Pacific Institute for Climate Solutions
Knowledge. Insight. Action.

Briefing Note 2016 – 45

20 September 2016

Shallow Groundwater Intrinsic Vulnerability Mapping in Northeast British Columbia

Produced by the Department of Earth Sciences, Simon Fraser University

Author: Shannon Holding and Diana M. Allen
Editors: Robyn Meyer, Sybil Seitzinger

Issue

There are mounting concerns surrounding water management and protection in Northeast British Columbia (NEBC) due to a rapidly developing shale gas sector that has not been matched by advances in understanding the potential impacts to water security[1]. NEBC is estimated to hold large reserves of unconventional natural gas and has experienced significant growth in shale gas development activities over the last several decades[2].

Shale gas development activities represent major industrial operations that pose a threat to drinking water supplies and aquatic ecosystems[1]. Among other impacts, shale gas development has the potential to contaminate groundwater[3]. The majority of contamination risk is related to spills and leaks resulting from the handling and transport of chemicals used in hydraulic fracturing or the wastewater that is produced during all phases of development[4]. Surface spills have a high likelihood of occurrence due to the large volumes handled and number of trucks used to transport wastewater[5, 6]. Therefore, it is clear that the groundwater resources of NEBC require protection, specifically in relation to spills or releases of contaminants at ground surface.

Background: Motivation for this Work

To provide information that can be used to help develop policies and regulations to protect groundwater in NEBC, shallow groundwater intrinsic vulnerability mapping of the region was undertaken by Simon Fraser University (SFU) with financial support from the Ministry of Forests, Lands, and Natural Resource Operations (FLNRO) and the Pacific Institute for

Climate Solutions (PICS). The research was carried out as part of a PICS major research project on BC natural gas development.

The work also directly addresses a key recommendation from a BC Ministry of Health commissioned report related to northern BC oil and gas development. Recommendation 10 of the *Phase 2 Human Health Risk Assessment of NEBC*[7] *Oil and Gas Activity* is that "the existing aquifer mapping (and vulnerability mapping) be expanded for the NEBC region to help enhance the protection of groundwater resources in relation to oil and gas development. This information would aid in regional and site-specific assessments of potential risks to groundwater."

In addition, the mapping will support other initiatives being carried out in the region, including cumulative effects assessments and joint (i.e., provincial-provincial and provincial-territorial) management of groundwater in the Mackenzie River and Liard River basins.

Study region: Northeast BC

Northeast BC covers two districts: the Peace River Regional District and the Northern Rockies Regional Municipality, where the principal urban centres include Fort. St John, Fort Nelson and Dawson Creek. The study area comprises part of the Cordilleran and Interior Plains hydrogeological regions, which include the mountains to the west as well as the low-lying flat areas where the majority of the population resides and shale gas development occurs.

Intrinsic vulnerability relates to the physical characteristics (thickness and permeability) of the geological materials that make them more or less susceptible to groundwater contamination. Groundwater is the water that is present underground in the soil pore spaces and in the fractures of rocks. Groundwater is an important source of fresh water for drinking, and normally contributes to streamflow throughout the year.

DRASTIC Assessment

Intrinsic vulnerability was assessed using the DRASTIC method[8], which is universally recognized and has been widely applied to hydrogeological settings in other areas of BC and elsewhere throughout the world. The method specifically focuses on the potential shallow groundwater contamination from land sources, an appropriate approach given the context of potential contamination risk in NEBC from shale gas activities. In this study, shallow geological materials < 30 m deep are considered, with no specific emphasis on aquifers.

The DRASTIC method is based on the rating of seven input parameters that influence the vertical migration of potential contaminants into the aquifer (these parameters also form the acronym "DRASTIC"): **D**epth to water; **R**echarge; **A**quifer media; **S**oil media; **T**opography; **I**mpact of the vadose zone; and hydraulic **C**onductivity. Using publicly available geospatial datasets from NEBC (such as water well records, land surface topography, soil survey data, and surficial/bedrock geology maps), the researchers created a gridded map for each parameter and ranked each parameter from 1-10 (low to high) according to the DRASTIC ranking tables[8]. Additional recharge modelling was also conducted to assess potential recharge rates in the region. For some parameters, the 'ranking table was modified in order to capture the local variability and data range.

The final intrinsic vulnerability was calculated using a weighted sum according to the standard DRASTIC equation 5D + 4R + 3A + 2S + 1T + 5I + 3C = intrinsic vulnerability. The total intrinsic vulnerability score ranged from 55 (low) to 191 (high) over the study area. Descriptions of the data sources and the ranking of each DRASTIC parameter are discussed in the assessment report[9].

The resulting intrinsic vulnerability map for NEBC is shown in Figure 1 and Figure 2. Areas of higher vulnerability are shown in red, and are predominantly present along the mountainous western edge of the region where there is high elevation bedrock. Areas of lower vulnerability are in green. Higher vulnerability is the result of generally shallow water tables combined with high recharge rates, high permeability weathered bedrock, and limited soil cover. Other higher vulnerability areas include river valleys where the shallow subsurface geological materials have large proportions of sand and gravel. It should be noted that the results represent the relative intrinsic vulnerability, so that areas ranked low are still vulnerable to surface contamination, although they are relatively less vulnerable than other parts of the study area.

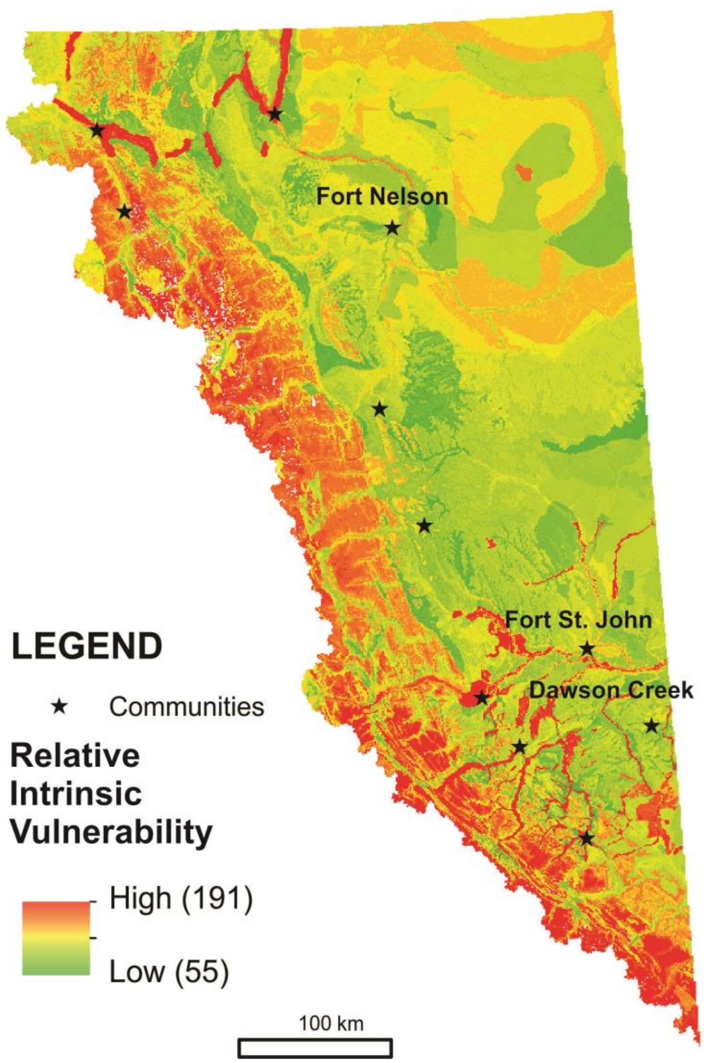

Figure 1: Relative DRASTIC Intrinsic Vulnerability

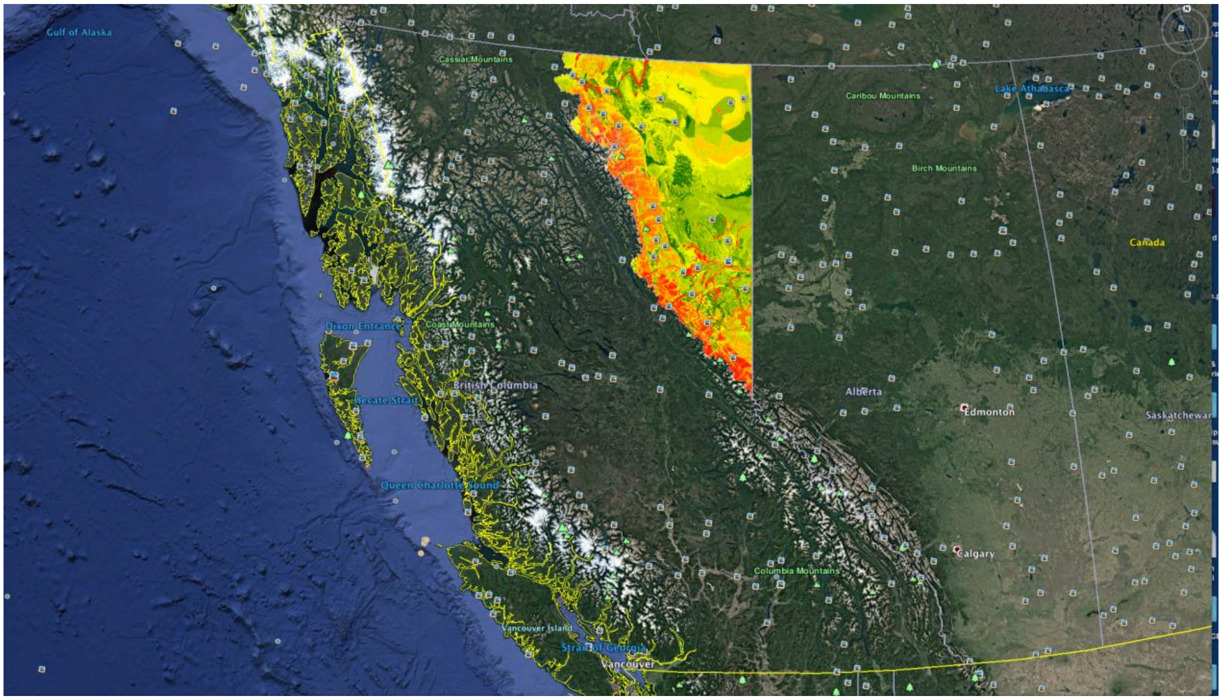

Figure 2: Relative DRASTIC Intrinsic Vulnerability (Google Earth)

DRASTIC Assessment (MOE)

The BC Ministry of Environment (MOE) uses an alternative classification for DRASTIC results based on the score to distinguish areas of low (0-100), moderate (100-160) and high (160+) intrinsic vulnerability. When the results are presented within this categorization, the study area represents predominantly low or moderate intrinsic vulnerability (Figure 3). Areas of high vulnerability are present at a local scale, particularly where the geological materials are characterized by high permeability.

The DRASTIC results shown using a relative intrinsic vulnerability scale (Figures 1) appear significantly different to the DRASTIC results using the MOE categorization (Figure 3). The spatial resolution of the input datasets is the same, and the calculated DRASTIC values are the same. The main visual difference in the two maps is simply because one uses discrete categories with pre-assigned intrinsic vulnerability ranges (MOE categorization) while the relative intrinsic vulnerability approach uses a graduated colour scheme with the smallest and largest DRASTIC values in the study region being assigned to low and high intrinsic vulnerability. In other words, the graduated colour scheme used in the relative intrinsic vulnerability map—compared to the three numerically specific MOE categories—presents a more nuanced picture. Therefore the added level of detail shown in the DRASTIC map in Figure 1 is better able to distinguish differences in vulnerability, providing information that can be meaningful for informing water managers and policies. In contrast, the map classified using MOE categorization is useful for comparison of the results with other areas across BC as they are based on the same categorization of the final DRASTIC scores (low, moderate and high).

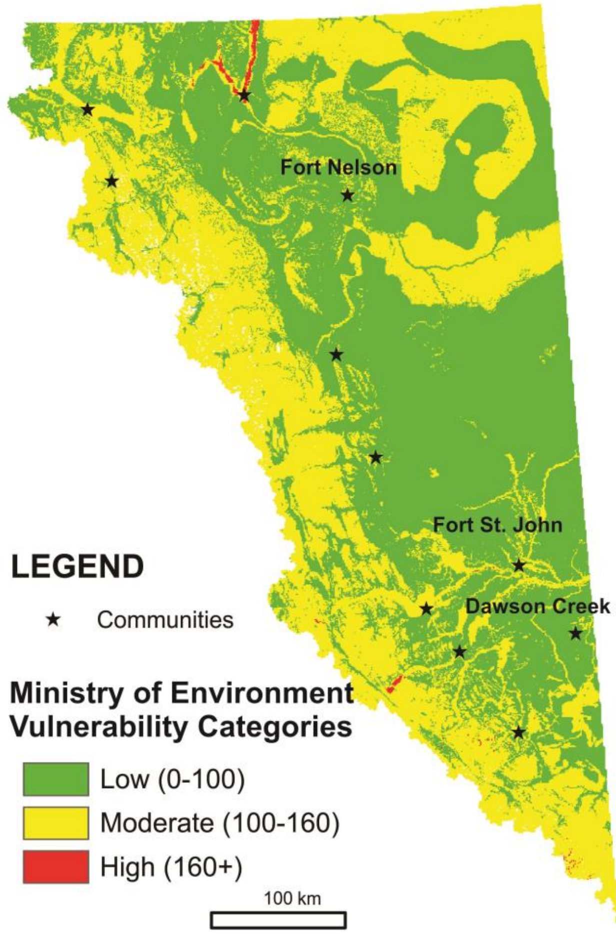

Figure 3: Categorized DRASTIC Intrinsic Vulnerability

Limitations and Extension of Research

One limitation of the intrinsic vulnerability assessment is inherent to the DRASTIC method, which only accounts for potential groundwater contamination occurring from a source at ground surface. This means that potential contamination sources from well below ground surface (e.g. gas migration along well casings) are not represented. However, the predominant contaminant sources in the study area are related to land surface activities[4] and the majority of water wells are installed within the top 30 metres[9]. Therefore, it is appropriate to focus on the shallow geological materials, and DRASTIC is considered a suitable approach.

Another limitation of the assessment is the coarse scale of the DRASTIC map. High resolution spatial datasets were not available for this vast region, and as a result, some local-scale features and areas of concern may not be captured. Similarly, many areas had sparse data, so a generalized approach was adopted to complete the assessment. The generalized approach relied on estimated and representative values, thus introducing uncertainty in the final maps. As additional data are made available, the assessment can be updated to reflect higher data resolution and to confirm or revise the approach as necessary. Thus, caution should be applied when using these maps to acknowledge the inherent limitations and uncertainty related to the data sources. This is particularly relevant for small-scale applications where local data should be included to augment the assessment and evaluate the vulnerability maps.

Recommendations

The shallow groundwater intrinsic vulnerability maps provide valuable preliminary information for decision-makers at many levels.

1. At a local level, knowing the location of moderate to high vulnerability areas can help inform water managers of the greater potential for land sourced contamination entering the shallow subsurface and potentially contaminating drinking water supplies. Where in proximity to surface water bodies, such as streams, there is also greater potential for contaminants to migrate laterally and enter the water bodies. Source water protection measures, including defining well and spring capture zones, should be put into effect in moderate to high vulnerability areas to protect both groundwater and surface water.

2. The intrinsic vulnerability maps may be used as a backdrop for the assessment of risk to shallow groundwater quality. The presence of potential chemical hazards, for example along pipelines or at industrial sites where leaks and spills may occur, can be overlain on the intrinsic vulnerability map to identify areas that may be more vulnerable to contamination given the presence of specific hazards. These areas could be avoided in decision-making concerning land use planning (e.g. siting of wastewater facilities and pipeline routes) or, if hazardous land uses already exist, for prioritizing provincial groundwater and surface water monitoring (e.g. the provincial observation well network) or for requiring enhanced monitoring by industry and detailed groundwater investigations.

3. The maps could also be used for spill response planning.

Overall, use of the DRASTIC results should be tailored to the intent of the application (i.e. local-scale decisions or province-wide comparisons).

Conclusions

This assessment for Northeast BC was carried out to evaluate the intrinsic vulnerability of near surface geological materials (shallow groundwater) to contamination originating at land surface. Although there are limitations to the assessment, particularly sparse data for such a large region of the province, the intrinsic vulnerability map represents the existing data and allows for preliminary interpretation of potential risk to groundwater from surface sources of contamination. It is anticipated that the assessment may be adjusted and updated as additional data characterizing the aquifers become available. The results of this assessment may provide useful information to support water management and protection, and the development of policy and regulations in this region of rapid shale gas development.

Further details and discussion regarding the intrinsic vulnerability maps and assessment are found in the full technical report[9] available on the PICS website.

Accessing the DRASTIC Intrinsic Vulnerability Maps

Accessing the Relative DRASTIC Vulnerability Map through Google Earth:

The Relative Intrinsic Vulnerability Map can be viewed in Google Earth. First you will need to download the free desktop version of Google Earth or Google Earth Pro here. The next step is to download the map file here and then save.

Open Google Earth and select “File” from the menu bar. Select “Open" and navigate to the rel_vuln_peace.kmz file you have downloaded. The map will open automatically.

Accessing the Relative DRASTIC Vulnerability Map through ArcGIS:

The same map can also be accessed through ArcGIS. The files to view the map in ArcGIS are available here.

Accessing the Categorized DRASTIC Intrinsic Vulnerability Map:

The map can be viewed using iMapBC. Launch iMapBC 4 Mobile. Within this online GIS platform, click on the top menu item “Data Sources”. Click below on “Add Layers”. Expand the “Fresh Water and Marine” item in the list, and tick “Aquifer Intrinsic Vulnerability - DRASTIC”. Click to check on both boxes and then click OK. The outline for the Peace region map is shown on the full map of BC. Zoom in considerably to view the categorized grid squares.

Acknowledgements

Funding for this research was provided by PICS and the FLNRO in the form of financial support of a post-doctoral fellowship for Shannon Holding. Additional funding was provided by the Research Institute for Humanity and Nature in Kyoto, Japan, and a Discovery Grant to D. Allen from the Natural Sciences and Engineering Research Council of Canada.

Endnotes

[1.] Council of Canadian Academies (2014) Environmental Impacts of Shale Gas Extraction in Canada. The expert panel on harnessing science and technology to understand the environmental impacts of shale gas extraction, Council of Canadian Academies, Ottawa, ON, Canada. 266 p.

[2.] Goss, G., D. Alessi, D. Allen, J. Gehman, J. Brisbois, J. Kletke, A. Zolfaghari Sharak, C. Notte (2015) Unconventional wastewater management: A comparative review and analysis of hydraulic fracturing wastewater management practises across four North American jurisdictions. Final Report submitted to the Canadian Water Network, 168 pp.

[3.] Vengosh, A., R.B. Jackson, N. Warner, T.H. Darrah and A. Kondash (2014) A critical review of the risks to water resources from unconventional shale gas development and hydraulic fracturing in the United States. Environmental Science and Technology 48: 8334-8348.

[4.] Rozell D.J. and S.J. Reaven (2012) Water pollution risk associated with natural gas extraction from the Marcellus Shale. Risk Analysis 32(8): 1382-1393.

[5.] Mokhatab, S., W.A. Poe, and J.G. Speight (2006) Handbook of natural gas transmission and processing. Burlington, MA: Gulf Professional Publishing.

[6.] Soeder, D.J., S. Sharma, N. Pekney, L. Hopkinson, R. Dilmore, B. Kutchko, B. Stewart, K. Carter, A. Hakala, and R. Capo (2014) An approach for assessing engineering risk from shale gas wells in the United States. International Journal of Coal Geology 126: 4-19.

[7.] Aller, L., T. Bennett, J. Lehr, R. Petty, and G. Hackett (1987) DRASTIC: a standardized system for evaluating ground water pollution potential using hydrogeologic settings. EPA-600/2-87-035, National Water Well Association, Dublin, Ohio / EPA Ada. Oklahoma.

[8] Intrinsic (2014) Phase 2 Recommendations Report. Human Health Risk Assessment of NE BC Oil and Gas Activity. Report prepared for BC Ministry of Health. http://www.health.gov.bc.ca/library/publications/year/2014/health-risk-assessment-phase-two-recommendations.pdf

[9.] Holding S. and D.M. Allen (2015) Shallow Groundwater Intrinsic Vulnerability Mapping in Northeast BC, Final Report to BC Ministry of Forests, Lands and Natural Resource Operations, and the Pacific Institute for Climate Solutions, November 2015, 41 pp.

[10.] Allen, D.M., Holding, S.T. and McKoen, Z. (poster presentation) Hazard-specific vulnerability mapping for water security in a shale gas context. American Geophysical Union Fall Meeting 2015. San Francisco, CA, December 14-18, 2015.