.

Table 4: Transmission Component for Groundwater Pathway

Transmission		
	Based on	Reclassified to
Observed Release	0 if no release	0 or 550
Containment	10 for confined and well protected	0 - 10
Net Precipitation	precipitation - net evaporation for area	0 - 10
Depth to Aquifer	depth to aquifer used for drinking water	1 - 5
Travel Time	based on conductivity and layer thickness	1 - 35

STEP 4 –CONTAMINANT SOURCE CHARACTERISTICS

The next step is to quantify each source based on the characteristics as outlined in Table 5. As above, the groundwater pathway is used as an example. EPA has a superfund chemical data matrix (SCDM), which provides the known toxicity and mobility for the various pathways; these chemical data are used for assessing the potential risk of each source (EPA 2004).

Chemical Characteristics = Toxicity x Mobility x Chemical Quantity [2]

For example, benzene has a cancer slope factor between 0.05 and 0.5 mg/kg per day, and is classified as having a toxicity factor of 1000 (EPA 2004).

Table 5: Source Characteristics Component for Groundwater Pathway

Chemical threat		
	Based on	**Reclassified to**
Toxcicity	HRS SCDM hazardous substance factor values (EPA, 2004)*	0-10000
Mobility	HRS SCDM hazardous substance factor values (EPA, 2004)*	0-10000
Chemical Quality	based on the volume, or weight of contaminant source	0-1000000

*SCDM can be found online: http://www.epa.gov/superfund/sites/npl/hrsres/tools/scdm.htm

STEP 5 – TARGETS

The target component of the site score is based on the receptor groups of the potential contamination, such as municipal drinking water wells, private drinking water wells, and water used for resources such as irrigation. Table 6 indicates the components needed to calculate the target group component of the vulnerability score for a groundwater pathway as an example.

A target rating is calculated as:

Targets = (nearest well + population + resources + wellhead protection zone) [3]

Table 6: Target Component for a Groundwater Pathway

Targets		
	Based on	Reclassified to
Nearest well	distance of source to well – over 6.5 kilometers away will be assigned a value of 0	0-50
Population	based on the distance to well and population drinking from that well. The shorter the distance to the well and the larger the population drinking from the well then the larger the number. Tables given in HRS Guidance Document may be used for assigning values.	0-5200000
Resources	if water is used for irrigation, livestock, recreation use then a value of 5 will be assigned	0 or 5
Wellhead protection zone	source within or near wellhead protection zone will be assigned a higher value	0-20

STEP 6 – ASSESS THE POTENTIAL CONSEQUENCES OF THE VULNERABILITY SCORE

Calculating the final score is accomplished by combining the three components using Equations 4 and 5.

Groundwater Pathway Score = [(Likelihood of Release x Chemical Characteristics x Targets)/82500] [4]

Equation 4 is used to calculate a score for each pathway and then the root mean square equation (Equation 5) is used to determine the overall score, which ranges from 0 to 100.

Score = [(GW +SW + GWSW)/3]0.5 [5]

where,

GW = Groundwater score
SW = Surface water overland flow score
GWSW = Groundwater to surface water score
Each score is capped to a maximum of 100

This vulnerability scoring method, in accordance with the HRS methodology, can be used as a screening tool (since it is only one component of a comprehensive risk analysis). As such, where scores are greater than 28.5 a priority review may be recommended, warranting further investigation. However, more likely, this tool can be used as a comparative framework; using variation between two scores to determine how changing a migration pathway may

decrease or increase vulnerability. The vulnerability score is assessed on a ranked basis, with one contaminant receiving a particular score based on a relative basis among all others. Comparing site scores under different scenarios will also provide insight into the relative vulnerability of each contaminant. This methodology can be used as a priority setting approach and can compare pre- and post-anthropogenic land-uses in a particular region. If the site score has changed dramatically, then the following options are recommended:

- Removal of the source of contamination, or perhaps better containment structure for the possible sources of contamination;
- Removal of nearby wells (especially private wells) which may not follow the same testing as municipal drinking water wells;
- Demonstrate that the land-use change will cause too much of an increase to risk and the change should be altered before the excavation phase;
- Further investigation, sampling or site follow-ups should be completed.

EXAMPLE OF THE METHOD

This general method can be used to assess vulnerability related to a variety of natural infrastructure and contamination issues. However, for this case study, the tool is applied to an aggregate extraction site as an example of how changing the land use may change pathways.

Although the model employs a general methodology, the case study is specific to a natural infrastructure issue common within the Grand River Watershed: aggregate mining. Aggregate resources (including limestone, sand, gravel, clay, shale and sandstone) are significant non-renewable resources in southern Ontario, including the Grand River Watershed. The Ministry of Natural Resources (MNR) manages aggregate mining under the Aggregate Resources Act, R.S.O. 1990, c. A.8. Aggregate extraction is a provincial interest; therefore municipal governments must, in their land-use planning, be consistent with the articulated provincial policy related to aggregate resources. Other provincial policy affecting aggregate mining in southern Ontario includes the Greenbelt Plan (2005) and the Greater Golden Horseshoe Growth Plan (2006).

Aggregate resources are critical in the building of infrastructure. Southern Ontario is experiencing significant population growth and needs to replace aging infrastructure. Thus, the need for aggregate resources is real and present. However, aggregate extraction has implications for water quality and quantity. In short, the aggregate mining debate is a complex issue. For example, 18,000 tonnes of aggregate are used per kilometre of a two lane highway in southern Ontario (MHBC Planning and Golder Associates 2009). The Province's interest in aggregate mining includes a desire to keep market supplies close to the point of use. The Grand River Watershed contains considerable aggregate materials and is located within the Greater Golden Horseshoe of southern Ontario.

Increasing pressures from green space protection legislation, and source water protection plans have fueled resistance to future aggregate mining sites.

The current licensing process for aggregate mining sites does not require a risk or cumulative impacts assessment on a site. Gravel pits are a land-use activity, the cumulative effects of which may contribute to environmental degradation (GRCA 2009). The Vulnerability Scoring tool can address both cumulative impacts and provide a relative risk score for the site.

In Ontario, mining for the most valuable aggregate is often carried out below the water table. This practice may compromise the protective aquitard layer and alter the three pathways of concern. The Vulnerability Scoring tool can evaluate cumulative impacts of multiple sources of contamination on a particular site, or address multiple aggregate pits and quarries. Pits and quarries are often clustered together to access the aggregate materials, a fact current assessment procedures do not account for.

The case study aggregate site is located within the Grand River watershed, where approximately 82 percent of the population relies on groundwater for water supply (GRCA 2009). The Greater Golden Horseshoe Growth Plan anticipates continued high rates of growth and intensification of use in the watershed's cities over the next 25 years (GRCA 2009). A current provincial emphasis on infrastructure renewal and development may also increase demand for aggregate resources (GRCA 2009).

The case study aggregate site is located within the City of Guelph and the Township of Guelph - Eramosa border (Figure 1). The City's growing population over the last few decades has infringed the limestone quarry because of increased residential areas and major roadways being built around the quarry. A mix of land-use types, such as residential, roadways, and rural, all border the site. The City relies on 23 municipal drinking water wells (Aqua Resources 2010), three of which are within 5 kilometres of the site. The limestone quarry has recently broken through the aquitard and into the aquifer the City relies on for its water supply. The quarry dewaters 8,000 m3/day from the bedrock aquifer, significantly influencing the groundwater (Aqua Resources 2010). Currently, the quarry is hydraulically controlled; however, once the resources are exhausted the quarry will have altered the surface water and groundwater pathways (Aqua Resources 2010). The quarry will fill with water which will be controlled by the local water table level and this may impact the nearby municipal wells by changing the hydraulic conductivity or direction of groundwater flow.

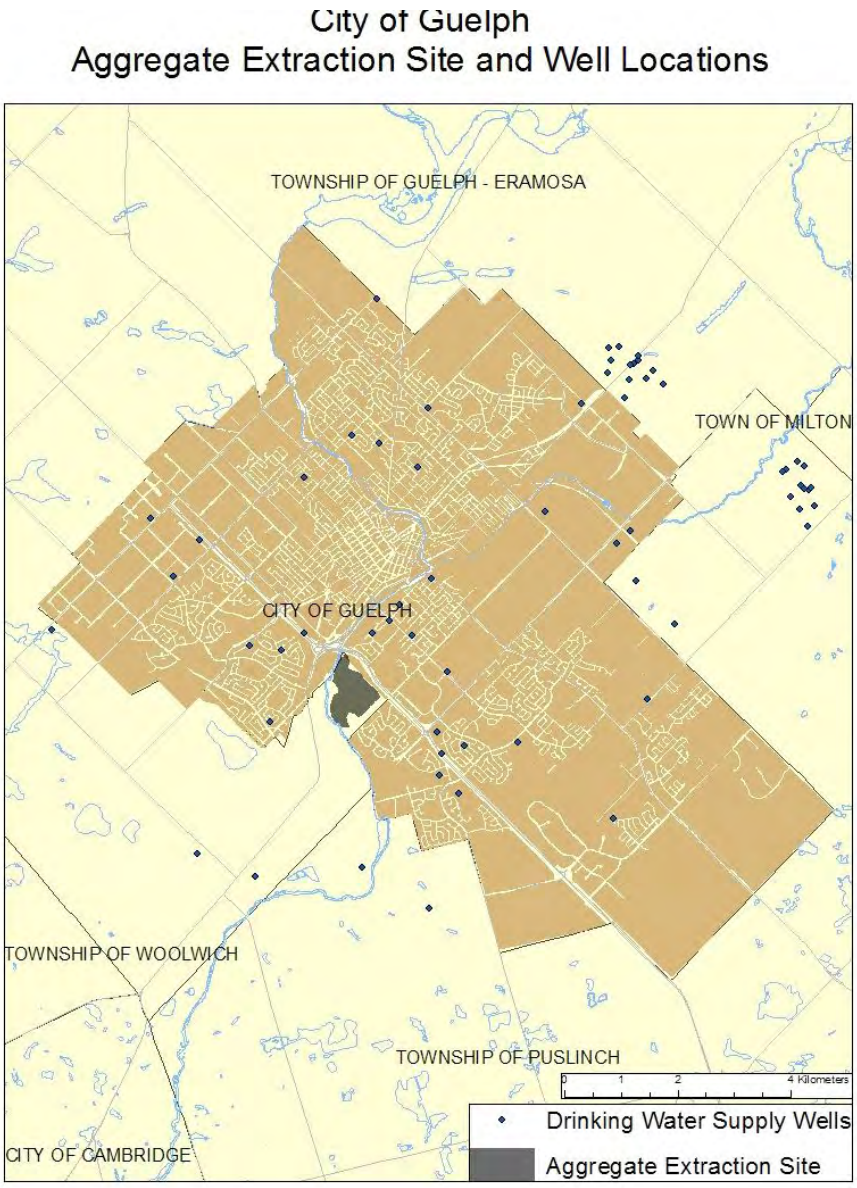

Figure 1: Location of Aggregate Extraction Site and Drinking Water Wells in Guelph

STEP 1 – DEFINE THE SCOPE AND SCALE OF THE STUDY

The scale of this case study is confined to a 6-kilometre radius surrounding the limestone quarry (Figure 1), in which the wells within that range are used for the target component of the scoring methodology. The potential contaminants are characterized as either being on site, or within a 0.5-kilometre radius of the site.

STEP 2 – PREPARE REQUIRED DATA

Data required to complete the assessment are best managed using a GIS database. Public GIS data sources can provide most of the data required for deter-

mining the score. Hydrogeological data can often be found in online GIS data, or printed maps from the local watershed authority, municipality or provincial level government.

STEP 3 – TRANSMISSION AND LIKELIHOOD OF RELEASE

The transmission pathway scores were calculated using the potential of release since there have been no observed releases of contamination at or around the site.

STEP 4 – CONTAMINANT SOURCES CHARACTERISTICS

Locating the specific contaminants on and near the site can be done with the aid of Google mapping or other satellite and orthophoto imagery, or reviewing source water protection documents which outline various threats to source waters. Conducting a final site assessment may be required to find any other sources of contamination. Specific containment data for each source must be found by contacting the responsible party for the source, such as containment characteristics for an underground gasoline storage tank.

Table 7 summarizes examples of the contaminants found near the site.

Table 7: Case Study Potential Contaminant Pathways

	Ground water transmission	**Surface Water Overland Flow Pathway**	**Groundwater to surface water**				
		Drinking Water Threat	Human Food Chain Threat	Environmental Threat	Drinking Water Threat	Human Food Chain Threat	Environmental Threat
Gas station with underground storage tank: Brenzene	x	x		x	x		x
Road Salt Application: Sodium chloride	x	x		x	x		x
Water Treatment Plant: Chlorine and Sodioun Bisulphate	x	x		x	x		x

STEP 5 – TARGETS

The only pathway having a final score above 0 is the groundwater pathway. This is because surface water sources are not being used for drinking water purposes in Guelph, and therefore no target groups exist.

Table 8 outlines the final scores for each pathway using the example of benzene, which is a chemical associated with underground gasoline storage tanks.

Table 8: Pathway Score Sheet

		Trans-mission	Source Charac-teristics	Targets	Pathway score
Groundwater		129	10	580.5	9.08
Surface water/ overland flow	Drinking wa-ter threat	27	6	0	0
	Human food-chain threat	27	56	0	0
	Environmental threat	27	56	0	0
Groundwater to surface water	Drinking wa-ter threat	129	6	0	0
	Human food-chain threat	129	56	0	0
	Environmental threat	129	56	0	0

STEP 6 - ASSESS THE POTENTIAL CONSEQUENCES OF THE VULNERABILITY SCORE

To calculate the final score, Equation 5 is used. The value for the final score for the quarry is 6.42 for benzene, and 2.2 for pre quarry conditions. Demonstrating this value can be done in a variety of ways, but using colour coded bars may help to visually represent the data (Figures 2 and 3).

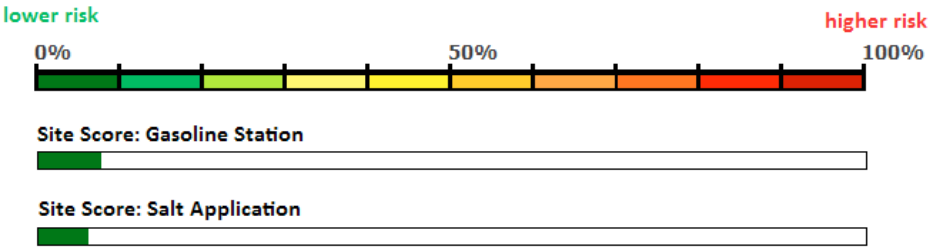

Figure 2: Vulnerability scores for two examples of sources of contamination: after aquitard removal

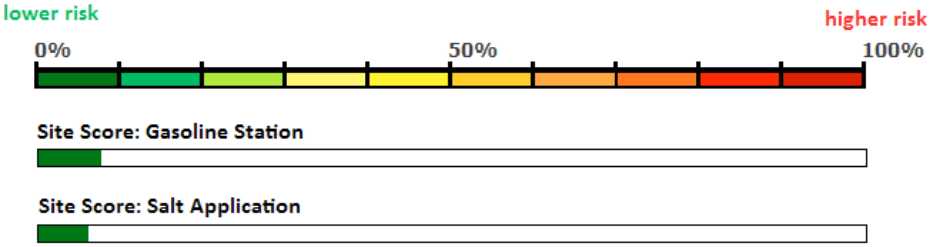

Figure 3: Vulnerability scores for two examples of sources of contamination: before aquitard removal

The colour bars can quickly indicate that the risk scores for those contaminants are low for the quarry site. However, these values are even lower when modeling conditions prior to the aquitard removal. Visually, one can see the risk score was lower for each source of contamination before the removal of the aquitard due to the quarry operations.

The final score can be used to prioritize decision-making. The vulnerability score does not demonstrate a comprehensive risk assessment to the site but may be used as an indicator for further site investigation.

Local concerns regarding the environmental impacts for new and expanded pits are strong. There is increasing pressure to find alternative sources of aggregate, such as recycled and reused aggregates supplies. Since aggregate mining is considered an interim land use, aggregate pit licences include rehabilitation plans. However, in 2009, 40% of pits and quarries had not yet initiated progressive rehabilitation (Skelton Brumwell Associates and Savanta Inc. 2009). Decommissioned aggregate sites may pose significant risk especially when the aquitard has been compromised and the sites have been repurposed as dumping sites.

RECOMMENDATIONS AND FURTHER AREAS FOR RESEARCH

Finding the best-suited risk assessment methodology for different environmental problems is an important aspect of assessing water security. Looking at contaminant transmission pathways that are affected by infrastructure serves to broaden the scope of problem investigation. Using the Vulnerability Scoring tool can help to illustrate the difficulties in capturing complex relationships between site characteristics. Cumulative risk involving multiple sources and exposure pathways can be difficult to quantify. The Vulnerability Scoring method organizes and analyzes multiple threats and exposure path-

ways, which can eventually be combined to address potential adverse effects. If additional sites are created they can be added into the vulnerability scoring tool to assess the changes to the risk score. This systematic scoring tool can prioritize different threats and concerns to the natural infrastructure and form an integral part of examining water security.

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WATER SECURITY GUIDANCE DOCUMENT

PART 2 SECTION 4
WATER SECURITY STATUS INDICATORS (WSSI)

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WATER SECURITY GUIDANCE DOCUMENT
PART 2 SECTION 4
WATER SECURITY STATUS INDICATORS (WSSI)

ABSTRACT

A step-by-step guide for communities to assess the *current status* of water security, in terms of water quality and water quantity in relation to aquatic ecosystem health and human health. The methodology is tested within the Township of Langley, British Columbia. The approach can be adapted to use site specific indicators of water quality and quantity for aquatic ecosystem and human health.

RELATED JOURNAL ARTICLE:

Norman, E., Dunn, G., Bakker, K. Allen, D. and Rafael Cavalcanti de Alburqurque (in review). **Integrating Governance in Water Indicator Assessment: Developing a Water Security Indicator Method**. Submitted to Water Resource Management (August 2011).

WATER SECURITY GUIDANCE DOCUMENT

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BACKGROUND: KEY ISSUES AND CONTEXT

The Water Security Status Indicator (WSSI) addresses three gaps in water assessment methods for local communities in Canada:

1. Whilst many water-related indicators are being developed to measure and assess water, few are user-friendly at the local scale (watershed or sub-watershed).

2. There are a large number of indicators focusing on a small range of issues (e.g., solely on drinking water), which do not consider the broader balance of aquatic ecosystem health and human health.

3. Narrowly-focused indices are of limited utility to water managers and communities grappling with competing users and integrated water systems, where balancing trade-offs can be a significant management challenge.

PURPOSE OF THE ASSESSMENT METHOD

Assessing 'current status' is a challenging task, but a key component of the broader assessment of water security. This section concentrates on assessing current status of water quality and quantity in relation to human health and aquatic ecosystem health. Approaches to mapping some of this information are detailed in *Part II, Section 5: Mapping Groundwater Contaminants*, and are also presented in this case study on page 16.

The WSSI should be viewed as the starting point since it does not include future risk. This assessment method can either be used as a stand-alone tool, or in conjunction with the *Water Security Risk Assessment (WSRA)* method outlined in *Part II, Section 2.* A combined approach, assessing current status and future risk, would give a community a more comprehensive understanding of its overall water security.

Indicators are commonly used in assessments, as they can facilitate the synthesis of large amounts of complex information into a simplified, accessible format that can be easily understood. Indicators can help identify progress (or lack thereof) as the results can be used to create baselines against which water-related variables can be measured over time. The WSSI is not a new indicator; rather, it is an assessment method designed for community use, using available indicators. The purpose of the WSSI is to assess the current status of freshwater, in terms of water quantity and quality, in relation to aquatic ecosystem health and human health.

The WSSI assessment method provides a framework to guide:

i. the selection of indicators;
ii. the simultaneous analysis of indicators; and
iii. the incorporation of the assessment results into water management decisions.

Communities are engaged in the indicator selection process, making participation by end-users central to its method. A key contribution of the WSSI is

this process of choosing and implementing indicators, strengthening the utility and applicability of the results, in turn resulting in improved water management outcomes.

INTENDED USERS

This method is primarily aimed at community watershed groups, citizen environmental committees, water managers, and municipal water policy and decision-makers.

DESCRIPTION OF METHOD

The WSSI assessment method is an integrated framework for selecting and simultaneously analyzing multiple indicators for water quality and water quantity, relating to aquatic ecosystem health and human health. Rarely do indicators cover all of these key criteria, which we argue are instrumental for communities in their efforts to assess water security status effectively.

A STEP-BY-STEP GUIDE TO APPLYING WATER SECURITY STATUS INDICATORS

Since the WSSI is a *process* by which indicators are selected to assess water security, in this section we present only a general guide to applying the WSSI assessment method. We do not recommend specific indicators, as these should be chosen by a given community specific to their needs and resources (including data availability). At the end of this document, we present an illustrative example of the application of the WSSI (including the rationale for the indicators selected), in our case study community, the Township of Langley, British Columbia.

Table 1: Summary table outlining the fundamental steps to apply the WSSI assessment framework

Step	
1	Define Scope and Scale of Assessment
2	Identify Stakeholders and Assemble the Assessment Team
3	a) Visioning and Goals
	b) Water Security Objectives and Targets
4	Prepare Information Required to Assess Water Security Status
	a) Decide the Time-Frame of the Assessment
	b) Identify Key Water Issues (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	Analyzing and Reporting Results

Step	
6	Risk Assessment and Back-Casting: Status in Relation to Water Security Goals
7	Governance Mechanisms to Move Towards Water Security

STEP 1 – DEFINE THE SCOPE AND SCALE OF ASSESSMENT

Define the scope and scale of the water security assessment, identifying the physical (geographic boundaries) of the area that will be assessed. Identify the water sources (e.g., river or aquifer). Ideally, the assessment area should consider both surface water and groundwater interactions. Transboundary watersheds may have water managers with different legal and administrative systems. Assess whether information from other parties can be accessed, and whether additional stakeholders can be brought to the discussion table (Refer to *step 2)*. Consider vulnerability of the water source, and threats to the water source (Refer to *Part III, Section 7 Boil Water Advisory Protocol – Part 1, Step 1 & Part 2 Step 1)*.

STEP 2 – IDENTIFY STAKEHOLDERS AND ASSEMBLE THE ASSESSMENT TEAM

Identify the stakeholders within the project boundaries. These should include those involved in monitoring water related issues and land-use planning; decision-makers (for example watershed groups, municipal sectors, provincial representatives, as well as private and public sectors); and stakeholders (industry, agriculture, medical, commercial, residential, first nations and so on). It is important that *all* decision makers be identified and included at the outset of the process, in order to successfully identify information needs and facilitate well-informed decisions. Note: the inclusion of a broad cross-section of stakeholders will likely aid in identifying data sources and parameters, as well as target setting.

STEP 3A – VISIONING AND GOALS

Discuss what water security would look like in your community. Scenario-building is a collaborative exercise whereby stakeholders collectively create 'desired futures' of water security in the region. The visioning is a 'qualitative exercise' where stakeholders articulate their desired futures. For example, in the Grand River Conservation Authority (GRCA) in Ontario, stakeholders articulated their needs and desires around what they want the river system to be (e.g., the ability to swim in the river or canoe in the river free of algae or odours). This is also an opportunity to identify potential risks to water security, which is discussed in more detail in *Part II, Sections 2 and 3*.

STEP 3B – OBJECTIVES AND TARGETS

Objectives tend to be more quantitative, and targets are usually specific to a particular variable. Ideally, objectives and targets should be based on sound science (enshrined in legislation or technical standards that are science based). It is helpful that people with technical and scientific expertise partici-

pate in objective and target setting to translate community goals into meaningful measures. As an example, the GRCA first identified a preliminary set of objectives to take to the community. This list was then discussed with various stakeholder groups and the broader public to ascertain whether these objectives were still current, or if modifications and/or additions were necessary.

Once the parameters of water security have been identified, and likely ways to achieve these objectives identified (e.g., targets to reach, and a timescale to achieve this by), identify potential governance barriers (and if feasible future risks – see *Part II, Section 2 and 3*) that could inhibit achieving these goals. (See also step 6).

STEP 4 –PREPARE INFORMATION NEEDED FOR ASSESSMENT

a. **Time frame**: Define the time frame for the water security status assessment i.e., whether it will be ongoing (which is recommended) or whether it will be conducted as a one-off.

b. **Key Issues**: Identify key water-related issues for your area, and compile a list of the parameters that need to be monitored and assessed. This could be further broken down to key issues in specific areas (e.g., a particular stretch of river, or aquifer). The issues should include *human health* and *aquatic ecosystem health* in terms of *quality* and *quantity*.

c. **Data Availability**: Data form the foundation upon which indicators are built, and consequently play a fundamental role in assessment. Data will most likely be dispersed across a number of organizations ranging from academics, consultants, industry, commercial, agriculture, NGOs, to municipal, provincial and federal agencies, each with varying degrees of quality, comprehensiveness and access. Identify organizations and/or departments that may have the data required for the assessment of water quality, quantity, aquatic ecosystem and human health. Find out whether staff are available and willing to provide advice and guidance; identify key contacts. Are there data for surface water and groundwater? Are the data accessible? Which parameters are monitored and recorded? Over what time periods are data collected (ongoing or ad hoc)? It is important to ascertain data gaps during the initial assessment, as this understanding can also inform future planning. If using data from a variety of sources, identify the methods used to collect data. Are the reporting units and collection methods the same or different between data sets? Once the parameters you want to measure have been identified, assess the datasets to see if these variables have been monitored consistently. Assess whether any of the data sets are compatible enough to be amalgamated (ensuring that the reporting units are consistent).

   Suggestion: If possible, arrange a meeting whereby representatives from all the agencies that collect data are brought together. Discussions should include why they collect data (what their drivers are); the relative comprehensiveness and gaps of their data (in terms of time periods or parameters measured); accessibility (data sharing); and the standards and methods used to collect and record data. This meeting could serve to establish stronger pathways to facilitate data exchange. In addition, this meeting

could be a good opportunity to explain your group's vision to develop the WSSI, and the participants could also help decide which indicators to use (see below).

Prior Studies: Identify any water related studies that have already been conducted. These could be used as part of the foundation for the assessment. In addition, consider if lessons can be learned from previous experience(s).

d. **Available Indicators**: Determine which indicators are already available to assess water status in your defined region in terms of water quality, water quantity, aquatic ecosystem and human health. (Refer to the indicator inventory conducted in 2009: http://www.watergovernance.ca/projects/water-security/program/ for a comprehensive list of fresh water-related indicators that have been developed at the federal, regional (large-scale watershed), and provincial levels. The list also includes some examples of local (small-scale watershed) indicators). Indicator selection should involve a critical analysis of whether or not existing indicators developed at various scales are appropriate and address community needs. If possible, technical and scientific input and advice are advised. It is also worth noting that if data are not available to comprehensively calculate an indicator of choice, the identification of such data gaps is itself useful. In the short term, data gaps could be filled by use of proxies. Over the longer term the identification of data gaps can help build a case toward developing a monitoring framework that will yield relevant data over time.

The following section of this Guidance Document presents an illustrative example to organise data as part of the WSSI assessment method. This approach was also utilized when testing the WSSI assessment in our case study community (see Example of Assessment Method, page 14). *Part II, Section 5 Mapping the Likelihood of Groundwater Contamination* is a further example demonstrating how to map data.

Table 2 shows the general framing of the WSSI assessment matrix, which would be populated by indicators identified by the community, specific to their needs. Assess whether there are sufficient data available to calculate the indicators selected.

Table 2: WSSI Assessment Matrix

Indicators that define safe water for	**Water Quality**	**Water Quantity**
Human Health		
Aquatic Ecosystem Health		

SELECTING INDICATORS: GENERAL TIPS AND SUGGESTIONS

Here are some general considerations when selecting indicators to assess the key criteria of water status—water quality and water quantity (in terms of aquatic ecosystem and human health):

- WSSI Indicators should be easy to understand, timely, relevant, reliable, consistent, credible, transparent and accurate.
- WSSI indicators should be comprehensive, integrative and accessible.
- Consider the water source (groundwater, surface water, or integrated), and whether the choice of WSSI indicators reflects this.
- Consider land use activities and intensity, which may impact water quality and quantity.
- A number of agencies develop indicators for multiple scales (international, national, regional, provincial and local). Consider how accessible relevant, existing indicators are (e.g., will the developer share the index formula or calculator?), and whether the indicators can be adapted to suit your needs.
- Once the variables (i.e. parameters) to be assessed have been selected, the standards against which they are to be compared also need to be chosen (local, provincial, pan-Canadian, or international).
- There are overlaps between water quality and quantity in terms of aquatic ecosystem health and human health. Some indicators can be applied to more than one category. For example the Canadian Council of Ministers of the Environment (CCME) Water Quality Index (WQI) http://www.ccme.ca/ourwork/water.html?category_id=102 (refer to Example of Assessment Method) can be used as an indicator for both human health and aquatic ecosystem health, if different parameters and objectives are applied (CCME 2001).
- Understanding the scale for which an indicator was developed is an important consideration. Is the indicator of choice sensitive enough (will it yield meaningful results) to be used at the scale identified for the assessment? (See *Example of Assessment Method* for an example of scalar challenges).
- Indicators that incorporate economic valuation are emerging. Assess whether it is feasible to include economic considerations in the assessment method.

Box 1: Considerations when selecting water *quality* indicators (in relation to aquatic ecosystem and human health)

- Scale: There are international (e.g., World Health Organisation), national (e.g., CCME or Health Canada) and provincial guidelines for drinking water quality. Parameters and standards vary accordingly.
- Flexibility and Adaptability: The CCME Water Quality Index (CCME 2001) http://www.ccme.ca/ourwork/water.html?category_id=102 is the only index to be accepted by all Canadian provinces and territories and adopted nationally, as it is flexible and adaptable.

- Natural Baselines: Are there any natural and anthropogenic water quality considerations, e.g., naturally occurring arsenic?

- Objectives: Identify the variables (i.e. parameters) that are to be assessed (e.g., pathogens, chemicals, metals). Can the selected parameters to be measured be calculated using the indicator formula? Identify which objectives will be used.

- Water Source: The water source will influence the choice of indicators available (groundwater, surface water or integrated i.e., both surface water and groundwater).

- Sampling Frequency: Sampling and testing frequency will vary depending on the type of system and regulatory requirement. Municipal systems will likely test daily, compared with private well owners who may only sample annually.[1] Sampling frequency directly affects the indicator results. Sampling should be done quarterly, at a minimum, to reflect seasonal variation, or after a major rainfall event, or significant up-land activity (such as a mining activity or construction of new buildings).

- We recommend ecological sampling at least four times a year, ensuring that sampling coincides with poor water quality events. For example, testing in the Pacific region could be carried out in:

  March or after the spring snow melt
  August or peak dry season
  November after heavy rains in the fall (which could flood septic systems)
  January or after road salt applications

(Additional samples could be taken to correspond with significant changes in upland activities).

- Infrastructure: Infrastructure indicators can include aquatic ecosystem health and human health. They range from treatment levels (water and wastewater) to facility design, or 'number of dam upgrades to meet safety criteria'.

[1] Water quality sampling at the municipal scale is conducted on a regular basis, and some of this information may be accessible to the public (contact your local water provider). However, few jurisdictions require private well owners to share water quality testing results. The BC-based Private Well Network is an example of a community-based initiative designed to encourage well owners to test well water quality on a regular basis and share results.

Box 2: Considerations when selecting water *quantity* indicators (in relation to aquatic ecosystem and human health)

- Scope: Avoid narrowly defined indicators that examine supply or demand in isolation. An integrated indicator, which assesses supply in relation to demand, is more robust.
- Method and Scale: Considerthe method and scale of assessment, both of which can influence the indicator results.
- Data sensitivity: Data sensitivity will influence the results. For example, whether the data are diurnal, weekly, monthly, seasonal or annual. Seasonal variations in supply and demand will present a different picture to annual reporting. Likewise, diurnal data is the most sensitive. Also, consider whether data are from dry or wet years.
- Use: Does the indicator fully address consumptive use, or just reflect withdrawals?
- Source: If water is supplied from an integrated water source, it is important to select an indicator that is sensitive enough to reflect groundwater concerns as well as surface water. Ideally, all sources of water supply and consumption should be accounted for.
- Infrastructure: Has the infrastructure type and integrity been reflected in the selected indicators?
- Economic instruments and conservation: Pricing, investment and conservation initiatives should ideally be reflected in the assessment framework.

STEP 5 – ANALYZING AND REPORTING RESULTS

Once indicators are calculated the results need to be analyzed, categorized and reported. The category's range needs to be determined to facilitate results analysis. Many ranges for reporting indicators are very subjective and not based on science (e.g., rankings are based on equal intervals between the best ranking and the worst ranking and are not based on critical thresholds). The methodology for ranking indicators should be stated and justified.

The next step, and a critical component of the assessment method, is communicating results to the decision-makers. The results can be presented in a variety of ways from traffic lights (red, yellow, green), to slider bars or maps (for illustrative examples refer to Table 3, and *Figures 2 and 3*).

Table 3: An example of water security assessment categories

Symbol	Initial Assessment	Follow up Assessments
	Indicator of Secure Water based on pre-determined ranges.	Significant change, in direction of meeting objective (improvement)
	Needs Work to Achieve Water Security, but within range of meeting goals	No significant change (little or no change)
	Insecure Water – indicates that major work is needed to achieve goal	Significant change, in direction away from meeting objective (deterioration)
	Insufficient or no comparable data	

Informing decision-makers of positive or negative changes needs to be done in a timely manner (information needs to be accessible, transparent and clear). If the results are adverse, then steps to improve water security must be clearly identified and strategies to implement necessary changes must also be clearly identified (see *Step 7*). The elements of risk should also be incorporated to give a more comprehensive view of overall water security (see *Step 6*).

STEP 6 – RISK ASSESSMENT AND BACK-CASTING (STATUS IN RELATION TO WATER SECURITY GOALS)

A detailed risk assessment (as outlined in *Part II, Section 2: Water Security Risk Assessment (WSRA)*) is a critical component to understanding the security of water quality and quantity in terms of aquatic ecosystem and human health. As outlined in *Part I*, if we consider the term "secure", we generally mean that currently something is secure, but this terms also implies there is a strong likelihood that it will remain so into the indefinite future. If we are saying that water is secure, then implicitly we are saying that right now the quality and quantity of water are meeting some performance measure (such as below a guideline for drinking water quality) and that the rate of use is sustainable. In addition, we also need to factor in how vulnerable or susceptible water quality and quantity are to deterioration over the longer term. This requires assessing risks (*Part II, sections 2 & 3*), as well as identifying how the risk(s) will be managed (*Part III*).

Back-casting is increasingly common in sustainability research and policy engagement. It involves working backwards from a 'desired future state' to determine the changes in laws, policies, behaviours and management practices needed today to achieve the goal of water security. If the assessment is to inform decision-making within an adaptive governance framework, there needs to be a commitment to ongoing assessments at intervals that can be expected to detect change.

STEP 7 – GOVERNANCE MECHANISMS

Narrow governance approaches often fail to link water quality and quantity both in terms of human health and aquatic ecosystem health, and can hinder the ability of communities to achieve water security. Furthermore, inadequate assessment of status and risk hinder long-term plans for communities to achieve water security. In short, a broad, integrative (and proactive) approach is needed. Practicing good governance is crucial for communities to achieve water security and an adaptive governance approach can facilitate this. Adaptive governance is a methodological approach to resource management, whereby policies are implemented as experiments and learning is integral to resource stewardship.

The utility of indicators is greatly enhanced when linked to decision-making. Adaptation is linking findings back to behaviour change. Adaptive governance is not just about changing plans, but assessing the effectiveness of management actions on the ground, formalizing a "learning by doing" approach that can link science and policy. Policies and decision-making processes are then adapted over time, creating a closed (and hopefully virtuous) feedback cycle.

Indicators of success should be part of the assessment process from a management or performance point of view as well as from a results perspective. As more information and new technologies change, the process can be revised and updated. Decision-makers need access to timely information (demonstrating whether a system is moving closer to, or further away from the outlined goals) in order to respond (adapt) governance and management. Step 7 should include the development of short and long-term policy recommendations for water security. An adaptive governance approach allows for communities to react to - and continually revise plans- as new information becomes available. It is an iterative, systematic process that emphasizes "learning by doing" for improving environmental management policies and practices, whereby decision making is made through a structured process in the face of uncertainty.

APPLICATION OF ASSESSMENT METHOD

The WSSI was applied in a case study community (Township of Langley, BC).[1] For additional information please refer to our Water Security Briefing Note, and journal article: Norman, Emma S., Karen Bakker, Gemma Dunn. 2011. ***Recent developments in Canadian water policy: An emerging water security paradigm***. Canadian Water Resources Journal 36(1), 53-66.

It is important to stress that this is just one example of application of the WSSI; the assessment method is designed to enable communities to identify indicators that best suit their needs and data availability.

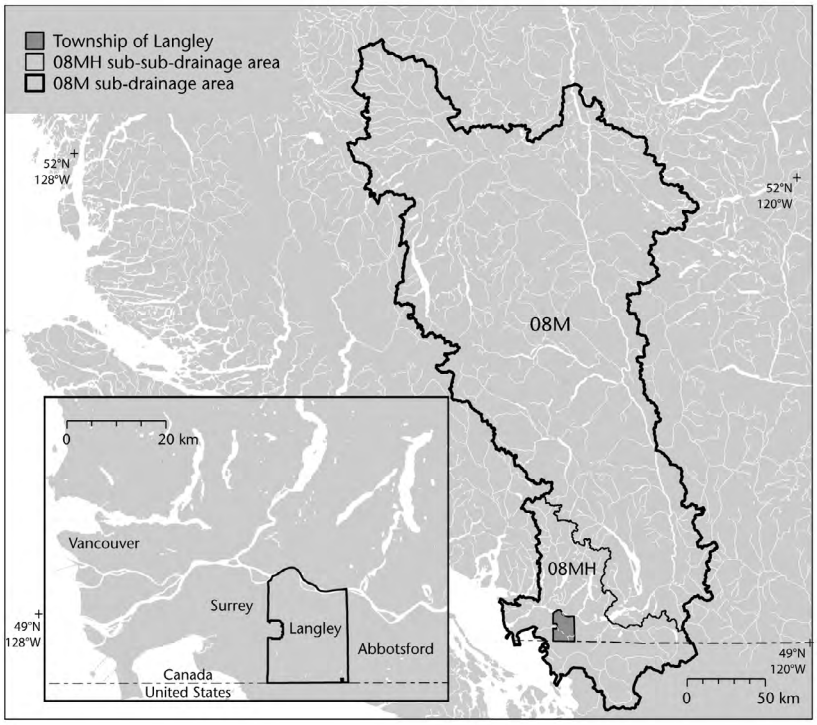

Figure 1. Map of study area, Township of Langley, British Columbia Canada and watershed areas (08MH and 08M; Environment Canada) used for Water Availability Index Calculation

1The Township of Langley (ToL), located 47 kilometres southeast of Vancouver, British Columbia (BC), is a predominantly rural community of approximately 100,000 residents. The land use is a mix of agricultural with commercial, industrial and residential, with 75 percent of its land base in the Agricultural Land Reserve (ALR). Growing population pressures and increasing commercial, industrial, and agricultural demands are impacting water supply and quality. For example, in some areas (solely dependant on groundwater) peak summer water demand nearly exceeds the Township's existing municipal supply capacity. Elevated nitrate levels in groundwater indicate groundwater vulnerability to contamination due to agricultural activities and poor wellhead protection (ToL 2009). The ToL is part of the massive Fraser River watershed system, illustrated in Figure 1. The lower reaches of the Fraser River are concentrated in the Fraser Valley, which supports a large portion of British Columbia's human population. The area contains critically important fish habitat, including approximately 700 kilometres of fish bearing streams and numerous wetlands (BC Ministry of Environment (BC MoE) 2011; ToL 2009). The ToL differs from other municipalities of the region in that groundwater is the primary source (80 percent) of water to meet agriculture, commercial, industrial, and residential needs. The remaining water needs are supplemented from the Greater Vancouver Water District (GVWD). The ToL operates 18 municipal wells; in addition, 20 percent of the ToL residents obtain water from private wells (numbering at least 5,000) (ToL 2009). Water management is complicated by the transboundary nature of the watershed, with different administrative and legal systems, in addition to fragmented data sources associated with the waters. Although pathways exist to coordinate with counter-parts in the United States, data sharing efforts are nascent and coordination limited (Norman and Bakker 2009; Norman 2009).

Table 4 summarizes the indicators selected to assess Water Security Status in the Township of Langley, BC. These indicators are the key criteria necessary for water security assessment covering water quality and quantity with respect to human health and aquatic ecosystem health.

Table 4: Water Security Status Indicators used in the Township of Langley, BC

Indicators that define safe water for	**Water Quality**	**Water Quantity**
Human Health	1) CCME Water Quality Index (WQI)	1) Environment Canada (EC) Water Availability Index (WAI), 2) Water Management Plan, Township of Langley
Aquatic Ecosystem Health	1) CCME WQI 2) Community Assessment, British Columbia Fish Protection Act	1) Water Availability Index, Environment Canada 2) Community Assessment, British Columbia Fish Protection Act

To assess water quality for human health in ToL, the Canadian Council of Ministers of the Environment Water Quality Index was applied (CCME 2001). This index provides a framework for assessing ambient water quality conditions relative to water quality objectives. It is flexible in terms of:

- the type and number of water quality variables to be tested;
- the period of application;
- the type of water body tested;
- variables used (both human health parameters and aquatic ecosystem health parameters can be calculated separately).

The human health objectives were based on the Canadian Drinking Water Quality Guidelines. In order to calculate the WSSI a number of data sources were identified ranging from academic, non-government organizations, industry, agriculture, municipal, provincial, and federal, each with varying data quality, comprehensiveness, and accessibility. Since the majority of the drinking water in the ToL is drawn from municipal or private wells, the most comprehensive groundwater data sets were identified and used: the community Private Well Network (PWN), and the provincial Environmental Monitoring System (EMS) (refer to *Part II, Section 5*).

The WQI requires a minimum of four samples per site, testing at least four (of the same) parameters, ideally over a one-year period. A significant challenge was having sufficient data to calculate the CCME WQI matching the criteria. Even when the two data sources (PWN and EMS) were combined, only a small number of wells had sufficient data that matched the CCME WQI criteria.

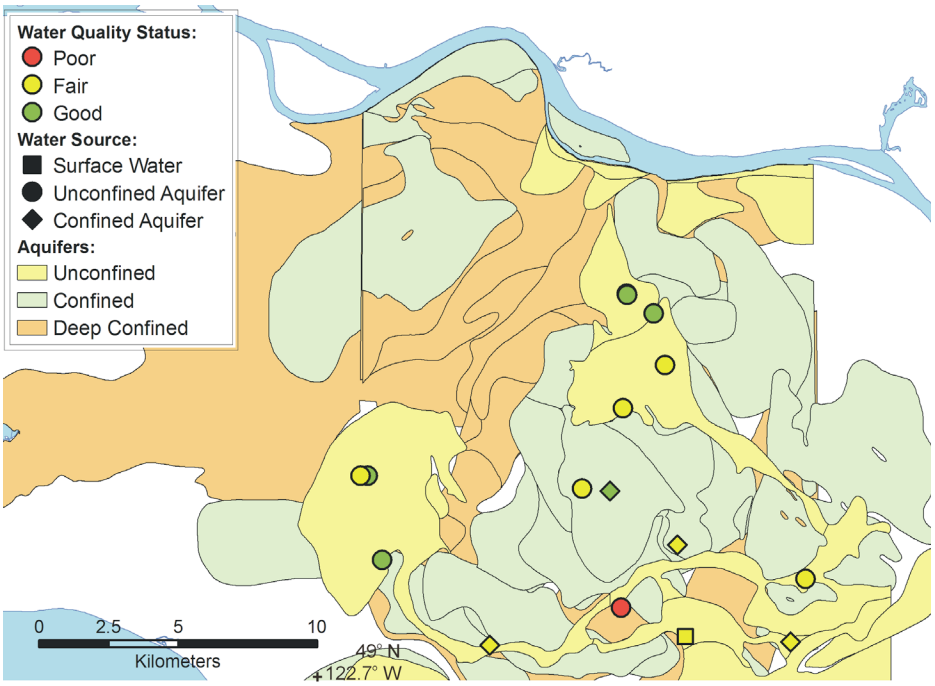

Figure 2. Geospatial Assessment Map for Water Quality in Township of Langley (refer to Part II, Section 5)
Data Sources: ToL 2009, British Columbia Ministry of the Environment (2011)

The WQI results ranged from "good" to "poor", with the majority (60 percent) indicating "fair" or "marginal" water quality. This diversity of water quality is unsurprising given the variety of aquifers in the ToL (confined and unconfined with different sediment types and variable chemical constituents). Each of these aquifers may have a unique sensitivity to natural and anthropogenic contaminants, which is a result of the complex hydrogeology of the ToL.

To assess **water quality** for **aquatic ecosystem health**, the CCME WQI was applied again, this time using surface water data, and parameters and objectives specific to aquatic ecosystem health. Finding 'objectives' for parameters to assess aquatic ecosystem health was harder than for human health.

Surface water (stream) data for Bertrand Creek (a representative creek in the ToL) were extracted from the provincial EMS database. Data availability was a significant issue. Of the two sampling sites in Bertrand Creek, only one site had sufficient data for CCME WQI to be calculated. Another significant issue was the time period of the sampling. Ideally, WQI data should cover at least one year; however, the data for sites were collected weekly over a one-month time period, which does not enable seasonal variation analysis. The parameters assessed were also selected based on data availability. Objectives were selected from either the CCME's Water Quality Guidelines for the Protection of Aquatic Health; Environment Canada's Freshwater Quality Index ecosystem health parameters; or from provincial guidelines (Environment Canada 2010b).

In addition to applying the WQI, we also identified the number of "critical streams" within the boundaries of ToL and number of known endangered fish species. Compromised riparian habitat and a reduced flow are causing conditions of hypoxia in several streams in the region and impacting fish pop-

ulations. Specifically, the Nooksack Dace and Salish Sucker (Catostomus sp.) have "endangered" status (Environment Canada 2010a).

To assess water **quantity** for **aquatic ecosystem** and **human health**, the Water Availability Index (WAI) currently under development by Environment Canada (EC) was selected. This federal indicator calculates the volume of water in rivers compared to the amount of water used.

The WAI was selected for this project as it appears to be the only Canadian indicator integrating demand in relation to supply at the watershed scale.1 (Canadian water quantity indicators typically assess either demand or supply, more often supply). Furthermore, the objectives of the WAI were to include aquatic ecosystem health, human health, groundwater and surface water suggesting close alignment with our water security project. However, this index is challenged by data limitations. Limited groundwater and aquatic ecosystem health data has resulted in these components of the index being excluded for the short to medium term. Currently, the WAI assesses water supply and demand for surface water in a limited number of Canadian sub-watersheds.

The WAI is designed to be a national or regional indicator assessing withdrawals at the watershed scale (although for our case study community the index was calculated at a sub-sub watershed scale). The WAI is calculated using data from three national surveys (EC's Municipal Water and Wastewater Survey, Statistics Canada's Industrial Water Use Survey, and Agricultural Water Use Survey), plus data from national hydrometric monitoring stations (HYDAT). Environment Canada is currently planning to report on this index approximately every two years (determined by data availability – national surveys are typically carried out once every two years).

At the time of testing the WAI was still under development and information on this index was not publically available. We collaborated with Environment Canada to explore the possibilities of applying the WAI at a scale that would be more meaningful at a municipal level. Using Environment Canada's watershed boundaries the WAI was calculated for the watershed that includes the Township of Langley (08M), and the neighbouring (08G) watershed (see Figure 1). As such, the WAI was also calculated at the sub-watershed (08M) scale and the sub-sub watershed (08MH) scale.

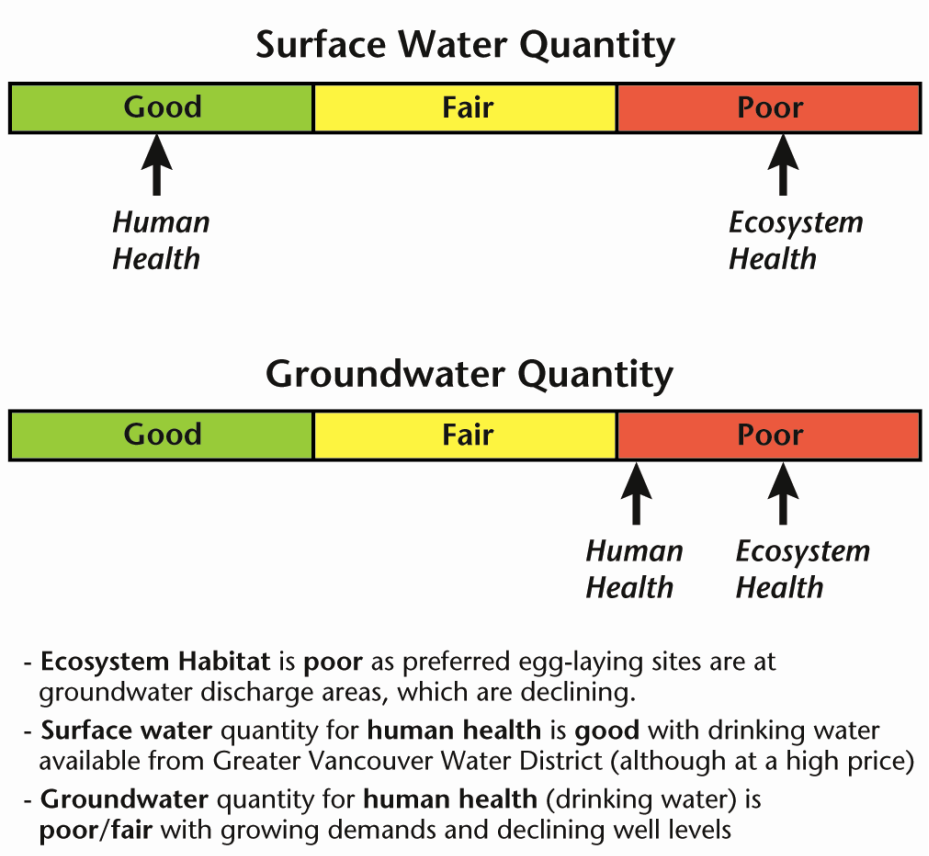

Figure 3. Water Quantity Slider Bar Assessment
Data Sources: ToL (2009); Environment Canada (2010); British Columbia Ministry of the Environment (2011)

The index results for both sub watershed (08M) and sub-sub watershed (08MH) were in the 'low stress' category, implying that there are no availability constraints in this region (Environment Canada 2010b: 15). The same results were seen at the sub-watershed scale, and in the neighboring (08G) watershed (i.e., Low >10%).

These results differed from the ToL studies, which identified a challenge in its ability to meet demand in relation to supply (ToL 2009). This discrepancy relates to scale of assessment, method of assessment, and data availability. Furthermore, these findings highlight that in this region, distribution (i.e., infrastructure) may be more the challenge rather than available natural supply. Other factors that could influence these results include: a mismatch of administrative and watershed boundaries; data availability; frequency of reporting; the lack of sensitivity to groundwater sources. Although the watershed is transboundary (Canada – U.S.), the calculations were run only using information available from the Canadian side of the watershed. Environment Canada used data from 2005 and 2007 national surveys, which were relatively wet years (Environment Canada's databases are only updated every two years). Data from dry years such as 2001 and 2002 were not used in this calculation. Seasonal variations in supply and demand would also present a different picture to annual reporting. The index also focuses on water withdrawals; consumptive use has not yet been fully incorporated into the index.

However, even if the all the above factors were adjusted the final WAI results are unlikely to change for this test community. This finding suggests the need for greater development of indicators that are accessible and sensitive at a sub-watershed scale and include both supply and demand. Thus, for the calculation of the WSSI assessment method, we suggest the application of more localized indicators, if available. For example, the ToL is currently undertaking a water balance study that could be applied to the WSSI assessment method. Other indicators relevant to groundwater supply include measured decline in groundwater level.

To provide additional assessment of water quantity and quality for aquatic ecosystem health, existing studies for aquatic ecosystem health were identified and results incorporated into the overall assessment. In our case study area, the British Columbia Fish Protection Act has started to assess fish habitat. The Act, for the first time, provides legislative authority for water managers to consider status of fish and fish habitat in approval (or renewal) of licenses for development projects. This Act focuses on four key areas: "ensuring sufficient water for fish; protecting and restoring fish habitat; improved riparian protection and enhancement; and stronger local government powers in environmental planning" (BC MoE 2011). This study provides an on-the-ground assessment of conditions related to aquatic ecosystem health using indicators species.

RECOMMENDATIONS AND FURTHER AREAS FOR RESEARCH

In closing, the inclusion of stakeholders is an essential component to integrated assessment methods, as they provide valuable local knowledge, access to data sources, and long-term commitments to adaptive planning. We argue that assessment 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. This may, we suggest, contribute to attaining goals of water security at the community level and beyond.

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WATER SECURITY GUIDANCE DOCUMENT

PART 2 SECTION 5
MAPPING THE LIKELIHOOD OF GROUNDWATER CONTAMINATION

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ABSTRACT

Maps are a valuable tool for displaying water quality information in an accessible format that allows the visualization of spatial patterns of concentrations of water constituents and the determination of areas of concern. A method is presented for producing maps of the likelihood of occurrence of a contaminant in groundwater based on available water chemistry data; knowledge of the aquifer system; and the uncertainty inherent to each. The methodology is tested within the Township of Langley, British Columbia, and specifically considers arsenic, a natural contaminant. The approach can be adapted to map other water quality parameters of concern.

JOURNAL ARTICLES RELATED TO THIS TOOL INCLUDE:

Cavalanti de Albuquerque, R., Allen, D.M. and Kirste, D. (in review). **A Methodology for Spatially Representing the Likelihood of Occurrence of Natural Contaminants in Groundwater**. Submitted to Environmental Earth Sciences (September 2011).

THESIS RELATED TO THIS TOOL INCLUDE:

Cavalcanti de Albuquerque, R. (2011). **Hydrogeochemical Evolution and Arsenic Mobilization in Confined Aquifers Formed within Glaciomarine Sediments.** MSc Thesis, Department of Earth Sciences, Simon Fraser University, 207 pp.

WATER SECURITY GUIDANCE DOCUMENT

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BACKGROUND: KEY ISSUES AND CONTEXT

Maps are a valuable tool for displaying water quality information in an accessible format that allows the visualization of spatial patterns of concentrations of water constituents and the determination of areas of concern. The production of generalized groundwater quality maps or specific maps that show the likely extent of groundwater contamination typically requires extensive geochemical surveys. Unfortunately, for many regions, available groundwater chemistry (or pathogen) data are insufficient for the production of such maps .

Some of the challenges associated with using groundwater datasets include an insufficient number of samples collected, poor spatial distribution of sample locations, constituents with an elevated method detection limit, and uncertainty in the quality of the data. In addition, the hydrogeology of a particular area of interest may be complex. There may be multiple aquifers (both unconfined and confined) that are poorly delineated or sampled.

For these reasons, maps showing only raw concentration data may not appropriately represent occurrences of a constituent in groundwater over the entire region. Rather, integrative approaches, which take into account knowledge of the aquifer system and uncertainty in interpretations, can augment raw groundwater quality data to provide a spatial representation of the likelihood of occurrence of particular constituents in groundwater.

PURPOSE OF THE ASSESSMENT METHOD

This mapping tool consists of a method of classifying aquifers and spatially representing the likelihood of occurrence of a specific constituent in groundwater at the scale of a municipality or watershed. In this method, geochemical interpretations are incorporated in addition to raw groundwater quality data to account for aquifers with insufficient groundwater chemistry samples available. Aquifers are also classified based on data quality and confidence of interpretation (or uncertainty), as groundwater information available for each aquifer within a given study area may vary.

This document focuses specifically on the chemical constituent arsenic, which is hazardous to human health when present at elevated concentrations in groundwater (i.e., above 10 µ g/l, the limit for arsenic in the Canadian Drinking Water Guidelines). However, the approach can be adapted to map other chemical water quality parameters of concern, which may be natural (e.g., arsenic) or anthropogenic (e.g., nitrate from fertilizer application or septic system sources) or a combination of both; for example, chloride from road salt application versus remnant seawater. The method's use for mapping biological contaminants, such as pathogens, has not been tested here, but in principle, such contaminants could also be mapped. The method could also be adapted to map water quality indictors, such as the CCME (Canadian Council of Ministers of Environment) Water Quality Index (refer to *Part II Section 4*). In all cases, raw water quality data are used in conjunction with knowledge of the aquifer system to map the likelihood of contamination.

INTENDED USERS

This method is primarily aimed at hydrogeologists who may be working with communities to map groundwater quality data. While raw water quality data could be mapped by a non-specialist, the interpretive component of the methodology will benefit from the expertise of a professional with experience in hydrogeology or groundwater geochemistry. The approach can be adapted to the level of expertise in the use of Geographical Information Systems (GIS) in that digital spatial datasets are not necessarily needed. A simple approach would be to use available maps of aquifers in the area, knowledge of their depths and whether they are unconfined or confined, along with available water quality data.

DESCRIPTION OF METHOD

Two components are used to classify the aquifers in the map produced:

1. interpretations provided through hydrogeochemical studies; and
2. raw groundwater chemistry data.

The approach consists of a series of steps for generating maps that highlight different groundwater chemical environments in the study area, geochemical interpretation for likelihood of occurrence of a particular constituent, confidence of interpretation, and raw concentration data. These maps are then superimposed to produce a map showing the likelihood of occurrence of a constituent of interest for each aquifer of a study area.

A STEP-BY-STEP GUIDE TO APPLYING THE MAPPING METHOD

Table 1: Summary table outlying the 4 steps to produce the likelihood of occurrence of a groundwater constituent map

Step	
1	Represent different groundwater environments of the study area on a map
2	Represent interpretation spatially on a map
3	Represent confidence of interpretation spatially on a map
4	Represent likelihood of occurrence of constituent on a map (superimposition of the maps produced through steps 1 to 3 and raw groundwater chemistry data)

STEP 1 – REPRESENT DIFFERENT GROUNDWATER ENVIRONMENTS OF THE STUDY AREA ON A MAP

In many areas, there is more than one aquifer and understanding how well the aquifers are connected to surface recharge and to each other is critical for evaluating water security. Unconfined aquifers are exposed at surface, meaning that the permeable materials comprising the aquifer are not protected by a cover of lower permeability materials that can act as a barrier to entry of

contaminants introduced at surface. Confined aquifers, in contrast, are overlain by a low permeability layer. In areas with a complex hydrogeology, an unconfined aquifer at surface may overlie a series of confined aquifers at different depths that may themselves be variably connected. Aquifers and the confining units may be comprised of unconsolidated materials (e.g., sands, gravels, silts, clays) or consolidated materials (e.g., rock). In the case of rock aquifers, fractures can create permeable pathways into and between aquifers.

Where more than one aquifer has been identified in a study area, these different aquifers must first be grouped into unique "groundwater zones". Grouping of aquifers into zones is done based on physical and chemical properties that are common among a given set of aquifers. Physical and chemical properties used as criteria for grouping aquifers should be relevant to the occurrence of the constituent of interest in groundwater, according to geochemical interpretations. Some examples of physical and chemical properties of aquifers that may be used as criteria for grouping aquifers are listed below:

- Unconfined aquifers versus confined aquifers
- Sediment or rock types forming aquifers and confining units
- Geographical location of aquifers
- Depth from surface to aquifers
- Susceptibility of aquifers to contaminants introduced at surface
- Groundwater chemistry (this may include a number of different criteria, such as water type, redox potential, pH, salinity, concentration of specific constituents, etc.)

STEP 2 – REPRESENT GEOCHEMICAL INTERPRETATION SPATIALLY ON A MAP

Each groundwater zone defined in step 1 is assessed as either having the constituent of interest 'likely' or 'unlikely' to occur in groundwater. This assignment is done based on interpretations provided through a geochemical study[1]. Raw concentration data are not used in this step. Where a geochemical study has not been undertaken, the available chemistry data may be visually associated with different aquifer zones. For example, there may be clusters of wells with high concentrations of a particular constituent that can be associated with a particular aquifer. The benefit of a geochemical study is that the reasons why certain constituents are found at elevated (or low) concentrations may be determined.

The assignment of a constituent as 'likely' or 'unlikely' to occur is applied to the entire area of each groundwater zone, and not to portions of zones. If it appears that the constituent of interest is likely to occur in part of a zone, but unlikely to occur in another part of the same zone, then step 1 should be revisited. In this case, the groundwater zone in question should be divided into two or more zones.

[1] A geochemical study involves sampling groundwater, analyzing the water for its chemical constituents, and interpreting the results based on the hydrogeology of the area and the chemical processes that may control the concentrations of the constituents.

STEP 3 – REPRESENT CONFIDENCE OF INTERPRETATION SPATIALLY

In step 3, different levels of confidence in the geochemical interpretation are represented on a map. This representation is based on availability of groundwater chemistry data within each aquifer. This step is taken in order to represent uncertainty in the geochemical interpretation as it pertains to likelihood of contamination.

Three levels of confidence are used: high, medium, and low confidence. High confidence is assigned as points on a map, while medium and low levels of confidence are assigned to aquifer polygons (i.e., the mapped extents of aquifers).

High Confidence: High confidence points are assigned at every sampling location where the data collected are of a satisfactory quality.

Medium Confidence: Medium confidence is assigned to aquifer polygons where sufficient groundwater chemistry data are available, and where the hydrogeological and geochemical controls on groundwater quality are well understood.

Low Confidence: Low confidence is assigned to areas with insufficient or no available groundwater chemistry data, or where the hydrogeology and hydrogeochemistry are poorly understood.

The assignment of areas with medium or low confidence is independent of the groundwater zones assigned in step 1. Hence, it is possible for parts of a groundwater zone to be assigned a low level of confidence of interpretation, and other parts of the same zone assigned a medium level of confidence. Note that assigning confidence is at the discretion of the mapper, in that some determination of what constitutes sufficient data available or well understood hydrogeology and hydrogeochemistry is needed.

STEP 4 – REPRESENT LIKELIHOOD OF OCCURRENCE OF THE CONSTITUENT ON A MAP

In step 4, the raw concentration data of the constituent of interest are superimposed over the interpretation map produced in step 2 and the confidence of interpretation map produced in step 3. The result of this superimposition (the final product) is a map showing aquifer polygons (outlines) that can be colour-coded based on likelihood of occurrence of the constituent of interest; for example, a hatch pattern may be coded based on the confidence of interpretation. Colour, shape, or size coded data points may be displayed on the map based on the concentration of the constituent of interest.

Likelihood of occurrence of a constituent is determined based on the superimposed raw concentration data with the interpretation map. Three levels of likelihood of occurrence are assigned to aquifer polygons on the map: high, medium, and low.

- **High Level of Likelihood**: High level of likelihood is assigned to aquifer polygons displayed on the interpretation map (step 2) as having the con-

stituent of interest likely to occur, and that have the vast majority of its data points at concentrations above the guideline.

- **Medium Level of Likelihood**: Medium level of likelihood is assigned to aquifer polygons displayed in the interpretation map as having the constituent of interest likely to occur, and that have a significant number of data points at concentrations below the guideline.

- **Low Level of Likelihood**: Low level of likelihood is assigned to aquifers that are both interpreted to not have the constituent likely to occur, and that also have most of the data points at concentrations below the guideline.

EXAMPLE OF THE METHOD

A case study is presented as an example to illustrate the likelihood of natural arsenic occurrences in groundwater in different aquifers in Langley and Surrey, Lower Fraser Valley, British Columbia.

STUDY AREA

The study area primarily includes the Township of Langley (the Township), as well as the eastern portion of the City of Surrey (more specifically the Nickomekl-Serpentine Valley, including Cloverdale), in the Lower Fraser Valley of British Columbia (Figure 1). The population of the Township of Langley is over 100,000 people (Township of Langley 2007), and the population of Cloverdale, in the City of Surrey, is approximately 50,000 people (BC Stats 2005). In the Township of Langley, approximately 18,000 residents rely on private wells and community wells as source of water, while 82,000 residents use water supplied through the Greater Vancouver Water District and 16 wells owned by the Township (Township of Langley 2007).

Four different groundwater chemistry datasets were available for this particular study area, all of which include arsenic concentration as one of the measured parameters. One dataset consists of water quality data collected by Cavalcanti de Albuquerque (2011), which focused on arsenic occurrences in groundwater in the study area. This dataset has 46 water well sampling locations, sourcing both confined and unconfined aquifers. It is the most complete of the four available datasets in terms of chemical parameters measured, as it contains major and minor elements, and some trace elements, as well as field measured parameters including pH, Eh, conductivity, temperature, dissolved oxygen, and redox sensitive species (arsenite, ferrous iron, ammonia and hydrogen sulphide gas). It is also the dataset with the best data quality, as it used the most up to date sampling and analytical methods. A second dataset consists of water quality data collected during a study by Wilson et al. (2008). It includes data from 98 sampling wells, sourcing both confined and unconfined aquifers. A total 51 parameters, including major and minor elements, are included in this dataset; however, it lacks field measured parameters as samples were submitted for analysis by well owners (conductivity and pH were measured in the laboratory). A third dataset is the Environmental Monitoring System (EMS) dataset maintained by the British Columbia Min-

istry of Environment (BC MoE 2008). It contains samples collected periodically as part of the groundwater sampling program conducted by the MoE, as well as other unknown sources. A total of 35 sampling locations from the study area are included in the EMS dataset. These are mostly sourced from unconfined aquifers, with few samples sourced from confined aquifers. Data completeness is quite variable in the EMS dataset, as some samples contain more than 40 measured inorganic parameters, while some samples have only 10 parameters. The fourth database is the Township of Langley's Private Well Network (PWN). It contains 1,045 samples in the Township only, with some samples sourced from the same well. Each sample has up to 37 parameters analyzed; however, data completeness is very variable in this dataset. Sampling and analytical methods used with the PWN dataset are unknown. It is likely that most samples in the PWN were collected by well owners and submitted to a laboratory for analysis; however, no information is given on the sampling method to verify its appropriateness. For this reason, the PWN is considered to be the dataset with the poorest data quality amongst the four datasets available for the study.

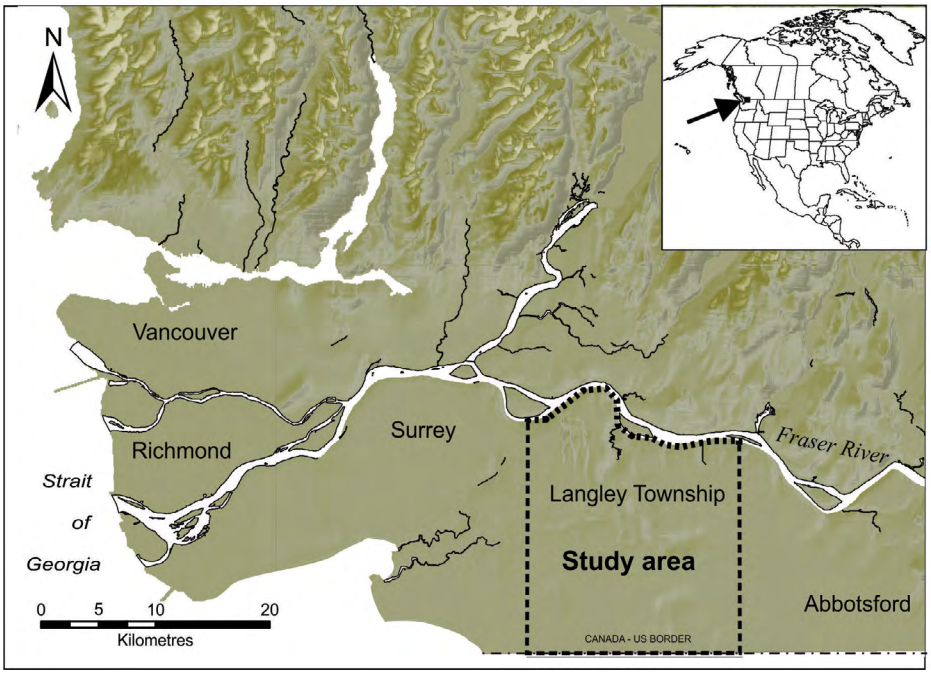

Figure 1: Map of case study area, the Township of Langley shown in the Lower Fraser Valley, British Columbia. The mapped aquifers extend slightly outside this boundary to the east in the eastern portion of the City of Surrey and to the west in Abbotsford

STEP 1: REPRESENT DIFFERENT GROUNDWATER ENVIRONMENTS OF THE STUDY AREA ON A MAP

The hydrogeology of the case study region consists of a complex network of confined and unconfined aquifers comprised of marine, glaciomarine, glaciofluvial and post-glacial Quaternary sediments that are several hundreds of metres thick and overlie Tertiary bedrock . A total of 45 permeable units forming 18 major confined and unconfined aquifers have been identified in this area . These aquifers differ from each other through a variety of physi-

cal and chemical characteristics, as they are comprised of different sediment types, have variable natural water quality, and have different levels of susceptibility to contaminants that may be introduced at the land surface .

A hydrogeochemical assessment of groundwater in this region (Cavalcanti de Albuquerque 2011) demonstrated that arsenic concentrations in most groundwater samples sourced from confined aquifers are above 10 µ g/l (the Canadian Drinking Water Guideline for arsenic), while concentrations in all groundwater samples collected from unconfined aquifers were below 10 µ g/l. In this geochemical assessment, it was suggested that most arsenic addition to solution takes place in glaciomarine sediments that form confining units to the confined aquifers.

Based on results of the hydrogeochemical assessment two groundwater zones are identified in the case study. One groundwater zone (Zone 1) is comprised of all unconfined aquifers, while a second zone (Zone 2) consists of all confined aquifers. The spatial distribution of these two zones is displayed in Figure 2.

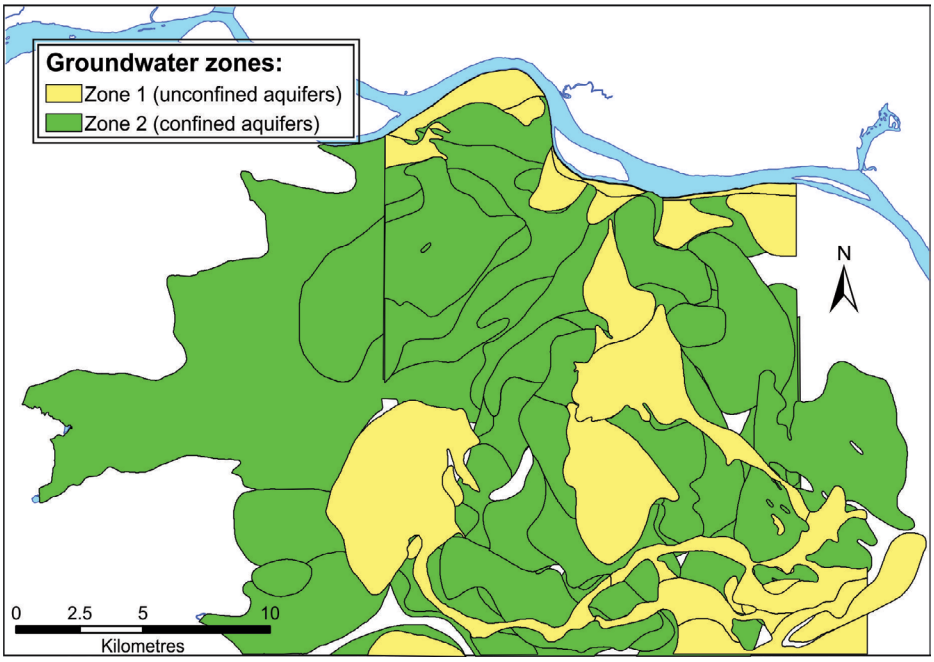

Figure 2: Map showing aquifers classified based on their groundwater zone. Zone 1 is comprised of all unconfined aquifers, whereas Zone 2 is comprised of all confined aquifers

STEP 2: REPRESENT GEOCHEMICAL INTERPRETATION SPATIALLY ON A MAP

As described above, it was determined that there is no tendency for arsenic to occur at elevated concentrations in groundwater in unconfined aquifers. It was also determined that there is a tendency for arsenic to occur at elevated concentrations in groundwater in confined aquifers. Hence, Zone 1 (all unconfined aquifers) is assigned as having arsenic unlikely to occur in groundwater, while Zone 2 (all confined aquifers) is assigned as having arsenic likely to occur in groundwater (Figure 3).

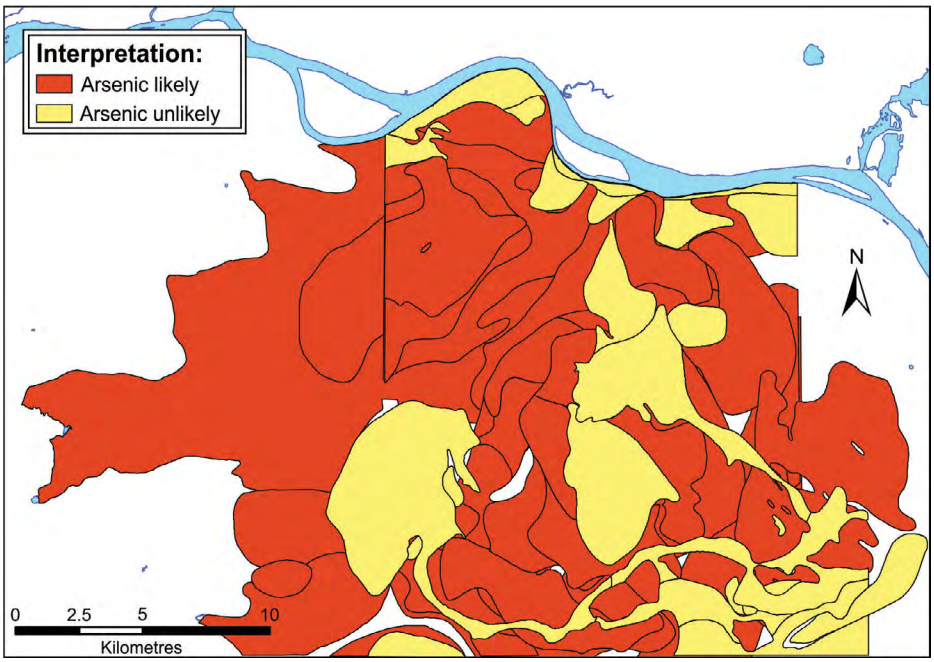

Figure 3: Based on interpretations provided through the geochemical study (Cavalcanti de Albuquerque 2011), Zone 1 (unconfined aquifers) is assigned as having arsenic unlikely to occur in groundwater, while zone 2 (confined aquifers) is assigned as having arsenic likely to occur in groundwater

STEP 3: REPRESENT CONFIDENCE OF INTERPRETATION SPATIALLY

In step 3, different levels of confidence in the geochemical interpretation are represented on a map. As noted above, four groundwater chemistry datasets were available for this study. Of these, the methods used for collecting and analyzing samples are known for the datasets collected through Cavalcanti de Albuquerque (2011) and Wilson et al. (2008), and for the majority of the data in the Environmental Monitoring System (EMS) dataset. The methods applied to collect the data for the PWN dataset are unknown. Thus, data points sourced for the first three datasets are assigned high confidence data points, while data points from the PWN dataset are assigned low confidence, and are not included as points in the confidence map.

A major confined aquifer in the west of the study area, a group of confined aquifers in the south, and two major unconfined aquifers in the center of the study area are assigned medium confidence of interpretation as a significant number of groundwater samples were collected from these aquifers. The remaining aquifers are assigned low confidence of interpretation (Figure 4).

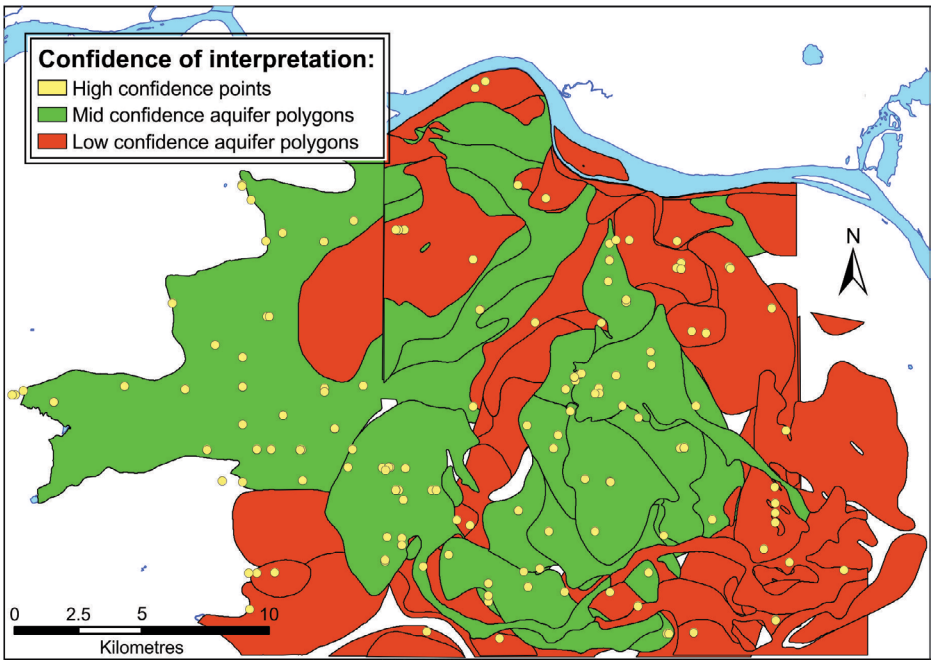

Figure 4: Confidence of interpretation map. Sample locations sourced from data collected by Cavalcanti de Albuquerque (2011), Wilson et al. (2008) and the Environmental Monitoring System (EMS) dataset (British Columbia Ministry of Environment 2008) are identified as high confidence points. Aquifers with many samples deriving from these datasets are classified medium confidence of interpretation, while aquifers with few samples are classified low confidence of interpretation.

STEP 4: REPRESENT LIKELIHOOD OF OCCURRENCE OF THE CONSTITUENT ON A MAP

The likelihood of arsenic occurrence map for Langley and Surrey consists of the superimposed interpretation map, the confidence of interpretation map, and the data points from three reliable datasets (Figure 5). All samples sourced from unconfined aquifers have arsenic at concentrations below the Drinking Water Guideline (10 µ g/l). In step 2, these aquifers were classified as having arsenic unlikely to occur in groundwater; hence, these unconfined aquifers all have a low likelihood of arsenic occurrence in the final map (Figure 5). In step 2, all confined aquifers were classified as having arsenic likely to occur in groundwater. Most of the samples sourced from the major confined aquifer in the west of the study area have arsenic at concentrations above the guideline. Likewise, a significant number of samples collected from a confined aquifer in the south of the study area have arsenic above the guideline. These aquifers are classified as high likelihood of arsenic occurrence in groundwater (Figure 5). The confined aquifers located in the center and in the eastern part of the study area contain a number of samples with arsenic above the guideline, but also a significant number of samples with arsenic at concentrations below the guideline. For this reason, they are classified as medium likelihood of arsenic occurrence. Finally, there are some deep confined aquifers that lie in between the major deep confined aquifer in the west of the study area and the confined aquifers in the center of the study area that are classified as medium likelihood of arsenic occurrence. These deep confined aquifers were identified as having a low confidence of interpretation due to few sample locations. The

fact that these aquifers are deep and confined possibly indicates that they have similar conditions as the major deep confined aquifer in the west, which was classified as high likelihood of arsenic occurrence. The few samples collected from these aquifers have arsenic at concentrations above the guideline value. For these reasons these aquifers are classified as high likelihood of arsenic occurrence (Figure 5).

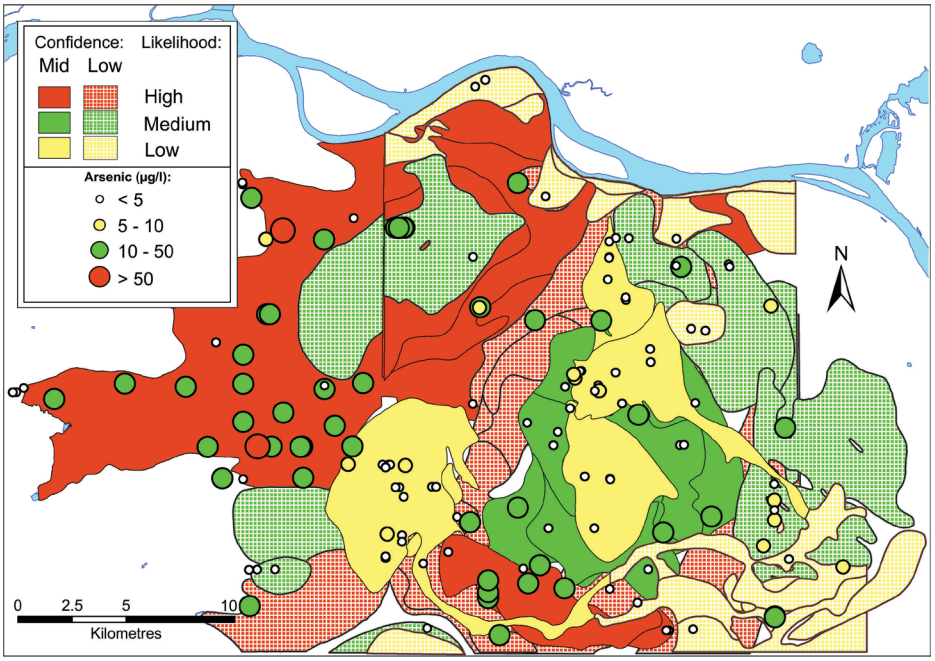

Figure 5: Map showing likelihood of arsenic occurrence in groundwater in aquifers in Langley and Surrey. Arsenic concentration data points are sourced from Cavalcanti de Albuquerque (2011), Wilson et al. (2008), and the EMS dataset. This is the final product of the method presented

RECOMMENDATIONS AND FURTHER AREAS FOR RESEARCH

The methodology presented herein has only been tested in the Langley-Surrey region of British Columbia. Likewise, the method only considered the likelihood of occurrence of arsenic in groundwater. However, the method can be adapted to other groundwater constituents, for example, nitrate. In this particular study area, the likelihood of occurrence of nitrate would be greater in unconfined aquifers, as these are exposed at ground surface and are unprotected by confining layers. However, nitrate is a highly mobile constituent, and high concentrations have been found in deeper portions of the aquifer system (Carmichael et al. 1995).

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WATER SECURITY GUIDANCE DOCUMENT

PART 3 SECTION 6
WORKING TOWARDS WATER SECURITY: FOSTERING GOOD GOVERNANCE PRACTICES THROUGH ADAPTIVE GOVERNANCE

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WATER SECURITY GUIDANCE DOCUMENT
PART 3 SECTION 6
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ABSTRACT

In this section, we outline and define an adaptive governance approach. This approach is based on three overlapping processes: participation of stakeholders, policy setting, and monitoring and enforcement. The adaptive governance process helps to identify the links between risk assessment and risk management. Through this process, communities gather information from water security status and risk assessment, stakeholders make and implement decisions based on the risk and status assessment, and decision-makers are held accountable in the development and management of water resources and delivery of water services. We also provide examples of steps communities can take to work towards achieving water security through "good governance" practices.

WATER SECURITY GUIDANCE DOCUMENT

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BACKGROUND: KEY ISSUES AND CONTEXT

The assessment of water security requires an integrated approach that includes both the evaluation of **current status** of water quality and quantity, through the use of indicators (see *Part II, Section 4*), and an assessment of ***risk*** to water, owing to uncertainty in foreseeable future events that may negatively impact water quality or quantity (see *Part II, Sections 2 & 3*). The uncertainties associated with stressors may include, but are not limited to, development pressures and climate change. The assessment of water security status and risk should be a long-term process through repeated (ideally continuous) evaluation (against thresholds or baselines), to determine improvements or decline, with this information being incorporated into a longer-term water ***risk management strategy*** (*Part III*).

Risk assessment (the identification, assessment and prioritization of risks) considers both the magnitudes of events, and the likelihood of those consequences occurring. Although the principles and methodologies are well documented for natural disasters (such as landslides and earthquakes), comprehensive risk assessments are seldom applied to water-related issues. In this Guidance Document, risk is defined as a function of *vulnerability* and consequence (*loss*), whereby *vulnerability* incorporates the susceptibility of the water source (e.g., stream or aquifer) and the presence of a hazard (potential contamination from land-use activities or excessive use of water). The magnitude of the consequences (i.e., *loss*) may be evaluated from social, health or economic perspective, such as consequence to human life or health, or ecological integrity. Through changes to resistance and capacity, a community's *vulnerability, loss,* and subsequent overall exposure to risk, can be strategically reduced over time.

An adaptive governance approach to managing water security risks focuses on the process by which the information from water security status and risk assessment is absorbed, decisions are made and implemented, and decision makers are held accountable in the development and management of water resources and delivery of water services.

PURPOSE OF THIS SECTION

In this section, we outline and define an adaptive governance approach and provide examples of steps communities can take to implement "good governance" practices with the aim of achieving water security. The adaptive governance process helps to identify the links between risk assessment and risk management.

INTENDED USERS

This approach has relevance for all water users including (but not limited to) volunteer groups, professionals, community watershed groups, citizen environmental committees, water managers, and municipal water policy and decision-makers.

GOOD WATER GOVERNANCE

Water governance is the range of political, organizational, and administrative processes through which communities articulate their interests, their input is absorbed, decisions are made and implemented, and decision makers are held accountable in the development and management of water resources and delivery of water services (Nowlan and Bakker 2010). It is conceptually distinct from water management, which is the operational, on-the-ground activity to provide and regulate water, although they are interrelated in practice.

Good governance is a means of facilitating improved decision-making; improving the efficiency of management and water use, and improving government responsiveness. Variables include: inclusiveness, participation, accountability, and transparency, which are linked to good governance outcomes.

Good governance requires a commitment to inclusion of stakeholders, adaptability, ongoing monitoring and assessment, and problem solving. No one-size-fits-all solution exists; rather, adhering to the basic principles of water governance can help communities in their effort to achieve water security. Furthermore, case studies of communities that have made changes to adopt the principles of good governance and water security into their water management plans may provide inspiration and guidance to other communities.

LINKING WATER SECURITY AND WATER GOVERNANCE

It is difficult to identify a singular water stressor for a community; rather, multiple stressors result in water insecurity. Narrow governance approaches that fail to link water quality and quantity, both in terms of human health and aquatic ecosystem health, hinder the ability of communities to achieve water security. Furthermore, inadequate assessment of status and risk hinder long-term plans for communities to achieve water security. In short, a broad integrative (and proactive) approach is needed.

Practicing good governance is crucial for communities to achieve water security and an adaptive governance approach can facilitate this. Succinctly defined, adaptive governance is a methodological approach to resource management, whereby policies are implemented as experiments and learning is integral to resource stewardship. Adaptive management is an iterative, systematic process for improving environmental management policies and practices, whereby decision-making is made through a structured process in the face of uncertainty. It is a learning by doing process, with the aim of reducing uncertainty over time through system monitoring.

Adaptive governance formalizes a “learning by doing” approach that can link science and policy. Risks and changes to ecosystem health and human health are monitored and assessed over time. Policies and decision-making processes are then adapted over time, creating a closed (and hopefully virtuous) feedback cycle.

Adaptive governance of human-nature systems relies on numerous institutions with decision-making ability at various scales from the local to the national (Folke et al 2005). Adaptive governance encourages synergy and align-

ment between these polycentric institutions, which enhances the resilience of human-nature systems because they offer greater flexibility, and improve the ability to respond to uncertainty.

Adaptive governance may be operationalized through adaptive management, where understandings of ecosystem dynamics are integrated into management institutions (Folke et al. 2005, 448). (A simple distinction between management and governance is that the former focuses on daily operational decision-making, whereas the latter focuses on higher-level institutions and 'steering' of systems). The Resilience Alliance[1] defines adaptive management as: an approach which uses management not only to control the system, but also to learn about the system, in an iterative, continuous process of scientific experimentation conjoined with day-to-day management.

Facilitating "good governance" and adopting a good governance model[2] includes integrating community governance processes, facilitating participation, and operating at a scale commensurate with local water management capacity. Achieving water security may seem like a daunting task, but through systematic planning and good governance, water security can – and should – be achieved throughout Canada (and beyond).

BOX 1 – WATER SECURITY IN ONTARIO

Reviewing the developments in Ontario over the decade since the Walkerton tragedy may provide context to understand the process of moving toward water security. The Walkerton Inquiry into the events of the tragedy issued a number of recommendations for the provincial government to implement in order to improve drinking water security. Review of Ontario's water governance, developments, including new laws, new training programs, and new agencies emphasizes that there are many facets to improving water security. Ontario exemplifies a provincial approach to water security that aims to engage communities.

Table 1: Water security initiatives in Ontario

Water Security Initiative	Example Ontario Institution
Watershed approach	Conservation Authorities (1946); Source Protection Areas & Regions (under *Clean Water Act 2006*)
Integration of land and water use planning	Source Protection Regions (2007)
Integration of ecosystem and human health concerns	*Clean Water Act (2006); Drinking Water Ontario, Safe Drinking Water Act (2002)*

[1] http://www.resalliance.org/index.php/adaptive_management

2 Governance model is a "description of good governance, and of the allocation of responsibilities and relationships between stakeholders for tasks and practices for good governance" (Bakker 2003, 4).

Water Security Initiative	Example Ontario Institution
Integrated assessment of stressors and effects	Ontario Regulation 387/04 *Water Taking*, O.Reg. 169/03 *Ontario Drinking Water Quality Standards*
Demand management	Ontario water conservation strategy (2009)

WATERSHED APPROACH

The watershed approach is a key aspect of water security, because it facilitates components of good governance—participatory management, collaborative decision-making, and delegation. Ontario adopted the watershed approach to address interrelated land and water management issues in 1946, when it created Conservation Authorities (CA) to work with the predecessor to the Ministry of Natural Resources. Historically, CAs have mainly focused on water in its 'natural environment'. Municipalities, which are responsible for drinking water service delivery under the oversight of the Ontario Ministry of Environment, also manage land use within the framework set by the Ministry of Municipal Affairs and Housing. These divisions in responsibility for water issues and land-use planning persist today, and present a continuing challenge for integration.

INTEGRATION OF LAND-USE PLANNING AND WATER MANAGEMENT

Since land use can have significant impacts on water quality and quantity, integration of land-use planning and water management is critical to water security, but has been elusive in Ontario. Traditionally, municipalities have limited their water management concerns to provision of drinking water and wastewater systems. As noted, watershed management is the purview of conservation authorities, which manage surface water flows and regulate floodplain protection. CAs are comprised of the territories of several municipalities (or parts of municipalities) that have jurisdiction over land-use planning within a provincially-set framework. In planning land use, municipalities must develop and implement 'official plans' which CAs review; this is one way municipalities and conservation authorities collaborate.

The *Clean Water Act* (2006) expands the watershed-planning framework to include source protection. As the key facilitators of the source protection planning process, CAs now have relationships with both the Ministry of Natural Resources (*Conservation Authorities Act*) and the Ministry of Environment (*Clean Water Act 2006*).

INTEGRATION OF ECOSYSTEM AND HUMAN HEALTH CONCERNS

Working toward water security requires integrated planning, since ecosystem and human health concerns are interdependent. Watershed planning in Ontario has tended to focus on management of the ecosystem rather than on ecosystem health. Post-Walkerton Ontario's new legislative framework is driven primarily by human health concerns. Making protection of drinking water sources the main purpose of the *Clean Water Act* (2006) underscores this point. Additionally, the government created *Drinking Water Ontario* as a clearinghouse for public information on drinking water in Ontario.

INTEGRATED ASSESSMENT OF STRESSORS & EFFECTS

Ontario Regulation 387/04 *Water Taking* introduces a set of indicators for assessment of stressors regarding water quantity. Under the regulation, the Minister of Environment is obligated to consider specific water availability issues (impacts on water balance, sustainable uses, water conditions, and allocated uses) prior to issuing a Permit To Take Water (PTTW). The PTTW scheme is intended to address the cumulative effects of a number of withdrawals in a watershed. However, critics, such as Garfinkel et al (2008), note the qualified nature of the mandatory consideration of water availability and the complaints-based nature of the PTTW scheme that, in effect, means that cumulative effects go unnoticed unless complained about by other water users. The effect of a complaints-based system is that by the time another water licensee reports a reduction in quantity, the watershed's hydrological integrity has likely already been affected.

The *Safe Drinking Water Act (2002)*, and its regulations addressed a number of the barriers envisaged by the Walkerton Inquiry Report by introducing "binding standards, enhanced operator certification, requirements for laboratory certification, source water protection, and public notification if drinking water is unsafe" (Hill 2006). Specific microbiological, chemical, and radiological standards for drinking water quality are set out in the regulations. A program to ensure safe drinking water must do more than focus on direct measurement of water quality because to do so necessarily results in reactive responses – most water quality monitoring tests are not useful indicators of effects because they cannot be done in real time. A preventative approach to assessment would include the adoption of best practices and continuous improvement; 'real time' process control (e.g., the continuous monitoring of turbidity, chlorine residual, and disinfectant contact time) wherever feasible; the effective operation of robust multiple barriers to protect public health; preventive rather than strictly reactive strategies to identify and manage risks to public health; and effective leadership (O'Connor 2002).

Subsequent to the Walkerton Inquiry, Hrudey et al (2006) note the value of good governance (namely, transparency, accountability, and inclusiveness) to a total water quality management framework. Specifically, they cite an Australian example, which "provide[s] consumers with the means

for judging whether their water provider is functioning as safely and effectively as circumstances reasonably allow" (Hrudey, S.E., Hrudey, and Pollard 2006).

DEMAND MANAGEMENT

The province has not done as much about demand management as certain municipalities have with pricing mechanisms and efficiency installations. However, more recently, Ontario has begun to consider, more broadly, conservation measures. In 2010, Ontario passed the Water Opportunities Act that has three objectives: (1) to make Ontario the North American leader in the development and sale of water conservation and treatment technologies; (2) to encourage sustainable infrastructure and conservation planning using made-in-Ontario technologies to solve water, wastewater and stormwater infrastructure challenges; and (3) encourage all Ontarians to use water more wisely.

LEGISLATIVE TOOLS FOR PROVINCIAL GOVERNMENTS

Based on our review of Ontario initiatives toward water security, we suggest provincial legislators and policy-makers keep three goals in mind:

- Create outcome-oriented legislation and regulations. Rather than mandating how something must be done, legislation should set expectations and goals.
- Create boundary institutions that bridge levels of government and science, law, and policy (e.g. watershed institutions can facilitate coordination but they must have capacity for both knowledge and skills as well as financial means to operate).
- Review regulations and legislation to ensure cumulative effects are accounted for (e.g. are applications for pollution permits reviewed in the abstract or in the cumulative?)

A STEP BY STEP GUIDE TO AN ADAPTIVE GOVERNANCE APPROACH

In this section, we outline key steps communities can take to implement "good governance" practices with the aim of achieving water security.

Step	
1	Identify Key Stakeholders and Decision-Makers and Define Scale
2	Create a Governance Map (to Understand the Decision-Making Process in your Defined Community)
3	Define status of water security (refer to *Part II, Section 4 WSSI*) - which includes identifying and locating key data sources
4	Identify Risks to Water Security (refer to *Part II, Section 2 WSRA*)
5	Identify Adaptive Management Practices
6	Develop Short and Long-term Policy and Planning Recommendations for Water Security (Decision-Making)
7	Undertake Ongoing Assessment, Monitoring, and Management to Reflect Changes in Status and Risk (Behaviour Change)

STEP 1 – IDENTIFY KEY STAKEHOLDERS AND DECISION-MAKERS AND DEFINE SCALE

The first step is to define who will participate in the assessment process and identify the physical boundaries and jurisdictional scale used to define your community (e.g., municipal, conservation authority, watershed). Identifying the scale will likely occur as a group process with key stakeholders and decision makers within the community.

The adaptive governance approach reflects ongoing calls by water practitioners and scholars for the integration of governance in assessment and the need for individual and community engagement.[3] What is the governance structure of your community? Identify the key actors, decision-makers, and special interest groups in your community. Identify the links between assessment, action and re-assessment in your community (including which if any, links are missing?).[4]

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3 Scholz and Stiftel (2005), in particular, highlight different challenges to adaptive water governance, which include the challenge of "representation" of stakeholders, such as resource users and managers.

4 A recent report by the United Nations Global Compact Cities Programme outlines a process in which citizens design their project assessment and methodological tools for achieving sustainable practices with the end goal of reducing stressors leading to global climate change (United Nations 2010). As Becker (2005: 88) suggests, "educating stakeholders about the process of achieving sustainable development may be the most important result of the indicator selection process, even if implementation remains uncertain." In addition, Local Agenda 21, launched at the UNCED conference in 1992, adopts a citizen-focused "process" approach to "good governance". Although this approach is widely adopted in other parts of the world (in particular Europe), its application in North America is limited (Brugman 1997; Smardon 2008).

STEP 2 – GOVERNANCE MAPPING

A preliminary step in assessment and adaptive governance is mapping the governance structure of your community and identifying key actors involved in the governance structure (i.e., community end-users, water managers, water policy specialists, and local decision-makers). Figure 1 shows a general diagram that outlines categories of stakeholders involved in the water policy-making process. The details of the specific stakeholders should be revised and updated to correlate with the specific community structure. Figure 2 provides an example of mapping the governance structure of a community by listing and categorizing different actors involved in water governance specific to the Township of Langley, British Columbia. This list is by no means exhaustive: rather it is used as an example of how to initiate the process. This activity would be a useful part of an introductory community meeting, where the mapping could be part of an interactive, facilitated process.

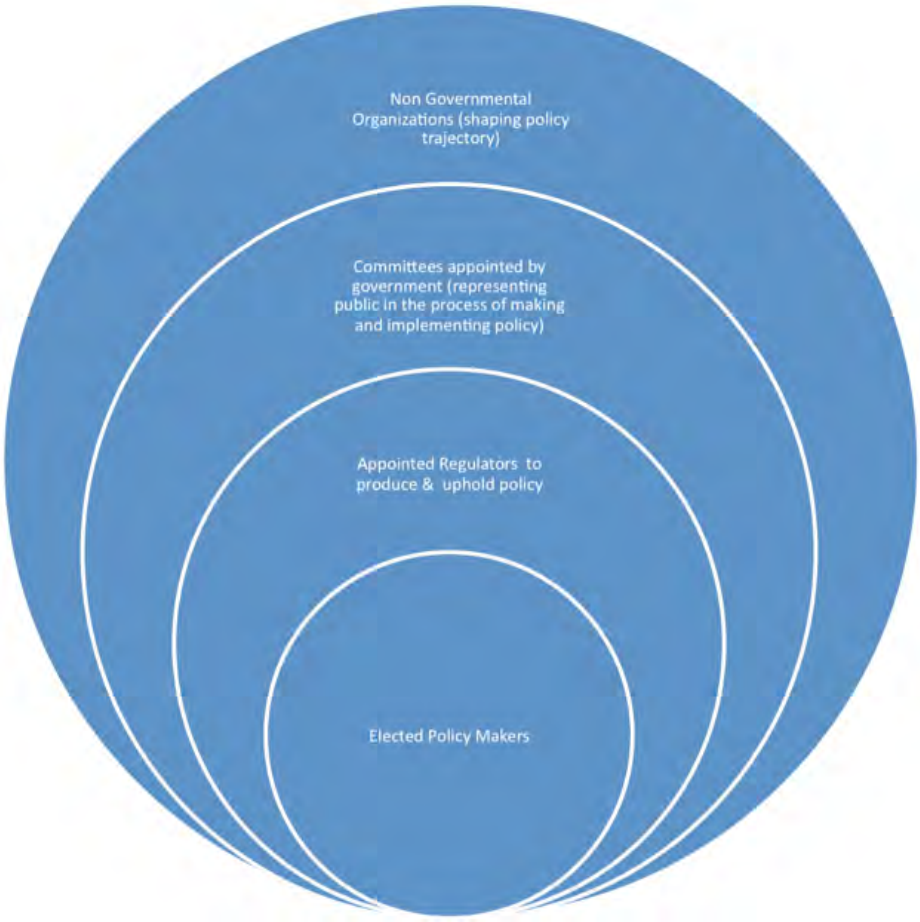

Figure 1: Outline of stakeholders involved in water policy – making process (Source: adapted from Bakker 2003)

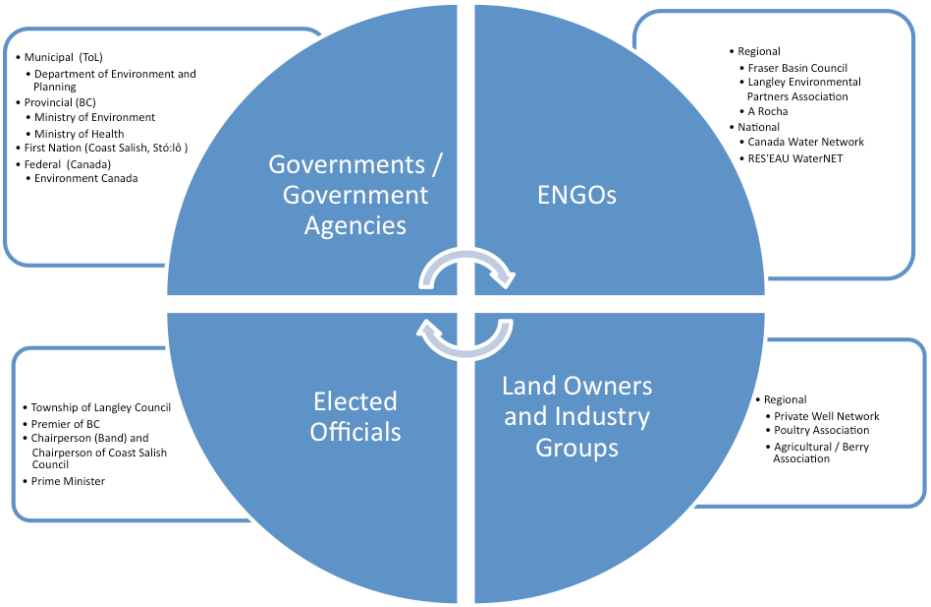

Figure 2: Mapping actors involved in water governance activities, using Township of Langley, British Columbia, as an example

STEP 3 – ASSESS WATER SECURITY STATUS

Two important steps in adaptive governance are the identification of appropriate indicators to monitor and assess the ***current status*** of water security (step 3), and the identification and evaluation of water-related ***risks*** (step 4). The utility of indicators is greatly enhanced when linked to decision-making (step 6). Using an adaptive governance approach means linking findings back to behaviour change (step 7), not just about changing plans, but assessing the effectiveness of management actions on the ground. Well-formulated policies could be structured to anticipate the conditions that lie ahead using integrated and forward-looking analysis. Indicators of success should be part of the assessment process from a governance or performance point of view, as well as from a results perspective. As more information is available and technologies change, the process can be revised and updated.

Decision-makers need access to timely information (demonstrating whether a system is moving closer to, or further away from the outlined goals). Developing adaptive short and long-term policies and informing decision-makers in a timely manner is central for water security in an uncertain world. Similar to the indicator development cycle (Figure 3), an adaptive governance approach allows for communities to react to - and continually revise plans - as new information becomes available. Indicators also have the potential to play an important role in the dissemination of information. For example, they can be used to transform complex scientific and social data points into a simplified and quantified expression that can be easily communicated to the general public.

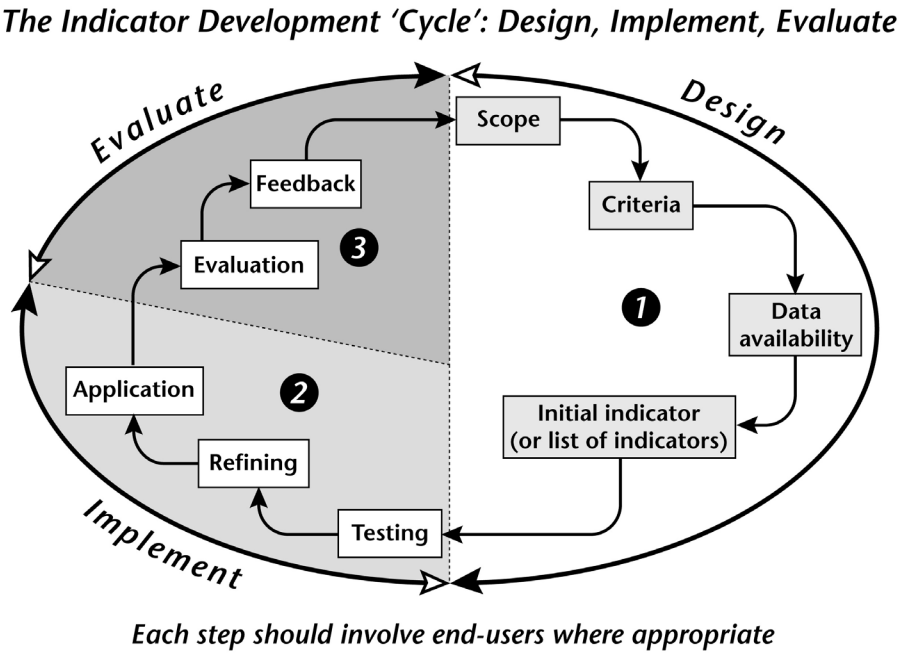

Figure 3: The Indicator Cycle: Design, Implement, Evaluate Source: Dunn and Bakker (2009)

For more detailed information refer to *Part II, Section 4 Water Security Status Indicators*, and *Part II, Section 5 Mapping the Likelihood of Groundwater Contamination.*

STEP 4 – ASSESS RISKS TO WATER SECURITY

An assessment of risks to water security should consider the hydrologic components of the community-defined scale (which includes both surface water and groundwater), together or separately, depending on the driving issues and practicalities (e.g. data availability, knowledge). The risk assessment framework should also consider water quality and quantity, together (or separately, for similar reasons).[5] Risk includes two fundamental components: vulnerability and loss. **Vulnerability** is the potential for damage caused by various hazards (e.g., contamination, over use), offset by the natural protection provided by the physical (unaltered or altered) system. **Loss** is the economic, environmental or health consequence associated with the deterioration of a water resource.

The Water Security Risk Assessment (WSRA) framework, based on the principles of risk assessment methodology, provides spatial indicators of risk by mapping attributes of the built and natural environments (ideally at a watershed scale). For further information refer to *Part II Section 2 Water Security Risk Assessment, and Part II, Section 3 Water Security Vulnerability Scoring.*

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[5] It may be impractical or unnecessary to assess risks to each hydrologic component and their respective attributes (quality and quantity), although integrated management of these two water sources is ultimately necessary.

STEP 5 – IDENTIFY ADAPTIVE MANAGEMENT PRACTICES

Adaptive management entails three overlapping activities: participation of stakeholders; policy-setting; and monitoring and enforcement. Participation is central to the process, as a means of improving information flows, improving compliance, and enabling stakeholders to be agents of change (rather than passive observers) (Sabatier and Jenkins-Smith 1993; Sabatier et al. 2005). This, in turn, can facilitate effective responses to changes in water security status and risks by, for example, lifting or imposing moratoriums, updating standards, addressing cumulative effects, coordinating across political jurisdictions, and acting to promote long-term goals. In order to assess whether policies have been implemented, and assess their effects, monitoring and enforcement are required. A robust monitoring system should be delivering regular updates on status. A long-term commitment to monitoring the system being governed relies on institutional capacity and community engagement. Institutional capacity requires an understanding of the stakeholders and their roles as well as investment in collecting and analyzing data. Each of these activities is associated with good governance goals: for example, participation should be inclusive; policy-setting should be responsive; monitoring and enforcement should be transparent and accountable. The ability and flexibility of a governance model to respond to changing conditions is critical to its effectiveness.

Once you have gained a preliminary understanding of the status of your community's water security and risks to water security you can work your way through the adaptive management approach--linking assessment, action, and re-assessment.

Key considerations of an adaptive management approach:

- Monitoring capacity – data availability (e.g. quality and timeliness) and comprehensiveness, accessibility to information;
- Regulatory capacity and rule of law – comprehensiveness of regulatory framework, training of water purveyors, effectiveness and predictability of the judiciary, enforceability of contracts;
- Decision-making capacity – accountability, transparency, inclusiveness and participation (e.g. integration of stakeholders into decision-making).

Identify how the information gained from assessment (i.e. the WSSI and the WSRA) can feed into land use practices and management. Steps 6 (Development of short and long-term policy and planning recommendations for water security) and step 7 (Ongoing assessment, monitoring, and managing to reflect changes in status and risk) are integral to this practice of adaptive management.

STEP 6 – DEVELOPMENT OF POLICY AND PLANNING RECOMMENDATIONS

The next critical piece is adaptation, i.e. having plans in place to link the findings back to behaviour change. This critical component requires continued buy-in from citizenry and policy-makers. Civic engagement and general awareness of water-related issues are important considerations for linking assessment to change (Nowlan and Bakker 2010; Sabatier et al. 2005).

It is essential to identify existing mechanisms for data assessment and water management. For example, in Township of Langley (ToL), British Columbia (one of our case study communities for the Water Security project), a number of special interest networks and community groups exist whose general goals include improving water quality through data exchange networks or through habitat restoration. However, the scope of these organizations is often narrowly defined and rarely integrated with other resources. Incorporating assessment methods - such as the Water Security Assessment Indicator (WSSI) - into the design and development of policy will aid the community to think more broadly about assessing water status and risk, and in turn, meet goals of water security in a more integrated manner.

In ToL, the community partners involved in the water security project noted that the process of undertaking the WSSI assessment method proved useful for highlighting gaps in current practices, particularly in relation to data collection and availability. In addition, participants indicated that the user-friendly output of the WSSI assessment could help revitalize the interest in ongoing assessment and planning, and be of particular use in engaging with community leaders and decision-makers. Similar approaches in other Canadian jurisdictions have yielded positive outcomes. For example, the town of Oliver, British Columbia has made great strides in closing the assessment-governance gap by incorporating a groundwater susceptibility map (Liggett and Allen 2011) into their official community plan (Smart Growth on the Ground 2008).

The assessment process also revealed some important gaps among data collection, assessment and implementation. In particular, the assessment revealed that although there were substantial "water quality" data, its utility was compromised (i.e. fragmented, poor quality, narrowly-defined, and location-specific). There are no guidelines for the collection and storage of water quality data. In addition, data gaps highlighted that many departments and organizations are not effectively communicating regarding existing data or ongoing monitoring efforts (Table 2). Step 7 can address these gaps to help close the link between assessment and application.

Table 2: Ongoing assessment of water status through WSSI assessment: Community reported benefits and new findings (institutional gaps)

Benefits of WSSI Assessment (Reported by case study communities)	**Key Findings & Institutional Gaps**
Overall, results corroborated municipalities findings (validating)	Existing datasets were not as streamlined (or complete) as the municipality originally understood
User-friendly output	Transfer (sharing) of information between departments and sectors needs greater attention
Presentation of results revitalized community interest in water-related issues	Data were often narrowly-defined, inconsistent (e.g., for aquatic ecosystem health data was largely collected in response to "incidents" rather than ongoing assessment)
Increased buy-in from community leaders and decision-makers	For drinking water quality, although the datasets are more complete (than aquatic ecosystem health databases), the different formats due to various types of water sources (private wells, public wells, and GVRD surface water) made it difficult and time consuming to compare
Closing assessment – governance gap	Greater work needs to occur to address mismatch between scale of assessment and scale of governance
Visually rich educational tools	Great need to improve feed-back loop between assessment and community education, and assessment and policy change

STEP 7 – ONGOING ASSESSMENT, MONITORING AND MANAGEMENT

In order to assess whether policies have been implemented, and assess their effectiveness, monitoring and enforcement are required. A robust monitoring system should deliver regular updates on status. A long-term commitment to monitoring the system being governed relies on institutional capacity and community engagement. Institutional capacity requires an understanding of the stakeholders and their roles as well as investment in collecting and analyzing data. Each of these activities is associated with good governance goals: for example, participation should be inclusive; policy-setting should be responsive; monitoring and enforcement should be transparent and accountable. The ability and flexibility of a governance arrangement to respond to changing conditions is critical to its effectiveness.

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CASE STUDIES [6]

Although the term, "water security" has not yet been fully embraced in Canada, many Canadian communities implicitly accept the goals of water security. Full implementation of this concept, however, is relatively rare. Here, we present three examples of communities integrating governance with elements of water security: the Yukon Intertribal Watershed Committee, the Okanagan Basin (British Columbia), and Oak Ridges Moraine (Ontario).

These communities, true to our definition, aim to achieve sustainable access to adequate quantities of water, of acceptable quality, for human and environmental uses, on a watershed basis.

CASE 1: HIGHLIGHTING BEST PRACTICES: YUKON INTERTRIBAL WATERSHED COUNCIL

The Yukon River Inter-Tribal Watershed Council (YRITWC or the Council) is a collective initiative of 70 First Nations and tribes across Alaska and the Yukon Territory that aims to improve the health and well-being of the watershed and the people who live within it. The Council's vision, simply put, is "to be able to drink water directly from the Yukon River" (YRITWC 2009).

The multijurisdictional (and transboundary) nature of the watershed (Figure 4) had, in years past, complicated the governance of the watershed. Whilst agencies at the federal, state, and / or territorial level had some regulatory responsibility for the watershed, no single group existed to manage the watershed in its entirety. Recognizing that need, the Council was established in 1997 as a treaty-based organization of indigenous governments dedicated to preserving and protecting the environmental quality of the Yukon River for the health of their communities, and the continuation of a traditional Native way of life for generations to come. The YRITWC is an innovative and highly collaborative organization. It is the first (committee) dedicated solely to promoting the responsible management, use, protection, and enhancement of the watershed. The council achieves these goals through a variety of methods, including education programs, water quality monitoring, stewardship and land management practices. In addition, the Council serves as a vehicle to involve the First Nations and tribal communities in direct decision making related to the governance of the watershed and to provide a forum in which to express the needs of the member villages, tribes, and nations collectively (YRITWC 2009). In 2005, Harvard University recognized the innovations of the Council as an award-winning program. The Council was described as a model of self-determination, governance, and collaboration, with high achievements in three main areas: the initiation of the YRITWC; the development of a complex and high quality operational system; and the impact and reach of the Council on the health of Native peoples along the Yukon River and beyond (Harvard University 2005).

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[6] These case studies are reproduced from Norman et al (2010).

The Council continues to develop new programs with a focus of five main tenets:

- Understanding the Watershed through monitoring, measuring and researching, and using this knowledge to clean, enhance and preserve life along the River.
- Education: Promoting environmental and traditional education for the Indigenous Peoples of the Watershed through education programs, scholarships, internships, volunteer opportunities and incentive programs.
- Stewardship: Honouring the traditional heritage through good stewards of the Watershed and its tributaries, and to restore and preserve its health for the benefit of future generations.
- Enforcement: Developing and enforcing strong state, federal, territorial and provincial environmental standards to preserve the long-term health of the watershed.
- Organization: Providing greater organizational strength to the Indigenous Peoples of the Yukon River Watershed, both by assisting and improving Indigenous governments, and by being a model of organization built on collaboration and mutual respect. (YRITWC 2009).

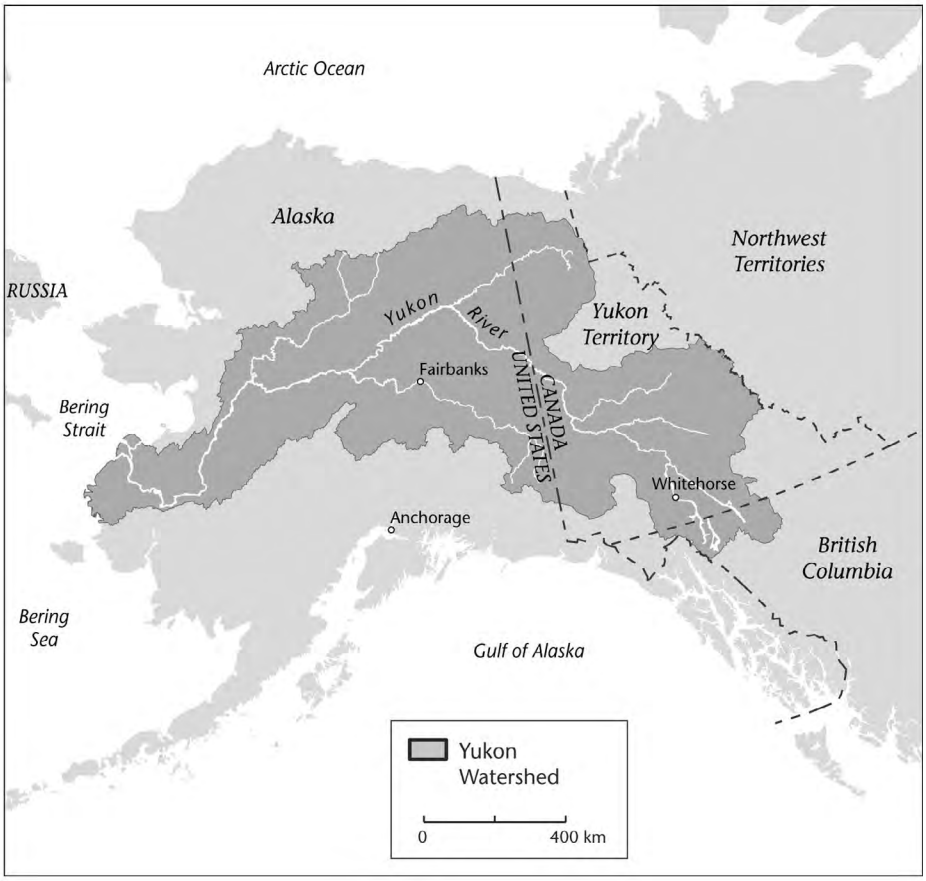

Figure 4: Map of Yukon Watershed

CASE 2: THE OKANAGAN BASIN, BRITISH COLUMBIA

The Okanagan Basin, located in south-central British Columbia, is almost 200 kilometres long and 8,000 square kilometres in area (Figure 5).1 As one of the most arid watersheds in Canada, the basin is at risk of severe water shortages, particularly in summer months. The Okanagan Basin is experiencing significant population growth, recently becoming one of the fastest growing regions in British Columbia. So much so, that the Okanagan Basin now has the smallest volumes of fresh water per capita in British Columbia (Neilson-Welch and Allen 2007).

The water users in the basin are primarily agricultural, making up approximately 70 percent of the total annual water consumption. However, there is now growing demand from commercial, institutional, and residential users (Patrick 2008). The pressure of agricultural and industrial demand, coupled with growing household needs, is placing strain on both surface and ground water sources in the basin. Similarly, a large proportion of the region's aquifers are highly vulnerable to surface contamination. Limited knowledge about the region's aquifers and their susceptibility to contamination exacerbates the issue (Neilson-Welch and Allen 2007).

The increasing population growth coupled with growing water scarcity prompted the lead basin water institution, the Okanagan Basin Water Board (OBWB), to develop the "Sustainable Water Strategy". Launched in October 2008, the plan includes methods to protect the area's water resources and secure the region's water supplies. This plan builds on more than forty years of water planning for the region; starting with the Municipalities Enabling and Validating Act of 1969, which created the OBWB. The original mandate of the OBWB was to coordinate the eradication of invasive weeds and provide grants to improve local water waste treatment. Since its inception the OBWB has expanded its mandate to tackle more holistic water security issues.

As a response to mounting ecological and social stresses, the Okanagan Basin is making great strides in achieving water security. Foremost among these strides are the partnerships between the OBWB, government agencies and universities which have produced useful studies such as the Water Supply and Demand Study and the Groundwater Assessment of the Okanagan Basin Program.

Other governance innovations include:

- The Smart Growth on the Ground Partnership in Oliver, British Columbia with a focus on groundwater and land use;[8]
- The Groundwater Bylaws Toolkit which brings together a number of tools for integrating land and water management;
- The development of an integrated information system - Okanagan Basin Information Network Water Balance model; and

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7 The Basin spans the communities of Osoyoos to the south to Armstrong in the north.

8 See, http://www.sgog.bc.ca/uplo/OliverSummaryMarch2007.pdf

- Assistance with groundwater mapping and vulnerability assessments by those at senior levels of government.

In sum, although the Okanagan Basin has not fully achieved water security in its region, it exhibits great strides in meeting its goals.

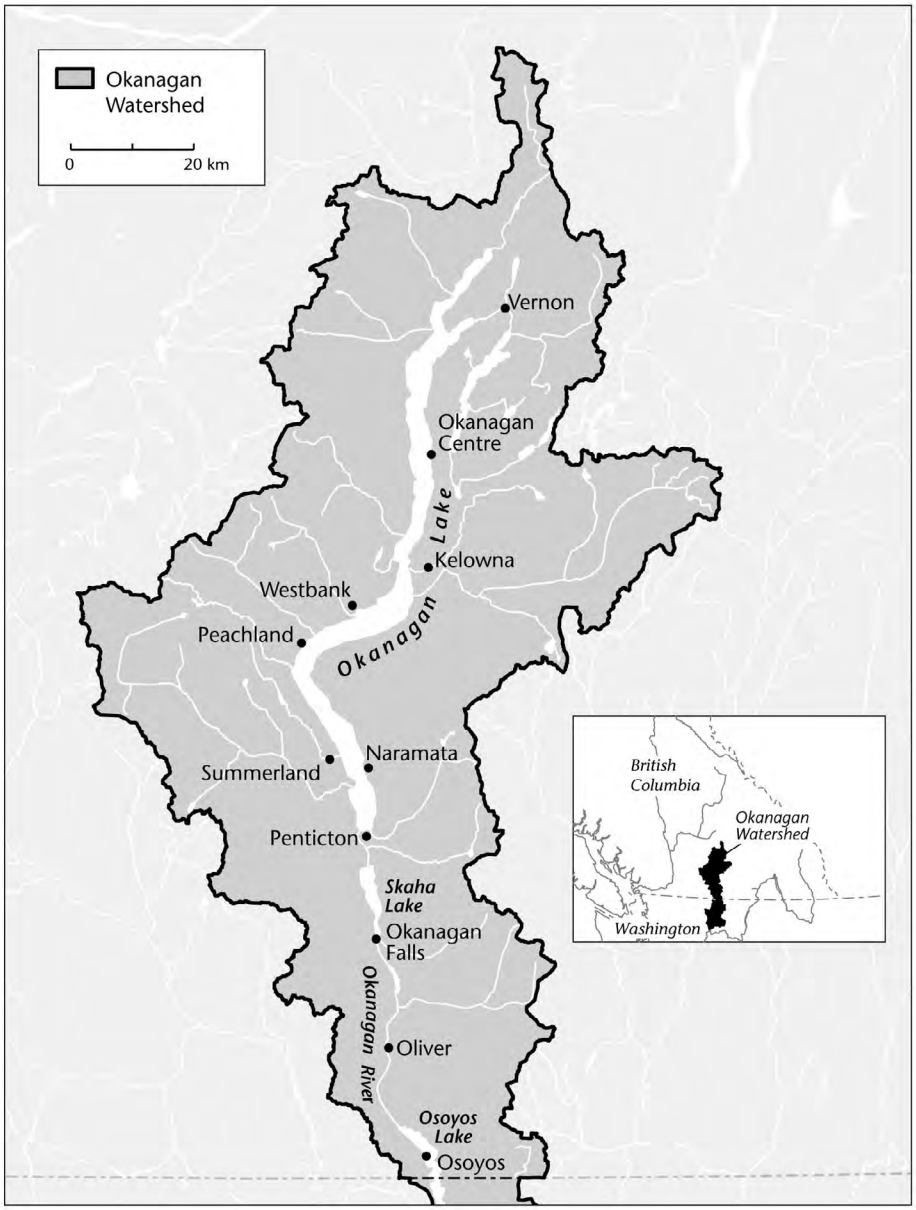

Figure 5: Okanagan Basin map

CASE 3: OAK RIDGES MORAINE, ONTARIO

Water security has become an important flash point in the ongoing debate about development in the environmentally sensitive, geological landform known as the Oak Ridges Moraine, which extends 160 kilometres from the Niagara Escarpment in the west to the Trent River in the east, north of Toronto (Figure 6). The moraine covers 190,000 hectares, contains the largest

concentration of headwater streams in the Greater Toronto Area, and is an important recharge area for groundwater.

The moraine is a regional groundwater recharge area and the source of drinking water for more than 250,000 people through municipal groundwater supplies and more than 135,000 private domestic wells. The moraine's water resources also support industrial uses, sand and gravel extraction, and processing which serves the Greater Toronto Area and a vibrant agricultural base (Bradford 2008; Holysh 2009).

Land and water management on the moraine is challenging given the 32 municipalities involved, as well as by the high concentration of privately-held land (upwards of 90 percent). The pressure to develop land on the moraine for housing and urban settlement is increasing as the Greater Toronto Area population grows and greenfield land is in short supply.

Although proposals to preserve the moraine have circulated for more than 60 years, the implementation of a comprehensive plan to protect groundwater and ecologically sensitive areas did not occur until 2001. In 1991, the Ontario Ministry of Natural Resources undertook a broad hydrogeological review of the Oak Ridges Moraine, which was followed by a five-year study by the Geological Survey of Canada. Despite these efforts, development continued on the moraine. A lengthy and controversial series of hearings at the Ontario Municipal Board in 2001 surrounding proposed new housing for an additional 100,000 people precipitated the development (and enforcement) of a conservation plan for the moraine.

An advisory panel made up of key stakeholders, as well as an inter-ministerial team of senior Ontario Government officials were established, both of which made a series of recommendations to the government. An extensive outreach process, involving a series of day-long stakeholder sessions and evening public meetings, strengthened the protection strategy. From this the Province developed and passed the Oak Ridges Moraine Conservation Act with all-party support on December 14, 2001. This was followed by the Oak Ridges Moraine Conservation Plan (ORMCP), which was released in April 2002.

The main objective of the ORMCP is to protect the ecological and hydrological integrity of the Oak Ridges Moraine Area. Although the ORMCP was created by the Provincial Government, it is administered by local and regional municipalities. At the same time as the ORMCP was released, the Province announced the creation of the Oak Ridges Moraine Foundation – a registered corporation with its own Charter. The Foundation operates primarily by funding others in five program areas including land conservation, land stewardship, education, research and support for the Oak Ridges Trail. It also offers leadership or coordination for moraine-wide activities by bringing people and interests together to identify common ground.

Despite great social and ecological challenges, the communities and government agencies are working together to achieve water security in the Oak Ridges Moraine.

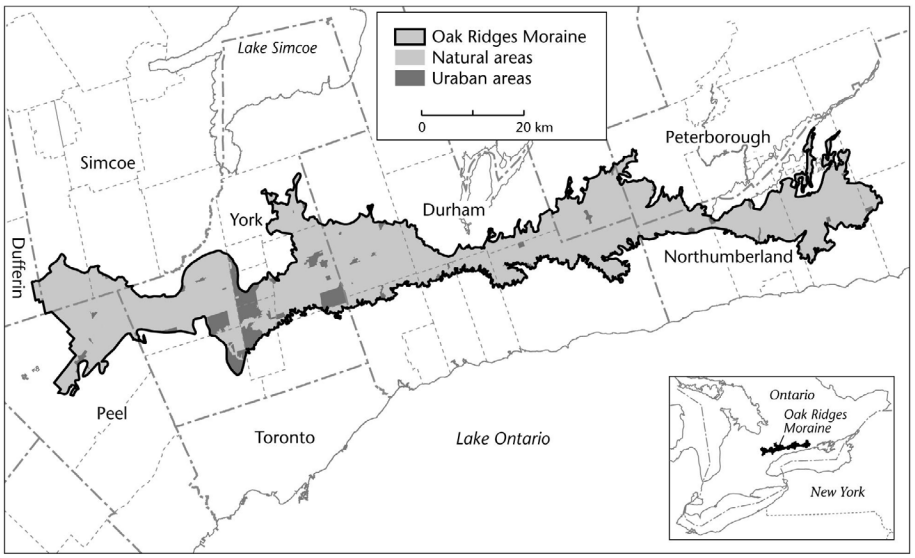

Figure 6: Oak Ridges Moraine map

SUMMARY TABLE OF KEY GOVERNANCE PRINCIPLES FROM CASE STUDIES

Table 3: Examples of Governance Principles for water management from Case Studies

Source	Governance Principles
Yukon River Intertribal Watershed Council (2009)	• Understanding the watershed: Ongoing monitoring, measuring and researching • Education: Promoting environmental and traditional education for the Indigenous Peoples of the Watershed • Stewardship: Honouring the traditional heritage through good stewards of the Watershed and its tributaries • Enforcement: Developing and enforcing strong state, federal, territorial and provincial environmental standards • Organization: Providing greater organizational strength to the Indigenous Peoples of the Yukon River Watershed
Okanagan Basin Water Board (OBWB)	• Strong Partnerships between the OBWB and government agencies • Commitment to producing meaningful research reports and assessment programs • Smart Growth plan with a focus on groundwater and land use • Commitment to integrating land and water management • Development of an integrated information system
Oak Ridges Moraine Conservation Plan	• Establishment of advisory panel made up of key stakeholders and senior government officials • Extensive outreach process • Development of meaningful legislation (*Oak Ridges Moraine Conservation Act*) • Development of governance plan (*Oak Ridges Moraine Conservation Plan*) • Commitment to protect the ecological and hydrological integrity of the Moraine • Ongoing Governance: Creation of Foundation operating with five program areas including land conservation, land stewardship, education, research and support for the Oak Ridges Trail • Provides leadership or coordination for moraine-wide activities by bringing people and interests together to identify common ground

WATER SECURITY GUIDANCE DOCUMENT

PART 3 SECTION 7
BOIL WATER ADVISORY PROTOCOL (BWAP)

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With grateful thanks to Dr. Diana Allen (Simon Fraser University), Mr. Barry Boettger (BC Ministry of Health), Paul Froese (Ontario Ministry of the Environment) and Dr. Judith Isaac-Renton (BC Centre for Disease Control) for their comments and input.

WATER SECURITY GUIDANCE DOCUMENT
PART 3 SECTION 7
BOIL WATER ADVISORY PROTOCOL (BWAP)

ABSTRACT

A step-by-step guide for government regulatory officials and water suppliers involved in the decision to issue and rescind boil water advisories.

This protocol is based on the thesis "**Boil, Boil, Toil and Trouble: The Trouble with Boil Water Advisories in British Columbia**" by Renuka Grover. The full thesis is available at: http://hdl.handle.net/2429/33790.

WATER SECURITY GUIDANCE DOCUMENT

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BACKGROUND: KEY ISSUES AND CONTEXT

Boil water advisories (BWAs) are public notifications of drinking water quality and are used as temporary, precautionary measures to protect the public from possible waterborne illnesses. In many Canadian jurisdictions, BWAs have been in place for months to years, leading to the concern that their use can be a substitute to the action needed for their removal. With lengthy or on-again-off-again BWAs, there is concern that the public will become complacent and not comply with the BWA. Research on BWAs is scarce, and little evidence is available to support practical decision-making by the two groups of key players responsible for BWA management – government regulatory officials and water suppliers.

The decision-making process has been found to be inconsistent from one decision-maker to the next, both within and across regulatory authorities. BWAs are handled on a case-by-case basis for the most part. This approach has both advantages and disadvantages.

The management of each BWA case within the context of the water system's unique circumstances allows decision-makers to consider what is likely best for the specific water system in question. Treating all water systems the same way would be a rigid approach; there needs to be some sensitivity to context. However, at present some of the diversity of approaches is not because of differences between systems but rather differences between decision-makers. Some decision-makers issue BWAs as a precaution and others only as last resort. Some consider numerous factors before making decisions; others do not. Some have years of experience in issuing BWAs and with specific water systems; others do not. There is the potential for such personal preferences and experiences (or the lack thereof) to affect sound decision-making.

Inconsistent approaches can therefore be problematic from a fairness perspective. This concern was raised in the Ombudsman's report on drinking water in British Columbia (Office of the Ombudsman 2008). The public should be able to rest assured that their drinking water is being managed in the best possible way, regardless of the type or size of their water system or where they live.

PURPOSE OF THE PROTOCOL

Part III of this Guidance Document focuses on managing risks to water security. The purpose of this protocol is to guide the overall management of boil water advisories, by acting as an information resource and by introducing a basis for consistency. It includes steps to take and factors to consider taking into account when deciding to issue and rescind boil water advisories.

INTENDED USERS

This tool is primarily intended for regulatory officials and water suppliers involved in the management of boil water advisories.

DESCRIPTION OF PROTOCOL

The BWA protocol defines and describes the three main types of public notifications, and the circumstances in which each should be issued. It also recommends steps for regulatory officials and water suppliers to take for issuing and removing BWAs.

This protocol functions to support decision-makers with adaptive procedures such that decisions to issue and rescind BWAs can be structured across roughly similar yet unique situations. The protocol may be used together with other related and jurisdiction-specific policies, regulations and guidance material; however, this protocol is subsidiary to any provincial/territorial and federal laws, directives, policies or regulations based on the management of BWAs. For information on what regulations apply in specific jurisdictions, the appropriate regulatory authority should be consulted.

The contents of the protocol have been partially adapted from resource materials from the local/regional authority, provincial and federal levels:

- *Guideline for Issuing and Rescinding a Drinking Water Public Notice (2007).* Health Protection, Environmental Health Services, Fraser Health Authority.
- *BC Drinking Water Officer's Guide (2007).* Drinking Water Leadership Council, Ministry of Health Services, Province of British Columbia.
- *Guideline for Boil Water Notice Decision Process (2009).* Public Health Protection Management Team, Northern Health Authority.
- *Guidance for Issuing and Rescinding Boil Water Advisories (2009).* Federal-Provincial-Territorial Committee on Drinking Water, Federal-Provincial-Territorial Committee on Health and the Environment, Health Canada.
- *Issue Paper: Drinking Water Public Notification Policy and Guideline Recommendation (2005).* Zibin S., Sigalet, E., Interior Health Authority.

Although the protocol materials and resources are specific to BWAs, the information could be extended to other forms of public notifications on drinking water quality.

A STEP-BY-STEP GUIDE TO APPLYING THE PROTOCOL

THE THREE MAIN TYPES OF PUBLIC NOTIFICATIONS

Knowing when to issue a BWA - or any type of public notification - first requires awareness of the different types of public notices.

For consistency in terminology, it is recommended that decision-makers in each province/territory adopt terms defined in relevant provincial policies and legislation. For instance, the terms used in the BC Drinking Water Officer's Guide should be used in BC (as shown in bold in Table 1).

Table 1: Relevant terminology used for issuing public notices

	Do not drink advisories *(Do not use water notices, Do not use, Do not use advisories)*	**Boil water notices** *(Boil water advisories, Boil water orders)*	**Water quality advisories** *(Drinking water advisories, Water quality notifications, Drinking water notifications)*
When to issue?	When there is a risk that cannot be adequately addressed by issuing a water quality advisory or by boiling the water (and in some cases, boiling would worsen the water quality); the water is not safe for domestic use.	When there is a known or potential threat to drinking water that is microbiological (bacterial, viral or parasitic) in nature. The risk can be adequately addressed by boiling the water as a short-term form of treatment. A boil water order is a legal written order and formalized version of a boil water advisory requiring water supplier to operate under boil water conditions.	When there is some level of threat particularly affecting a subset of the general population (susceptible individuals) and not necessarily everyone; the threat is not significant enough to require a boil water advisory or do not drink advisory.
Common reasons to issue	• Chemical contamination or exceedances (such as unacceptable levels of naturally occurring nitrates, lead or arsenic) • Accidents – such as chemical spills • Acts of vandalism, sabotage or bioterrorism that may affect water supply • Natural disasters, such as earthquakes or mudslides • For precautionary purposes when there is some unknown threat that will require time to determine.	• Waterborne outbreak conditions • Bacteriological quality of water is below the accepted standard (presence of E.coli in water and/or repeated trends of total coliform) • No treatment in place at water system • Water system treatment breakdown • Inadequate disinfection at water system • High turbidity	• Chemical exceedances (such as high sodium or high iron levels, which may affect individuals on a sodium-restricted diet or infants, respectively) • Water is not aesthetically pleasing (colour, odour) • Medium-to-high turbidity

PART 1: ISSUING AND REMOVING BWAS: A GUIDE FOR GOVERNMENT REGULATORY OFFICIALS

Table 2: Summary table outlining the recommended steps to the decision, issuing and removing of BWAs for regulatory officials[1]

Step	
1	Identify Threat to the Drinking Water Supply that May Require a BWA
2	Initiate Communication with Water Supplier and Required Personnel
3	Review Water System File and Assess Risk **Checklist A*
4	Conduct Site Inspection
5	Consult and Communicate to Reach a Decision
6	Issue BWA **Checklist B and C*
7	Confirm Issuance of BWA
8	Develop Removal Criteria
9	Keep Everyone in the Loop
10	Meet Removal Criteria **Checklist D*
11	Rescind BWA **Checklist E*
12	Review BWA

* *See the Checklist section of this document (page 17) to view the checklists referenced in the table above and in the text below.*

Note: Especially in events where time is of the essence, steps 1 – 5, which take place prior to the actual issuing of the BWA, should be attempted promptly so as to not unintentionally delay the issuing of the advisory. The amount of time spent on each step and whether the completion of one step is necessary before proceeding linearly onto the next step is discretionary and dependent on the type of threat and situation on hand.

[1] The information provided in this section primarily used the Fraser Health Authority's Guideline for Issuing and Rescinding a Drinking Water Public Notice (2007) as a guide, but has been adapted specifically for BWAs, rather than for all public drinking water notifications.

STEP 1 – IDENTIFY THREAT TO THE DRINKING WATER SUPPLY THAT MAY REQUIRE A BWA

Determine whether there is a potential or confirmed threat to the drinking water supply. The threat can be any situation, condition, or thing that renders the water unsafe for consumption. Awareness of a threat may occur via notification from the laboratory, from the water supplier, from a member of the public, or by an on-site water system inspection, for instance. Threats may include:

- A drinking water sample is not in compliance with relevant provincial or territorial legislation;
- There is no water treatment and/or disinfection in place at the water system or the treatment system is malfunctioning due to mechanical failure;
- Unexpected and unacceptable changes to water quality are observed, such as high turbidity;
- The water system is not being properly maintained. This could be when a new or previously un-permitted water system is discovered and there is no water supplier or no trained or competent water supplier onsite to maintain daily water system operations (e.g. water quality monitoring);
- There is epidemiological evidence indicating water from the system as a possible source of a waterborne disease outbreak.

Moderate to high-risk, time-sensitive events may require decision-makers to proceed towards a course of action more quickly than low-risk events. Moderate to high-risk events include:

- waterborne disease outbreaks;
- laboratory reports of E.coli in multiple water samples collected from different locations with no evidence of sampling error;
- interruption or loss of water treatment;
- unfiltered surface water systems with unacceptable raw water turbidity;
- zero or negative pressure due to water main break or loss of source; and
- tampering and introduction of a harmful substance into the water system.

Low-risk events - primarily from inconclusive water bacteriological results – include:

- the potential for sampler error;
- no evidence of operational and maintenance issues or loss of disinfectant residual at the time of water sampling;
- a water system with no history of poor water quality; and
- no evidential change to water quality (e.g., turbidity or colour).

STEP 2 – INITIATE COMMUNICATION WITH WATER SUPPLIER AND REQUIRED PERSONNEL

Make contact with the water supplier to inform him/her about the identified potential risk to drinking water, possible causes, and to initiate dialogue on next steps. Review the water supplier's water sampling protocol and arrange to have follow-up water samples taken immediately by the water supplier for confirmatory testing. Inform appropriate managers, the medical officer of health and any other required personnel about the threat to the drinking water system.

Having an incident response team established prior to and in preparation for such events, as recommended by the Federal-Provincial-Territorial Committee on Drinking Water, would expedite the effective exchange of information. Such a team may include professionals experienced in water quality monitoring, drinking water regulation, source water protection, treatment plant operation, water distribution, and public health surveillance.

STEP 3 – REVIEW WATER SYSTEM FILE AND ASSESS RISK

Collect and compile risk assessment information about the water system. Consider what is known and unknown about the situation. Refer to C*hecklist A: Water System Risk Assessment.*

STEP 4 – CONDUCT SITE INSPECTION

If additional or confirmatory information is needed for risk assessment, you may conduct an onsite water system inspection, if there is sufficient time.

STEP 5 – CONSULT AND COMMUNICATE TO REACH A DECISION

Once sufficient information about the water system and the risk posed to water users has been compiled, consult with the manager, medical officer of health, and other colleagues, as appropriate. Discuss the situation with the water supplier.

Given that the main purpose of a BWA is to protect public health from a confirmed or possible microbiological threat to drinking water – where boiling the water is sufficient to render the water potable – decide whether issuing of a BWA would be the correct action to take, and not some other form of public notification.

STEP 6 – ISSUE BWA

Review proposed course of action and request the water supplier to initiate action immediately. The water supplier should be notified of the issuing of a BWA by the best means (written notice, email, telephone, fax or in-person). In the case of noncompliance, issue a formal boil water order to the water supplier.

In communication with the water supplier, the regulatory official should indicate how to inform the water users about the BWA and what specific information or instructions they should be given. Direct the water supplier to prepare the BWA notice and submit a copy to the regulatory authority for review prior to disseminating. The water supplier should confirm by what means the BWA will be communicated to the water users. Alternatively, clearly and directly indicate to the water supplier what the BWA message should include. This may especially be required in the case of small water systems, where the water suppliers may not have the experience, resources, and know-how to develop an effective strategy and message to communicate the BWA to water users. *Refer to Checklist B: Creating the BWA Message*.

Prohibit the use of language that nullifies or defeats the purpose of the notice. Ensure the language is not too technical and encourages broad understanding of the BWA message.

Decide on the best means to disseminate the information to the all water users and the general public, according to the water system in question. The use of multiple methods is recommended. *Refer to Checklist C: Ways to Disseminate the BWA message*.

Inform support staff and agencies affected by the BWA, such as other health unit facilities, Nurse lines, etc. The regulatory authority's website should be immediately updated with information about the BWA. It is recommended that at least the following information be provided online on the regulatory authority's website:

- Name and location of water system
- Date the BWA is issued/effective
- Why the BWA was issued (the reason, the threat)
- What specific actions will determine when the BWA can be lifted (the criteria for removal)
- Up-to-date information regarding the current status of the BWA (updated as soon as new information is available or progress is made)

STEP 7 – CONFIRM ISSUANCE OF BWA

Verify with water supplier that the BWA has been communicated to the water users. Furthermore, verify that the issuance has been clearly communicated by checking media reports, directly contacting select water users, onsite visits, or other means.

If there is any reason to believe that the water supplier has not adequately complied with the requirement to inform the water users of the BWA, initiate action to inform the water users yourself. If you need to implement further compliance activity, take appropriate action as per relevant legislation.

STEP 8 – DEVELOP REMOVAL CRITERIA

Once a sound rationale for issuing a BWA has been developed, and the BWA is communicated in a timely manner, formulate removal criteria and develop a timeline by which required corrective actions should be taken and the BWA lifted. The timeline should be realistic and created in conjunction with the water supplier and with consideration of the water system's unique circumstances.

Note: A BWA should not be removed without approval of the appropriate regulatory authority.

STEP 9 – KEEP EVERYONE IN THE LOOP

Arrange to discuss the BWA and progress made with the water supplier on a regular basis. Schedule the next follow-up phone call at each meeting. Maintain a set minimum frequency of follow-up and communication to ensure progress in addressing the BWA is made.

Ensure the water supplier is reminding the water users about the BWA frequently and informing them of progress/updates since the issuance. Keep public postings updated and refresh them as needed.

Ensure that the regulatory authority's website has up-to-date information about the BWA at all times.

STEP 10 – MEET REMOVAL CRITERIA

To ensure progress towards the BWA's removal is maintained, it is important to follow the timeline that indicates what steps need to be taken by the water supplier to remove the BWA.

Once the water supplier has informed you that the threat has been eliminated or corrected, review the removal criteria and decide whether the BWA can be lifted.

Refer to Checklist D: BWA Removal Criteria.

STEP 11 – RESCIND BWA

Compile information indicating that the risk to drinking water is no longer in place. Consult with managers, medical officers of health and other required personnel to discuss removal of BWA.

Authorize water supplier to remove the BWA and inform water users. Have the water supplier develop and submit the BWA removal message for your review. Alternatively, clearly and directly indicate to the water supplier what the BWA removal message should include. This may be required especially in the case of small water systems, where the water suppliers may not have the experience, resources and know-how to develop an effective strategy and no-

tice communicating the removal of the BWA to water users. Once an approved message has been created, the water supplier should immediately inform the water users in the most appropriate means. *Refer to Checklist E: Creating the BWA Removal Message.*

Notify support staff and agencies of the BWA's removal, and update the regulatory authority's website.

STEP 12 – REVIEW BWA

Complete a full review or record of the BWA event. Determine if any changes in approach to the management of the water system are needed. Make necessary improvements to the water system's emergency response plan as needed. This is a key component of an adaptive management and governance approach (see *Part III, Section 6, Fostering Good Governance Practices*).

PART 2: ISSUING AND REMOVING BWAS: A GUIDE FOR WATER SUPPLIERS [2]

Table 3: Summary table outlining the recommended steps to the decision, issuing and removing of BWAs

Step	
1	Identify Threat to the Drinking Water Supply that May Require a BWA
2	Initiate Communication with Regulatory Official and Required Personnel
3	Assess Risk **Checklist A*
4	Consult and Communicate to Reach a Decision
5	Issue BWA **Checklist B and C*
6	Develop Removal Criteria
7	Keep Everyone in the Loop
8	Meet Removal Criteria **Checklist D*
9	Rescind BWA **Checklist E*
10	Review BWA

** Refer to the Checklist section of this document (page 137) to view the checklists referenced in the table above and in the text below.*

Note: Especially in events where time is of the essence, steps 1 – 4, which take place prior to the actual issuing of the BWA, should be attempted promptly so as to not unintentionally delay the issuing of the advisory. The amount of time spent on each step and whether the completion of one step is necessary before proceeding linearly onto the next step is discretionary and dependent on the type of threat and situation on hand.

STEP 1 – IDENTIFY THREAT TO THE DRINKING WATER SUPPLY THAT MAY REQUIRE A BWA

Determine whether there is a potential or confirmed threat to the drinking water supply. The threat can be any situation, condition or thing that renders the water unsafe to drink. You may come to know about a threat to drinking water via notification from the laboratory, from the regulatory authority, from a water user or from your own observations of the water system.

[2] The information provided in this section primarily used the Fraser Health Authority's Guideline for Issuing and Rescinding a Drinking Water Public Notice (2007) as a guide, but has been adapted specifically for BWAs, rather than for all public drinking water notifications.

A threat to drinking water may include the following situations:

- A drinking water sample is not in compliance with relevant legislation in your province or territory;
- There is no water treatment and/or disinfection in place at the water system or the treatment system is malfunctioning due to mechanical failure.
- Unexpected and unacceptable changes to water quality are observed, such as high turbidity;
- The water system is not being properly maintained. This could be if your water system is new or was previously un-permitted and was recently discovered by the local health authority. A well-maintained water system requires a trained and certified water supplier on site to maintain daily water system operations – such as water quality monitoring. If you lack training or are unsure how to manage the water system, your water system may not be considered well maintained and drinking water from the system may not be safe for consumption;
- There is epidemiological evidence indicating water from the system as a possible source of a waterborne disease outbreak.

STEP 2 – INITIATE COMMUNICATION WITH REGULATORY OFFICIAL AND REQUIRED PERSONNEL

Once you identify or become aware of a potential risk to the drinking water, contact your designated regulatory official to inform him/her about the threat, possible causes, and to initiate dialogue on next steps. Review your water sampling protocol with the regulatory official and arrange to have follow-up water samples taken immediately for confirmatory testing.

Inform required personnel, following your emergency response and contingency plan, such as managers, supervisors, community water system President, as deemed appropriate.

STEP 3 – ASSESS RISK

Collect and compile risk assessment information about the water system for consideration into the decision on whether issuing a BWA would be the best course of action to take. Consider what is known and unknown about the situation to develop rationale. *Refer to: Checklist A: Water System Risk Assessment.*

If the regulatory official requests additional or confirmatory information about the water system, you may need to conduct a complete risk assessment of the water system. If the regulatory official plans to conduct an onsite water system inspection, make yourself readily available for the visit and provide as much detailed information and assistance as you can.

STEP 4 – CONSULT AND COMMUNICATE TO REACH A DECISION

Once sufficient information about the water system and the risk posed to water users has been compiled, inform the regulatory official and discuss what actions to take.

Given that main purpose of a BWA is to protect public health from a confirmed or possible microbiological threat to drinking water – where boiling the water is sufficient to render the water potable – decide whether issuing of a BWA would be the correct action to take, and not some other form of public notification.

STEP 5 – ISSUE BWA

Review proposed course of action with the regulatory official. The regulatory official may request that you issue a BWA.

As per jurisdictional legislation, water suppliers are required to provide public notice to water users (with or without request from the regulatory official) when an immediate reporting standard is not met or when there is some threat to the drinking water. The failure of water suppliers to do so will result in the issuing of a boil water order by regulatory officials. Further negligence in complying with the issuing of a BWA and failure to communicate the BWA to water users may result in legal enforcement by regulatory officials.

Activate the water system's emergency response and contingency plan. The BWA should not be removed without approval of the regulatory official.

In communication with the regulatory official, indicate how you will inform the water users about the BWA and what specific information or instructions they will provide. Prepare the BWA notice as will be communicated to the water users and submit a copy to the regulatory authority for review prior to disseminating. Inform the regulatory official how you plan to communicate the BWA to all water users. *Refer to Checklist B: Creating the BWA Message*.

Be careful of the language and tone by which you convey the BWA message to the water users. Prohibit the use of language that defeats the purpose of the notice. Ensure the language is not too technical and encourages broad understanding of the BWA message.

Decide on the best means to disseminate the information to the all water users and the general public, according to the water system in question. The use of multiple methods is recommended. *Refer to Checklist C: Ways to Disseminate the BWA Message*.

STEP 6 – DEVELOP REMOVAL CRITERIA

Once a sound rationale for issuing a BWA has been developed, and the BWA is communicated in a timely manner, formulate removal criteria and develop a timeline by which required corrective actions should be taken and the BWA lifted. The timeline should be realistic and created in conjunction with the

regulatory official and with consideration of the water system's unique circumstances.

Note: A BWA should not be removed without approval of the appropriate regulatory authority.

STEP 7 – KEEP EVERYONE IN THE LOOP

Arrange to discuss the BWA and progress made with the regulatory official on a regular basis. Schedule the next follow-up phone call at each meeting. Maintain a set minimum frequency of follow-up and communication to ensure progress in addressing the BWA is made. Inform the regulatory official when any progress is made, of any updates, questions or concerns.

Ensure that you are reminding the water users about the BWA frequently and informing them of progress and updates since the issuance. Keep public postings updated and refresh them as needed.

STEP 8 – MEET REMOVAL CRITERIA

To ensure progress towards the BWA's removal is maintained, it is important to follow the timeline that indicates what steps need to be taken to remove the BWA.

Once the threat has been eliminated or corrected, inform the regulatory official and proceed towards reviewing the removal criteria and decide whether the BWA can be lifted. *Refer to Checklist D: BWA Removal Criteria.*

STEP 9 – RESCIND BWA

Once authorized by the regulatory official in writing, remove the BWA and inform water users. Develop and submit the BWA removal message for review and approval by the regulatory official. Once an approved message has been created, immediately inform the water users by the most appropriate means. Refer to *Checklist E: Creating the BWA Removal Message*.

Notify support staff and personnel with a need to know about the BWA removal.

STEP 10 – REVIEW BWA

Complete a full review/record of the BWA event. Determine if any changes in approach to the management of the water system are needed. Make improvements to the water system's emergency response plan as needed.

CHECKLISTS

CHECKLIST A: WATER SYSTEM RISK ASSESSMENT [3]

When deciding to issue a BWA, consider the following:

Water system characteristics:

- ☐ What is the source of the water system?
- ☐ Is the water source protected?
- ☐ How old is the water system infrastructure? Is it well maintained?
- ☐ What is the size of the system? How many connections does it have?
- ☐ What type of water system is it? What is the system's purpose?
- ☐ What type of population is served water from this system? Does the population include high-risk groups, such as elderly, children and/or infants?
- ☐ Does the system run year-round or only seasonally?
- ☐ Is there any water treatment (filtration, disinfection) in place? Is treatment at point of use/entry or centralized at the water system?

Sampling Information:

- ☐ Where was the last water sample taken?
- ☐ What was the sampling procedure?
- ☐ How many samples were taken? How many sample results are available?
- ☐ If water sample(s) were positive for E.coli or total coliform, were the counts low (example: 1 count E.coli or 10 counts total coliform per 100 mL) or high (example: over 10 counts per 100 mL)? With low counts, sampling error needs to be ruled out.
- ☐ Has the system been flushed, disinfected and re-sampled for confirmatory testing? What are the results?
- ☐ Was the sample shipped appropriately (within required time-frame)?
- ☐ How much confidence do you have in the lab results?
- ☐ Was the lab fully capable and certified?
- ☐ Have the results been interpreted correctly?

Monitoring Data:

- ☐ What monitoring data are available?
  - Chlorine residual records
  - Turbidity records
  - Past bacteriological lab results, trends
- ☐ Have there been any public complaints about water quality?
- ☐ Is there a known communicable disease outbreak in the community?
- ☐ Is there any recent raw water quality events?
- ☐ When was the last water system inspection done? By whom?

Operational Factors:

- ☐ Is the water supplier certified and/or trained and competent in running the water system?
- ☐ What is the history of the water system operations?
- ☐ Has this system been on BWA(s) in the past? For what reason(s)?
- ☐ Is there a cross connection control program in place?
- ☐ Is there an approved Emergency Response and Contingency Plan in place at the water system?

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[3] The list of factors was heavily influenced by the risk evaluation checklist that included in *BC Drinking Water Officer's Guide* (Drinking Water Leadership Council, Province of British Columbia, Ministry of Health Services; 2007), but was further refined with respect to BWAs.

Environmental Factors:

- ☐ Were there any recent weather events that may have affected water quality?

Other things to think about:

- ☐ Are there any other legislative requirements on this system? Systems linked to institutions or businesses may be subject to regulations other than those specific to drinking water (e.g., food handling regulations for restaurants).
- ☐ Is potential liability a concern?
- ☐ What would be the possible consequences if a BWA is not issued?
- ☐ Are concerns over expense or inconvenience to water supplier and/or water users affecting the decision to issue a BWA?

Regulatory Officials should consider factors relevant to their working relationship and history with the water supplier that may influence decision-making:

- ☐ From past communication and experience, is the water supplier generally cooperative and compliant?
- ☐ If this is the first time dealing with this water system or with the water supplier, could the lack of experience or information be affecting your decision?

CHECKLIST B: CREATING THE BWA MESSAGE

In creating the BWA message, consider including the following information:

- ☐ Name of water system and jurisdiction/regional health authority
- ☐ Date BWA issued/effective
- ☐ Reason why the advisory is being issued; what the water quality problem or threat is
- ☐ What the associated health risks are
- ☐ Who is at risk
- ☐ What to do to avoid health risk
    - Bring tap water to 1 min of rolling boil before use
    - Use bottled water in place of tap water
    - Treat tap water with household bleach before use
    - Use other household water treatment
    - Use boiled, bottled, or treated water for washing fruits and vegetables
    - Use boiled, bottled, or treated water for food and beverage preparation
    - Use boiled, bottled, or treated water for washing dishes
    - Use boiled, bottled, or treated water for brushing teeth
    - Use boiled, bottled, or treated water for making ice
    - Give pets boiled, bottled, or treated water for consumption
- ☐ What corrective action is being taken to end the advisory
- ☐ Who to contact for more information and where to get more information
- ☐ Additional information for susceptible populations, such as infants and the elderly
- ☐ How long the advisory is anticipated to last
- ☐ How the water users will be notified of advisory removal
- ☐ Any special instructions for landlords with tenants, retail food establishments, day care facilities, schools, hotels, restaurants, spas, swimming pools, etc.

CHECKLIST C: WAYS TO DISSEMINATE THE BWA MESSAGE

- ☐ Press release: television, radio, newspaper
- ☐ Internet: the local government jurisdiction's website, the water system's website, e-mail, social utility websites (Facebook, Twitter)
- ☐ Telephone, short message services (SMS)
- ☐ Posting of signs or print notices in clearly visible public locations
- ☐ Door to door canvassing of houses/units to verbally and personally inform water users and/or distribute print notices or letters
- ☐ Announcements in community meetings

CHECKLIST D: BWA REMOVAL CRITERIA [4]

- ☐ The following should be considered when deciding to lift the BWA:
- ☐ The threat to the drinking water and its source has been identified and resolved
- ☐ The water quality results are in compliance with relevant drinking water legislations in your province/territory
- ☐ Confirmatory water sample testing has been done and the results are satisfactory
- ☐ The water system has been returned to normal operating conditions
- ☐ Distribution system has been flushed to displace any affected or contaminated water
- ☐ Water system operating procedures have been reviewed
- ☐ Turbidity and/or heavy run-off events have resolved
- ☐ Water treatment has been installed
- ☐ There is a trained and certified water supplier on site to operate system
- ☐ Water quality surveillance and monitoring is in place
- ☐ An approved emergency response plan, with directives on the issuing and removing of BWAs, has been developed
- ☐ Full site inspection of the water system has been conducted
- ☐ The waterborne outbreak event has ended, as supported by epidemiologic surveillance data

[4] This list was based on the risk evaluation checklist that was included in the Interior Health Authority's Issue Paper: Drinking Water Public Notification Policy & Guideline Recommendation (2005)

CHECKLIST E: CREATING THE BWA REMOVAL MESSAGE

When creating the BWA removal message, consider including the following information:

- ☐ Name of water system and jurisdiction/regional health authority
- ☐ BWA removal date
- ☐ How the water quality problem or threat was resolved
- ☐ What to do to before using tap water
    - Flush all water-using fixtures for 1 minute
    - Run cold water faucets and drinking fountains for 1 min
    - Drain and flush all ice-making machines
    - Drain and refill hot water heater
- ☐ Who to contact for more information or where to get more information

RECOMMENDATIONS AND FURTHER AREAS FOR RESEARCH

A water system will be better managed if the relationship between the regulatory official and water supplier is based on mutual understanding and concern for public health; a relationship in which a regulatory office can *convince*, rather than force, a water supplier to issue a BWA. Therefore, there are many benefits to maintaining a healthy working relationship involving communication and trust between the regulatory official and water supplier – whether a BWA is in place or not.

The challenge in decision-making comes in determining whether or not action is truly needed. Ideally, we want to avoid outcomes where a decision was made not to issue a BWA when it was truly needed or a decision was made to issue a BWA when it was not truly needed. Failure to act - or issue a BWA - could lead to disastrous consequences, as was evident from the infamous Walkerton, Ontario tragedy. It is, therefore, generally thought valid for decision-makers to take the precautionary approach to public health decisions in order to avoid such severe consequences. However, there are inevitable consequences to taking action when not required either. The disadvantages to issuing BWAs - or liberally issuing BWAs - include: message fatigue and loss of compliance, creating unnecessary panic among the public, the potential for the public to lose confidence in their water system, and increasing the risk of burn injuries among the public from boiling water. On the other hand, BWAs may enhance the public's awareness of their water supply and water system, serving as a catalyst that triggers further remedial action and improvements to the water system.

Further studies are needed to help provide empirical evidence for the best means by which decisions to issue BWAs should be made. At present, no

study has investigated the decision-making process behind issuing BWAs in a large sample and across all of Canada. As many water systems have long-standing BWAs in place in lieu of more permanent upgrades to the water system's infrastructure, it may also be of value to collect information on what specific upgrades or actions are effective in improving water systems. Such data and any lessons learned could be used to guide future actions and decisions regarding water system upgrades that work.

USEFUL WEB LINKS

Health Canada: Boil Water Advisories and Boil Water Orders
http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/boil-ebullition-eng.php

Health Canada: Canadian Drinking Water Guidelines:
http://www.hc-sc.gc.ca/ewh-semt/water-eau/drink-potab/guide/index-eng.php

Health Canada: Guidance for Issuing and Rescinding Boil Water Advisories:
http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/boil_water-eau_ebullition/index-eng.php

Health Canada: Water Quality – Reports and Publications:
http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/index-eng.php

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WATER SECURITY GUIDANCE DOCUMENT

APPENDIX A – PROJECT OVERVIEW

The Water Security Guidance Document is the final product of a four-year (2008–2012) research project "***Developing a Canadian Water Security Framework as a Tool for Improved Governance for Watersheds***". Led by Dr. Karen Bakker (UBC), and Dr. Diana Allen (SFU), a team of researchers from 7 Canadian universities, and 20 project partners from across Canada, collaborated on a project to improve water security in Canada. The multi-disciplinarily research team comprised experts from the natural sciences (biology, hydrology, ecology); social sciences (geography and law); engineering (civil); and healthcare (microbiology and public health).

- Dr. Karen Bakker (University of British Columbia)
- Dr. Diana Allen (Simon Fraser University)
- Dr. Ed McBean (University of Guelph)
- Dr. Kay Teshcke (University of British Columbia)
- Dr. Monique Dubé (University of Saskatchewan)
- Dr. Judy Issac-Renton (BC Centre for Disease Control)
- Dr. Graham Daborn (Acadia University)
- Dr. Rob de Loë (University of Waterloo)
- Dr. Murray Journeay (Natural Resources Canada)
- Oliver Brandes (POLIS, University of Victoria)

This project was funded by grants from the Canadian Water Network (CWN), Walter and Duncan Gordon Foundation, Social Sciences and Humanities Research Council of Canada (SSHRC), the Natural Sciences and Engineering Research Council of Canada (NSERC), and the BC Ministry of Environment. We would like to thank our 20 project partners including Environment Canada, Natural Resources Canada, and Policy Research Initiative for their time and support. We would also like to extend our gratitude to staff within our two case study communities: the Township of Langley (BC), and the Grand River Conservation Authority (ON), for their time, input, feedback and overall support of this project.

- Environment Canada
- Natural Resources Canada
- Walter & Duncan Gordon Foundation
- BC Ministry of the Environment
- Policy Research Initiative
- Health Canada
- Township of Langley

- Grand River Conservation Authority
- Golder & Associates Ltd.
- Dept. of Earth Sciences at SFU
- Natural Sciences and Engineering Research Council (NSERC)
- Okanagan Basin Water Board
- Program on Water Governance, UBC
- SmartGrowth BC
- Polis Project at University of Victoria
- BC Ministry of Agriculture
- Guelph, Waterworks Department
- Brantford
- Clearbrook Waterworks District
- GW Solutions
- Canadian Water Network

The overall objective of the project was to create a Water Security Assessment Framework (WSAF) to improve water security in Canada, by improving governance for source protection and land use. The WSAF is a 'toolkit' comprised of decision-support tools, which consider aquatic ecosystem health, human health (including water quality and quantity) and governance capacity. It has been developed for communities to use for evaluating the current risk to water security and identifying what actions should be taken to reduce risks to water security. It differs from other similar frameworks in its:

1. comprehensiveness and integration (e.g., incorporation of governance variables);

2. sensitivity to spatial variation (in some tools); and

3. inclusion of decision-support tools.

The WSAF was developed and tested in two case study communities, the Grand River Conservation Authority, Ontario and the Township of Langley, British Columbia. Consultation with water professionals formed an integral part of the project and included:

I. 2008 Water Security Survey: a large-scale web-based survey of Canadian water practitioners

II. 2009 Water Security Interviews: following the survey the team conducted in-depth interviews with 30 water managers and policy makers.

III. 2009 Water Security End-user Workshop: 60 practitioners from across Canada participated in a 1-day workshop. During the workshop experts debated water assessment approaches, providing useful insight into water security issues. The development of the water security assessment framework was discussed in-depth.

IV. 2010-2011 Water Security Tools Development: Working with community and case study partners, various components of the water security assessment framework were refined and tested.

The team has made knowledge translation a key priority to ensure that the research benefits water managers, policy makers and community watershed groups. We have introduced the concept of water security to a broad public audience through the publication of ***Water Security: A Primer (2010)*** and ***Water Security Briefing Note (2011)***, culminating with this final document, the **Water Security Guidance Document**, published in 2012. For a complete list of the project-related publications please refer to Appendix B.

CANADIAN WATER NETWORK
RÉSEAU CANADIEN DE L'EAU

NSERC
CRSNG

Walter & Duncan
GORDON FOUNDATION

GROUNDWATER RESOURCES
RESEARCH GROUP

Social Sciences and Humanities
Research Council of Canada

Ministry of Environment

WATER SECURITY GUIDANCE DOCUMENT

WATER SECURITY GUIDANCE DOCUMENT
APPENDIX B
PROJECT OVERVIEW

APPENDIX B – PROJECT RELATED PUBLICATIONS

SUMMARY OF CWN FUNDED WATER SECURITY PROJECT RELATED PUBLICATIONS (2008-2012)

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JOURNAL ARTICLES IN REVIEW

Cavalanti de Albuquerque, R., Allen, D.M. and Kirste, D. (in review). ***A Methodology for spatially representing the likelihood of occurrence of natural contaminants in groundwater.*** Submitted to Environmental Earth Sciences (September 2011).

Dunn, Gemma and Karen Bakker (in review). Comparative assessment of Canadian drinking water quality guidelines across Canadian provinces and territories: The challenge of place-based variation in the context of decentralized water governance. Submitted to Health and Place (January 2012).

Norman, E., Dunn, G., Bakker, K., Allen, D.M., and Cavalcanti de Albuquerque, R. ***Integrating Governance in Water Indicator Assessment: Developing a Water Security Indicator Method.*** Submitted to Water Resource Management (August 2011).

Simpson, M.W. Allen, D.M. (in review) ***A Groundwater Quality Risk Assessment Framework***. Submitted to Water Resource Management (September 2011).

POLICY REPORTS

Norman, E., Dunn, G., Bakker, K., Allen, D., Cavalcanti de Albuquerque, R., Simpson, M., and Cook, C. (2011). ***Water Security Briefing Note*** Submitted by Simon Fraser University and Program on Water Governance-UBC to BC Ministry of Environment.

http://www.watergovernance.ca/wp-content/uploads/2010/04/WSAF-Briefing-Note-FINAL-25Feb2011.pdf

Norman, E., with Bakker, K., Cook, C., Dunn, G. and Diana Allen (March 2010). ***Water Security: A Primer*** (Policy Report). Vancouver, BC: UBC Program on Water Governance. (Note: This document represents the first formulation of our Water Security Assessment Framework, which has since been refined and updated).
http://www.watergovernance.ca/wp-content/uploads/2010/04/WaterSecurityPrimer20101.pdf

Version française: ***La sécurité hydrique: Guide d'introduction***
http://www.watergovernance.ca/wp-content/uploads/2010/05/Water-Security-Primer-FRENCH.pdf

Dunn, G. and Bakker, K. (2009). ***Canadian Approaches to Assessing Water Security: an Inventory of Indicators*** (Policy Report). Vancouver, BC: UBC Program on Water Governance.
http://www.watergovernance.ca/PDF/IndicatorsReportFINAL2009.pdf

Bakker, K. (2009). ***Water Security: Canada's Challenge.*** Policy Options. July-August 2009.
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CONFERENCE AND WORKSHOP PRESENTATIONS

Cook, C. (oral presentation on behalf of project team) (2012). ***Approaching Water Security from a Risk Perspective.*** Water Security, Risk and Society: International Water Security Conference, Oxford University, UK, 16-18 April 2012.

American Association for the Advancement of Science – Annual Meeting: Vancouver, February 2012:

> **Friday February 17, 2012** (afternoon panel session)
> Topic: ***Links and trade-offs between water, energy and food security***
> Speakers: Howard Wheater (USask), Patricia Gober (Arizona State U), Gordon Young (former UN WWAP coordinator), Dennis Lettenmaier (U of Washington), Peter Gleick (Pacific Institute), and Karen Bakker (UBC)
> Moderator: Diana Allen (SFU)
>
> **Friday February 17, 2012** (evening event open to the public)
> Topic: ***Water Security in Canada***
> Speakers: Howard Wheater, Gordon Young, Tom Pedersen (UVic), Judy Isaac-Renton (BC Centre for Disease Control)
> Moderator: Karen Bakker
> Sponsors: AAAS, University of British Columbia, the Royal Society of Canada (RSC) and the Canadian Water Network (CWN)

Allen, D.M., Bakker, K., Dunn, G., Norman, E., Simpson, M., and Cavalcanti de Albuquerque, R. (oral presentation) (2011). ***A Water Security Framework for community-level assessment***. Canadian Water Resources Association

64th Annual Conference, St. John's NFLD, June 28-31, 2011.

Allen, D.M. (on behalf of project team) (2011). ***Water Security Assessment at a Community Level.*** Canadian Water Network Project Leaders Meeting, Toronto, Ontario, May 19-20, 2011.

Allen, D.M. (on behalf of project team) 2010. ***Developing A Canadian Water Security Framework as a Tool for Assessing Cumulative Impacts and Improving Watershed Governance.*** CWN Project (Dube), Saskatoon.

Allen, D.M., Bakker, K., Simpson, M.W., Dunn, G. and Norman, E. (2010). ***Incorporating risk and indicators into a Water Security Framework.*** American Geophysical Union Annual Meeting, San Francisco, CA, December 2010.

Allen, D.M. (on behalf of project team) (2010). ***Developing a Canadian Water Security Framework as a tool for assessing cumulative impacts and improving watershed governance.*** CWN Project Meeting (M. Dubé), Saskatoon, SK, October 2010.

Asnaashari, A., McBean, E., Gharabaghi, B. and Tutt, A. (2010). ***Asset rehabilitation planning using neural network models.*** Water 2010, Quebec City, July 2010.

Asnasshari, A., Gharabaghi, B., Bradford, A., McBean, E., and Whiteley, H. (2009). ***Jurisdictional review of stormwater management in light of climate change impacts on water quality.*** Presented at New Directions '09 in Stormwater Management, Vaughan, Ontario November 30-December 2, 2009.

Bakker, K. (2010). ***Water Security: Canada's challenge.*** Canadian Water: Towards a New Strategy. McGill Institute for the Study of Canada, McGill University, Mar 2010.

Bakker, K. (2009) ***A National Water Strategy for Canada?*** Workshop: BC's Living Water Smart Policy: Is it smart for Canada? Institute for Research on Public Policy, November 2009.

Bakker, K. (2009). ***Water Security: Policy dimensions of a global challenge.*** Presented at the University of Saskatchewan, School of Environment and Sustainability/School of Public Policy, November 2009.

Banting, C., and McBean, E. (2011). ***Application of risk model to below water table aggregate mining extraction site in Guelph.*** Presented at Canadian Water Network National Conference, Ottawa, Ontario, Feb 28-Mar 3, 2011.

Canadian Water Resources Association – Annual Conference: Vancouver, June 2010:

Cook, C. and K. Bakker. ***Water Security: Emerging Debates in Policy and Academia*** (Cook presented)

Norman, E.S. and K. Bakker. ***Moving towards water security in Canadian Water Policy*** (Norman presented)

Bakker, K. and D. Allen. ***Water Security: A new framework for water governance policy*** (Bakker presented).

Dunn, G. and K. Bakker. ***Fresh water-related indicators in Canada: An inventory and analysis*** (poster presentation). http://www.watergovernance.ca/wp-content/uploads/2010/03/GD-CWRA-Indicator-Poster-FINAL.pdf

Simpson, M.W., Allen, D.M., Journeay, M.M. and Korteling, B. 2010. ***Assessing risk to groundwater quality: a proposed integrated groundwater risk framework.*** (Simpson presented)

Cavalanti de Albuquerque, R., Kirste, D. and Allen, D.M. (2010). ***Indicators of arsenic contamination for groundwater risk analysis***. (Cavalcanti de Albuquerque presented).

Cavalcanti de Albuquerque, R., Kirste, D., and Allen, D.M. (2010). ***Arsenic mobilization in confined aquifers formed in glaciomarine deposits.*** Water Rock Interaction conference, August 16-20, 2010, Guanajuato, Mexico.

Cook, C. and Bakker, K. (2011). ***Water Security: Competing perspectives across the natural and social sciences.*** University of East Anglia Water Security Workshop, London, UK, November 4, 2011. (Cook presented)

Cook, C. and Bakker, K. (2010). ***Water Security: emerging debates in academia and policy***. Annual Meeting of the Association of American Geographers, Washington, April 13-18, 2010. (Cook presented)

Farrow, C., McBean, E., and Salsali, H. (2011). ***Viral contamination and attenuation in fractured bedrock groundwater aquifers.*** Presented at 25th Canadian Association for Water Quality, Burlington, Ontario, Feb 22-23, 2011.

McBean, E. (2011). ***Vulnerability assessment procedures for small water supply systems, in present conditions and under climate changing conditions.*** Plenary Presentation, International Conference on Drinking Water Safety, Security and Sustainability, to be presented, Hangzhou, China, Oct 9-12, 2011.

McBean, E. (2011). ***Managing security for water distribution systems.*** Keynote paper, International Waterworks Symposium, Seoul, Korea, Sept 2011.

McBean, E. (2011). ***Water, the ultimate recycled good.*** Keynote presentation at International Conference on Water and Wastewater with Focus on Privatization and Benchmarking, Tehran, Iran, April 27-28, 2011.

McBean, E., and Lagos, G., (2010). ***The emerging focus on pharmaceuticals in water.*** Enviropharm 2010, Toronto, Ontario, October 7, 2010.

McBean, E., (2010). ***Drinking water security at small systems in Canada.*** Presented at Consensus Conference on Small Water Systems, Management for the Promotion of Indigenous Health, University of Victoria, Victoria, B.C., March 21-23, 2010.

McBean, E., (2010). ***Trends in climate in Canada - past and future characteristics.*** Presented at Stressors, Habitat, and Biology in Agricultural Streams, Utopia, Ontario, February 17, 2010.

Norman, E., Dunn, G., Bakker, K., Allen, D.M., Simpson, M., and Cavalcanti de Albuquerque, R. (2011). ***Water Security Assessment and Community Governance.*** Presented at CWN Connecting Water Resources 2011: Responding to the Opportunities, Ottawa, February 28th -March 3rd 2011.

Norman, E., Dunn, G., Bakker, K., Allen, D.M., Simpson, M., and Cavalcanti de Albuquerque, R. (oral presentation and poster) (2011). ***Integrating Governance in Water Indicator Assessment: Developing a Water Security Indicator Method*** (poster). Poster presented at CWN Connecting Water Resources 2011: Responding to the Opportunities, Ottawa, February 28th -March 3rd 2011. http://www.watergovernance.ca/wp-content/uploads/2011/03/CWN-Poster-FINAL-Updated-16March2011.pdf

Simpson, M.W., Allen, D.M., Journeay, M. M. and Korteling, B. (oral presentation Allen) (2011). ***Assessing Risk to Groundwater Quality Using an Integrated Risk Framework.*** GeoHydro 2011, Joint Conference of the Canadian Quaternary Association (CANQUA) and the Canadian Chapter of the International Association of Hydrogeologists (IAH-CNC). Quebec City, Quebec, August 28-31, 2011.

Project Workshop (2009). ***Water Security: An emerging Paradigm.*** Lui Institute, University of British Columbia, BC, September 28-29, 2009.

ADVISORY ROLES

- National Round Table on the Environment and the Economy: Water Use Information Round Table
- National Round Table on the Environment and the Economy: Governance
- Canadian Council of Ministers of the Environment
- Environment Canada – Water Availability Index Interdepartmental Working Group
- BC Ministry of Environment: Water (Sustainability) Act Revisions
- BC Ministry of Environment: Expert Advisory Group on Indicators
- Honourable James A. Richardson Round Table
- Canadian Water Resources Association (CWRA) – Canada-wide Strategy Meeting