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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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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.

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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.

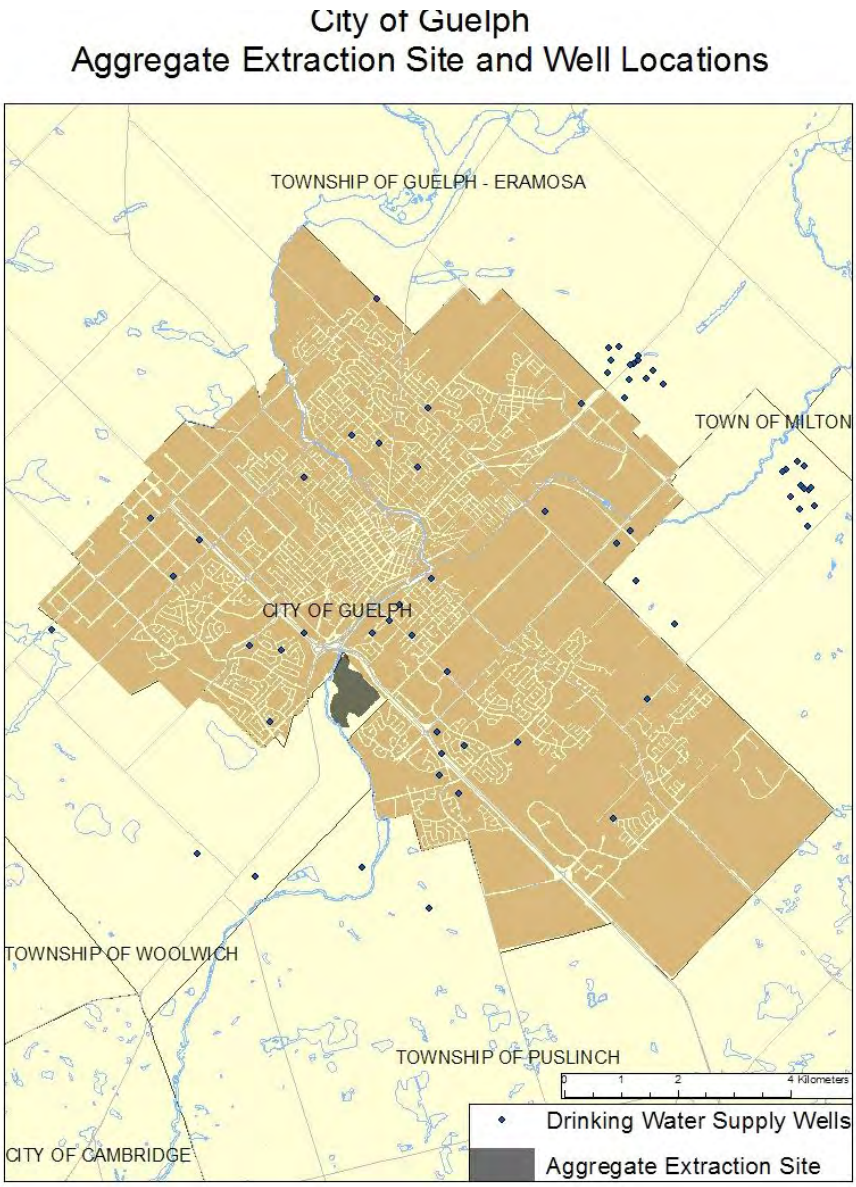

Figure 1: Location of Aggregate Extraction Site and Drinking Water Wells in Guelph

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 water threat	27	6	0	0
	Human food-chain threat	27	56	0	0
	Environmental threat	27	56	0	0
Groundwater to surface water	Drinking water 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).

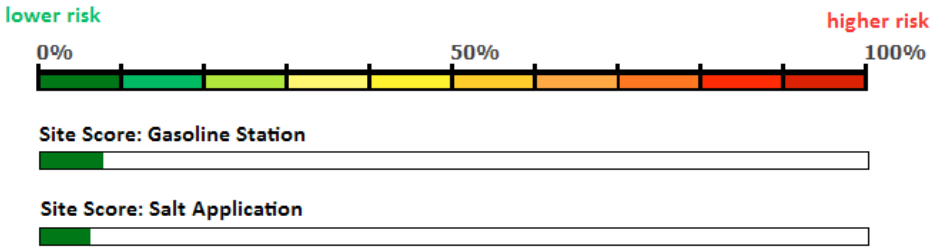

Figure 2: Vulnerability scores for two examples of sources of contamination: after aquitard removal

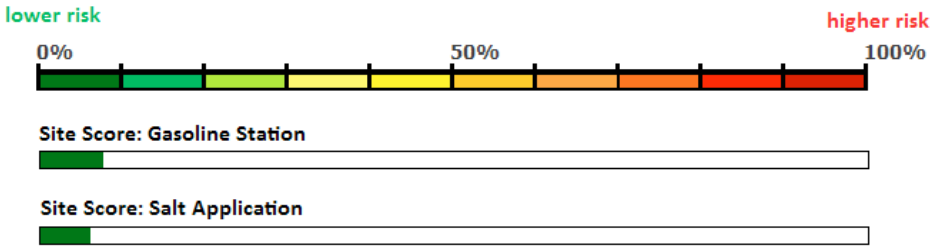

Figure 3: Vulnerability scores for two examples of sources of contamination: before aquitard removal

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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