

### WATER SECURITY GUIDANCE DOCUMENT

### PART 2 SECTION 2 WATER SECURITY RISK ASSESSMENT (WSRA)

### **Earth Sciences**

Simon Fraser University

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### SECURITY GUIDANCE DOCUMENT SSESSING WATER

### **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.

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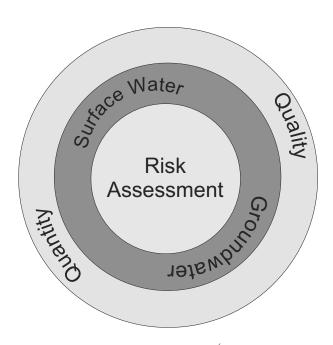
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### **BACKGROUND: KEY ISSUES AND CONTEXT**

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.

### RISK $(R_H)$ = Vulnerability $(V_H)$ x Loss (L) [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 Vulner- ability Scoring Tool	Vulnerability	Banting and McBean (2011: Part II, Section 3)
BC Wellhead Protection Toolkit	Vulnerability	BC Ministry of Envi- ronment, 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):

Aquifer Susceptibility  $(S_A)$  = Intrinsic Aquifer Susceptibility  $(S_I)$  + Conduit (C) [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:

Chemical Hazard Threat  $(T_H) = \sum (Chemical Intensity (CI) \times Quantity (Q) \times Extent (E) \times Probability (P)) [3]$ 

where,

### Chemical Intensity = (Toxicity + Environmental Fate) / 2 [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.

Vulnerability 
$$(V_H)$$
 = Aquifer Susceptibility  $(S_A)$  x Hazard Threat  $(T_H)$  [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.

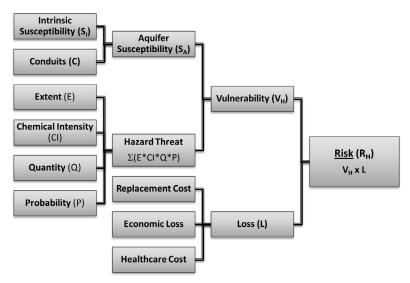


Figure 2: Groundwater quality risk assessment methodology

### 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.

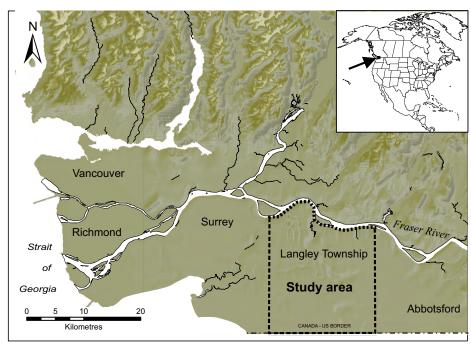
### APPLICATION OF THE GROUNDWATER QUALITY RISK ASSESSMENT METHOD

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<sup>1</sup> 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.

The resources devoted to this project were not sufficient to complete a parcel

<sup>&</sup>lt;sup>1</sup>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.

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:

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

where,

d = layer thickness [Length], andK = 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  $50m \times 50m$  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
Draggan as of a well	О	No well present on the property
Prescence of a well		Well present on the property
	0	Good seal installed
Effective surface seal	1	Adequate seal installed
	2	Seal installed but characteristics are unknown or are not ideal
	3	Seal not installed
	0	Watertight cap installed
Well cap cover	1	Adequate cap installed
	2	Inadequate/no cap installed
7 . 1 . 1	О	Ponding is unlikely
around the wellhead	1	Ponding is probable
	Ponding is highly likely	
Abandoned	О	Well in use or closed
Anamoned	2	Well likely abandoned and in disrepair

### FINING AND ASSESSING WATER SECURITY SECURITY GUIDANCE DOCUMENT

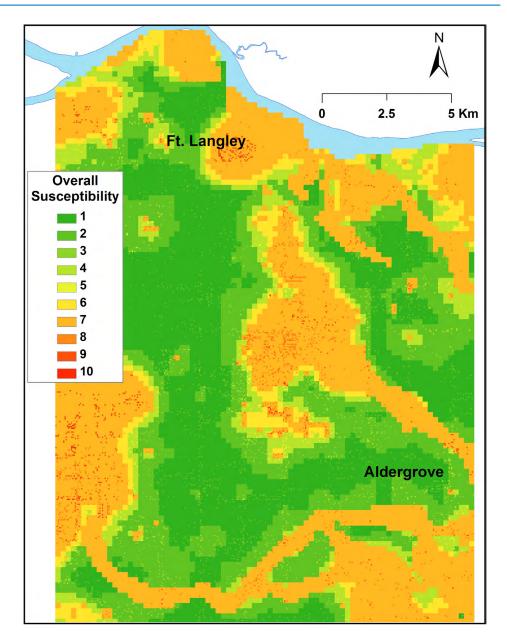


Figure 4: Aquifer Susceptibility map

### **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).

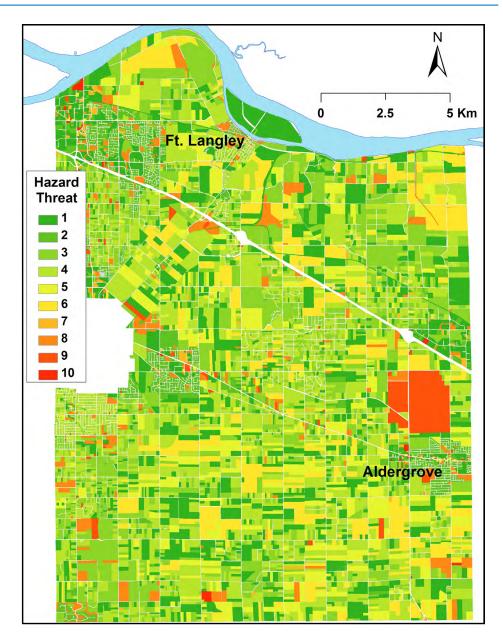


Figure 5: Hazard Threat Assessment

### 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 production 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).

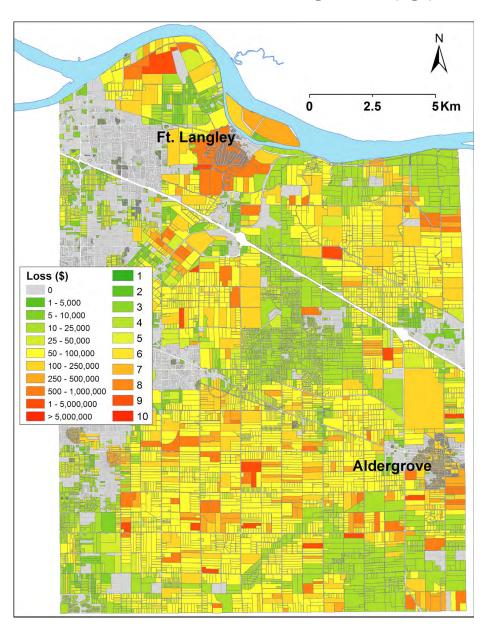
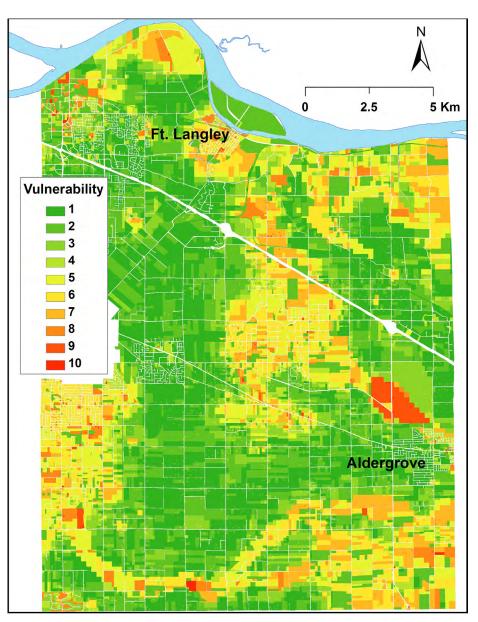


Figure 6: Total Loss in \$'s; Total Loss for the base case reclassified using a 1-10 scale

### 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

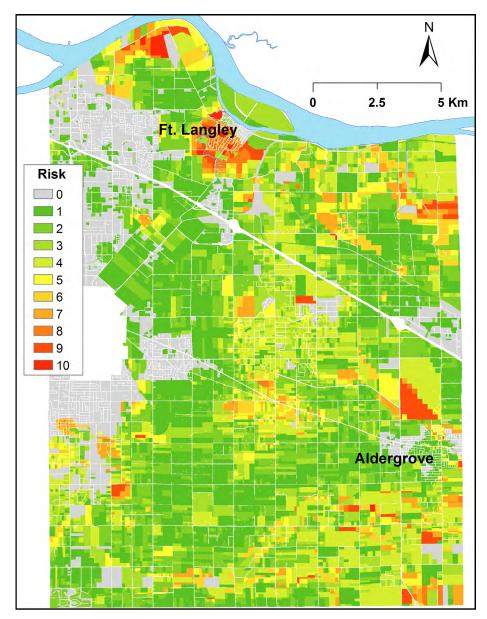


Figure 8: Final Risk results

### **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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