Groundwater Vulnerability Mapping in North Eastern Alberta – preliminary results

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ABSTRACT
Throughout North-Eastern Alberta increasing demands on groundwater supplies for municipalities and industry give rise to the need for assessment of groundwater vulnerability in this region. For this project, several publicly available vulnerability mapping methods have been carefully studied and considered (such as the DRASTIC, CAPIT, AVI, GOD methods), yielding a tailor made vulnerability approach, that sheds light on the state of the groundwater in North-Eastern Alberta. The produced vulnerability maps indicate groundwater vulnerability for the groundwater reserves for North-Eastern Alberta.

RÉSUMÉ

A travers L'Alberta du Nord-est la demande croissant sur l'alimentation de nappe phréatique pour les municipalités et l'industrie, mettent en exergue le besoin de l'estimation de faiblesse de la nappe phréatique dans ce région. De cette façon, pour ce projet, plusieurs modes de l'estimation de la faiblesse de la nappe disponible publique ont été étudiés et considéré (comme les modes DRASTIC, CAPIT, AVI, et GOD), donner une approche de la faiblisse conçu spécialement, qui donne une vue sur la situation de la nappe phréatique dans L'Alberta Nord-est. Les plans indiquent la faiblesse pour les réserves de la nappe phréatique en Alberta Nord-est.

1 INTRODUCTION

The Lower Athabasca Regional Plan (LARP) is being developed to provide an improved way of managing public resources, environmental regulation, and decision-making in a manner that addresses the potential cumulative effects of development over the regional footprint. The plan is based on the principles of integrated resource management, which is the interdisciplinary and comprehensive approach to decision-making. Integrated resource management recognizes the inter-relationships between natural resources and incorporates decisions, legislation, policies, programs and activities across various sectors to gain the best overall long-term benefits for society and the environment, while minimizing conflicts. In support of this framework development vulnerability and risk mapping is provided as a tool to support the land use planning exercises. (Figure 1 provides an overview of the LARP area within the Province of Alberta).

2 VULNERABILITY MAPPING

2.1 Potential Sources and Pathways

Vulnerability mapping assesses the relative exposure of groundwater to pollution from sources at surface. These sources can have a variety of origins. In this study the area can be divided up into three sections based on major potential contaminant source type. The North area has developments of oil sands mining operations, the middle area is predominantly occupied by in-situ operations (i.e. primarily SAGD), and finally the southern area has mixed in-situ and agricultural development.

There are a number of potential pathways for groundwater movement in the regional study area. These primarily take the form of direct or indirect pathways allowing movement of industry or agriculture related constituents and natural formation waters towards, and potentially into, receiving water bodies.

With respect to this study, surficial outwash sands and buried channels deposits with a high potential for connectivity to surface water features like wetlands, fen and bog complexes, tributary streams to the major rivers like the Athabasca have been designated as direct pathways. In turn, buried channels and outwash deposits with a low potential for interaction with surface water bodies have been designated as indirect pathways by virtue of low permeability geological materials residing between them and down-gradient water features.

The occurrence of risk with respect to groundwater is predicated on the occurrence of a well-defined pathway, the type of constituent that may reside in the groundwater and the type of receptor. In the study region, a number of potential key source-pathway-receptor interactions have been identified by virtue of the prevailing hydro geologic conditions.

It is important that pathways and receptors be identified in any development evaluation process, so that the vulnerability of the interval or intervals can be assessed, sensitive areas identified, that risk management plans be developed and evaluated accordingly, and groundwater monitoring strategies can be devised (Liggett et al. 2006).

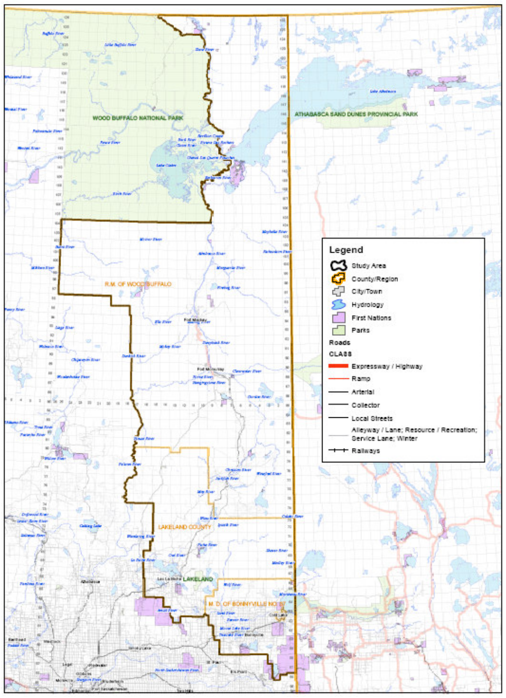

Figure 1. Study area location in north-eastern Alberta

2.2 Intrinsic Vulnerability Mapping for the Study Area

A groundwater vulnerability approach was used to identify areas of the study region requiring special attention or treatment with respect to current and future development activities. After careful consideration of existing groundwater vulnerability mapping techniques it was concluded that with the data available the (modified) DRASTIC approach was the best suitable. The aquifer vulnerability was mapped for the surficial sands and buried channel/valleys using a modified approach to a technique developed by the USGS. Figure 2 below shows how the different elements in the original US-EPA DRASTIC approach fit together.

DRASTIC is a point counting method which assesses groundwater vulnerability via a system of weighted parameters (Aller et al. 1987). A numerical score is obtained by multiplying the score assigned to a parameter by the weighting factor assigned to the parameter and summing the results. The model is based on the following assumptions:

- the contaminant is introduced at the ground surface;
- the contaminant is flushed into the groundwater by precipitation;
- the contaminant has the mobility of water; and
- the area of evaluation is 100 acres or larger.

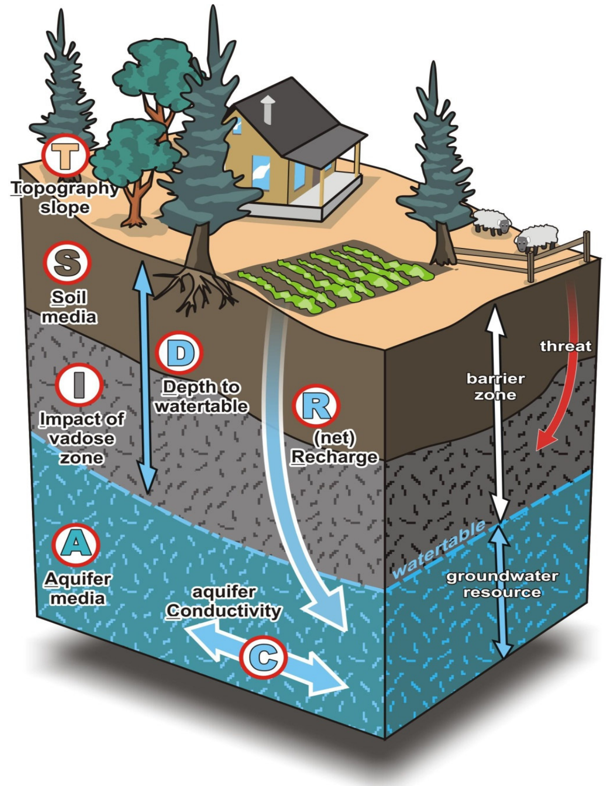

Figure 2. DRASTIC components (from AENV 2009)

It should be noted vulnerability mapping is a management tool and should never be considered a replacement for on-site hydro geological investigations.

As shown in Figure 2 above, there are seven attributes included in the method which make up the acronym DRASTIC. These include:

Depth to water;
Recharge (net);
Aquifer media;
Soil media;
Topography;
Impact of vadose zone; and
Conductivity (hydraulic).

The approach used to assess vulnerability is to rate each attribute depending on its characteristics and distribution within the given study area. These factors are weighted on a scale of one to 5 based on their relative importance (this is the number in front of each of the DRASTIC attributes in the formula below). The attribute weighting (the “w” in the formula) is based on relative significance of each attribute related to each other. The following equation is then used to determine the final vulnerability rating of a given area (V) (where w = attribute weighting):

$$V = 5Dw + 4Rw + 3Aw + 2Sw + 1Tw + 5Iw + 3Cw$$

Once a final vulnerability value has been computed for a given area it is possible to spatially identify those more susceptible to groundwater contamination relative to others. Aggregate values obtained using this method typically range from high to low (in this case 211 to 59) indicating areas with increased potential for effect from area activities (high values) or area of lesser vulnerability (lower values).

The general approach of the DRASTIC model was followed, but some modifications were required due to lack of certain data and consideration of the regional hydro geological understanding of the study area. Each factor will be discussed below in more detail. A modified rating table was used to improve the spatial representation at the local scale. A similar approach has been used by Liggett et al. 2006. The model consisted of a 100 m pixel spacing for all DRASTIC layers, and was limited in areas to the north and north-west due to lack of available data, primarily surficial geology which has not been mapped to date.

3 VULNERABILITY OF SURFICIAL SANDS & BURIED CHANNELS

The DRASTIC model was only applied to the surficial sands and buried channel aquifers at this time as it was determined the deeper basal McMurray Aquifer would require a slightly different approach. The following sub-sections describe how each layer of the DRASTIC model was derived, including attribute weighting. In Table 1 shows the rating system is shown for all the DRASTIC layers used in this project.

3.1 Depth to Water

The spatial distribution of available groundwater level data was plotted by major aquifer interval (where available).

Unfortunately the spread of data was insufficient to use an interpolative method to determine the general “Depth to Water” across the area. Instead, a method similar to that of Liggett et al. 2006, was followed using the relationship between water elevation (h) and ground surface elevation (z). In a previous study executed by WorleyParsons Komex (2008) the following correlation was determined between depth to water and ground elevation. Given the complexity introduced by using water levels from the surficial sands (i.e. unconfined versus confined conditions), the decision was made to use data from monitoring wells completed within the upper 5 m of the surficial till. Water level data were used form the oil sands area only since in other areas no meaningful relationship could be derived from the groundwater data.

By running a linear regression through the resulting data points, the following equation was identified (where h = measured water level, and z = ground elevation:

$$h = 0.0157z - 3.8537$$

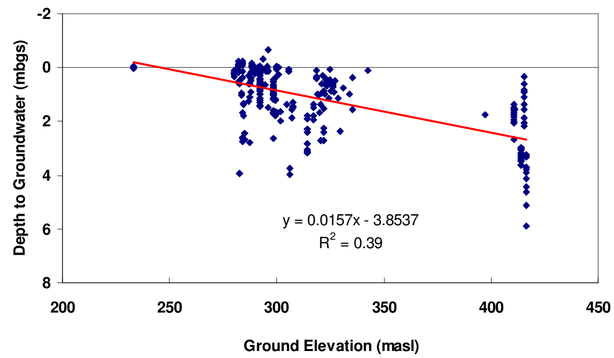

Figure 3. Relationship between ground elevation and depth to water

This regression coefficient associated with this equation was 0.39. Although this regression coefficient would appear a bit low, there was an obvious trend for deeper water levels at higher elevation (recharge zone) and artesian conditions at lower elevation (discharge zone). Using this equation as a reasonable approximation of depth to water below ground surface, the digital elevation model (DEM) was converted into a continuous depth to water surface for the area assessed.

3.2 Recharge

Recharge in the DRASTIC model is defined as a broad value for a region equal to the total quantity of water which is applied to the ground surface and infiltrates to reach the aquifer (Aller et al. 1987). To assess recharge conditions in the study area, predicted recharge values based on elevation were used instead of estimated net recharge and in the more southern areas based on professional judgement as well.

The DEM (digital elevation model) was used to define zones of recharge, discharge, and the transition zone based on the elevation of the topographical surface. For the mineable area the review of the histogram of elevation data along with professional judgement resulted in a cut-off value of 343 masl for the top of the “discharge zone” and 449 masl for the top of the “transition zone”. The top of the “recharge zone” was defined by the highest elevation in the regional dataset (859 masl). For the remaining areas recharge and discharge areas were assessed based on the DEM data and professional judgement.

3.3 Aquifer media

Data available from the Alberta Geological Survey was used to define the presence of buried channel aquifers beneath the study area (Andriashek and Atkinson 2007 and EUB/AGS 2005). Based on this information a rating of eight (high vulnerability) was applied to the major channels with accumulations of sands and gravel, while all other zones outside of the defined channels were assigned a rating of one (low vulnerability).

3.4 Soil media

Data defining the soil media underlying the study area was accessed using the surficial geology provided through the Alberta Geological Survey. Data for a portion of the study area to the west and north, has yet to be mapped and thus was not available for assessment. As a result, the final vulnerability map was reduced in extent to only cover the area where surficial geology exists (i.e. the coloured area of DRASTIC seen on the maps demonstrates the extent of coverage). Vulnerability ratings values were assigned to the different surficial geology types in the study area using professional judgement. For example, a rating of seven (higher vulnerability) was applied to the more permeable outwash sand deposits and kames as opposed to a value of three (low vulnerability) for lower permeability till deposits.

3.5 Topography (% slope)

The topographic layer of the DRASTIC model was derived from the DEM data obtained for use in this study. The degree of slope (as %) was calculated from the information provided using the Spatial Analyst “slope” tool available in the ArcGIS version 9.3 software. Higher vulnerability was associated with low % slope as opposed to areas with a higher % slope. The reasoning behind this is that water on steeper slopes will tend to runoff versus infiltrate, thus the potential for any constituents within the runoff water to enter the subsurface is less.

3.6 Impact of vadose zone

Instead of using the traditional DRASTIC parameter “Impact of Vadose Zone”, a layer characterizing the thickness of protective cover above the aquifer was created. Using the surficial geology GIS layer, hydraulic conductivity values (K in m/s) were identified for the various units using measured values provided by existing oil sands applications, government reports and/or professional judgement. A bias toward overestimating the most probable hydraulic conductivity was used. The following table summarizes the various types of deposits and assigned K values.

Aggregate overburden thickness was calculated by subtracting the thickness of the buried channels from the overall drift thickness (both obtained from Andriashek and Atkinson, 2007 and EUB/AGS 2005.). Surficial deposits with the highest K values were assumed to have a 0 m thickness of protective cover. The resulting layer was combined with the layer of 0 m thickness for surficial sands to create a final “thickness of protective cover” layer.

3.7 Conductivity

Hydraulic conductivity values measured from shallow wells in the region were overlain on the outline map of the buried channels. Using available data and professional judgement, a hydraulic conductivity value was averaged for the aquifers, and given a vulnerability rating based on one of the tables in Liggett et al. 2006. Everywhere else (where there were no buried channels) was given a rating of one.

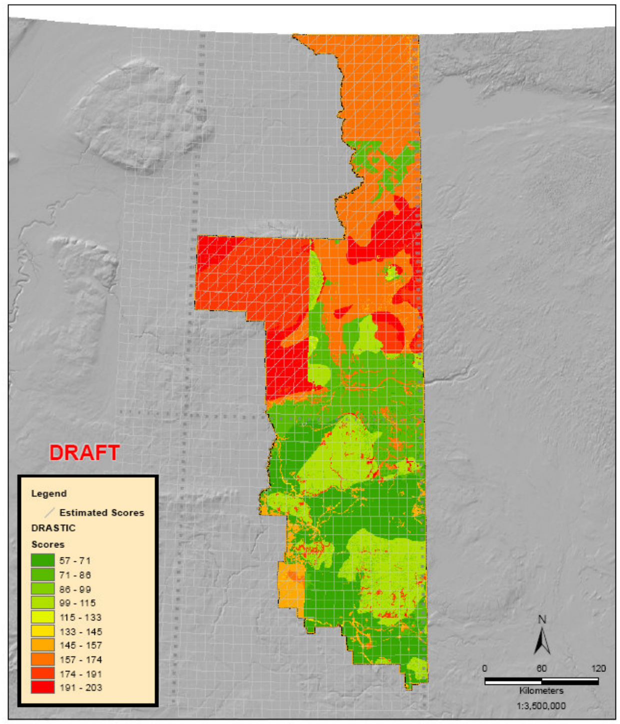

Figure 4. Overall intrinsic vulnerability DRASTIC

3.8 Results of DRASTIC

To produce the final vulnerability map for the LARP area, all the layers were assigned weightings, as in the standard DRASTIC approach, and summed together. The overall intrinsic aquifer vulnerability calculated using this method is shown in Figure 4.

Higher vulnerability was identified over major portions of Northern regions of the study area. This is in line with the soil media and aquifer material and corresponding hydraulic conductivity found in the oil sands region North of Fort McMurray. In the central and southern (Beaver River) areas steeper slopes and soil types conducive to higher vertical mobility of groundwater yielded a higher vulnerability. Other areas were found to be of low to moderate vulnerability due to the associated soil media, which is identified on the surficial geology map as predominantly till. Depth to water has increasing influence on groundwater vulnerability towards Northern regions. The far north, and area to the West and a small area in the South-West had insufficient data to do a complete intrinsic vulnerability, hence a conservative approach has been chosen for these areas. They have been assigned the highest vulnerability scores based on lack of knowledge.

4 MODIFIED DRASTIC

For the modified DRASTIC an alternative method was developed including buried channels. It differs from the traditional DRASTIC in that it assesses groundwater vulnerability in deeper laying features (i.e. buried channels). Where channels are present a weighting of 4 was used, and a value of 1 where channels are absent. To calculate the groundwater vulnerability, the original DRASTIC formula has been changed to the following (where w = attribute weighting):

$$V = 5\mathbf{D}w + 4\mathbf{R}w + 3\mathbf{A}w + 2\mathbf{B}w + 2\mathbf{S}w + 1\mathbf{T}w + 5\mathbf{I}w + 3\mathbf{C}w$$

For the “B” parameter, the weight has been set at four for areas with buried channels, and one where channels are absent. A comparison has been made between the original DRASTIC and modified DRASTIC which is displayed in Figure 5. In this figure the buried channels are clearly visible. The reasoning behind adding this attribute is that the regular DRASTIC method has a tendency to underestimate the groundwater vulnerability in areas where there are buried channels. These channels can form a conduit for vertical and lateral groundwater movement towards receptors, and thus make the area more vulnerable to impacts from subsurface.

5 VULNERABILITY MAPPING AND RISK MAPPING

It was recognized during the assessment process that the DRASTIC model has some limitations with respect to the attributes used. These limitations were addressed by creating a modified DRASTIC approach as described previously. In addition to this, development features were added to DRASTIC to assess risk.

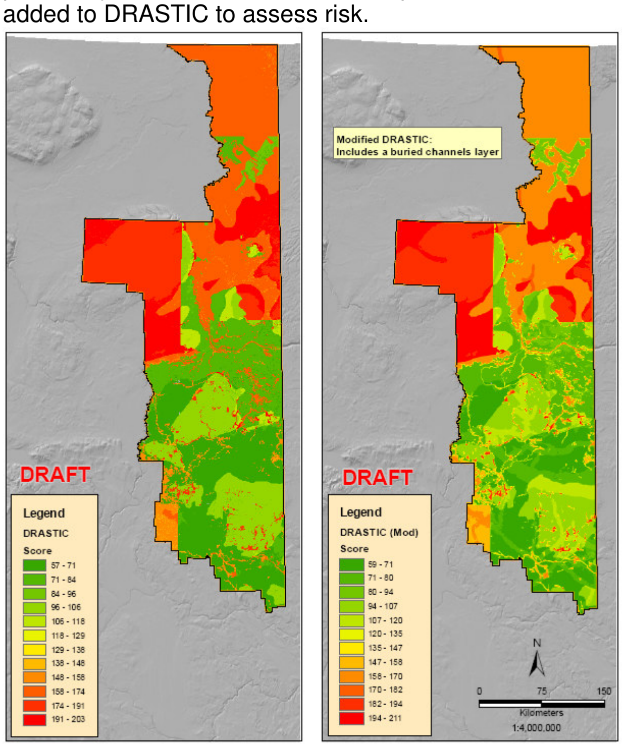

Figure 5. Overall intrinsic vulnerability – DRASTIC and modified DRASTIC compare

The definition of risk can be described as follow;

Groundwater vulnerability * Hazard = Risk

The two added layers are:

1) adding a layer to the overall DRASTIC model that identified sources, ranked pathways and potential receptors in the area; and

2) adding a “development” layer that was an additive summary of ranked contaminant sources, age of proximal infrastructure and overall development footprint in the area.

GIS layers were created and summed to yield the final maps, which help identify risk of potential cumulative effects in the area. The final potential risk map was instrumental in identifying areas at highest risk from area development, and thus worthy of future monitoring to assess cumulative effects.

5.1 Overall potential risk (modified DRASTIC)

Vulnerability mapping (i.e. DRASTIC) plus the modified layers (receptors and pathways) were assessed in relation to the development layer (contaminant sources, age of infrastructure and development footprint) to provide an overall picture of cumulative effects for the study region. Different GIS shape files created for pathways, receptors and development were joined together in different ways based on shape type (i.e. point, polylines, polygons) to determine the sum of potential vulnerability values based on the receptor/pathway and development tables.

Areas with the highest development rating are concentrated around the older mine areas such as Suncor and Syncrude given their age and existing infrastructure (i.e. tailings ponds). Smaller areas of high development rating are present at the newer mines in the north central portion of the study area (Albian and Aurora) and SAGD activities in more southern areas with a lower density of contaminant sources.

In the central and southern region developments of SAGD can be found for developments such as Surmont, Kirby, IOR Cold Lake, CNRL Primrose, Tucker Lake, and Wolf Lake. These developments are smaller in size than the traditional oil sands developments, however, they do have potential risk for impacts on surface water bodies and deeper aquifers. Impacts on deeper aquifers in the area (besides for the Basal aquifer, these data were readily available from previous projects) have not been assessed, due to a lack of data and project time constraints.

Overlaying the hazards of producing/active developments and proposed/under construction developments over the alternative DRASTIC intrinsic vulnerability map yields the Risk to surface features and aquifers (Figure 6). The resulting Risk map shows areas of potentially higher concern related to Risk in the Northern Oil sands area and in the central and southern areas where the (SAGD) facilities and agriculture and corridors are underlain by buried channels and outwash/sand features.

6 RESULTS

Results of the groundwater vulnerability mapping (using DRASTIC and alternative DRASTIC) show that the area of highest vulnerability can be identified in the northern portion of the mapped extent of the study area. In the central and southern region the highest vulnerability associated with features such as buried channels, and steep and incisive river banks. For the alternative method using development footprints, the highest risk is identified in the north-central portion of the mapped extent of the Basal McMurray (on the east side of the Athabasca River), this is also due to the previously mentioned conservative approach used to address areas with insufficient data. Besides the outcome of the conservative approach, the main reason for higher risk in the area is the associated level of current and planned development, as well as the intensity of current and future de-watering activities. A moderate to high degree of vulnerability was also identified on the east side of the Athabasca River near CNRL's and TOTAL's leases, as well as along the river itself.

7 CONCLUSION

Different methodologies are currently available for groundwater vulnerability mapping, and for this project the modified DRASTIC method was deemed most suitable and was thus applied. Vulnerability mapping has been proven to be a useful tool in assessing the landscape as it relates to groundwater vulnerability, and give regulators a valuable tool for land use planning activities.

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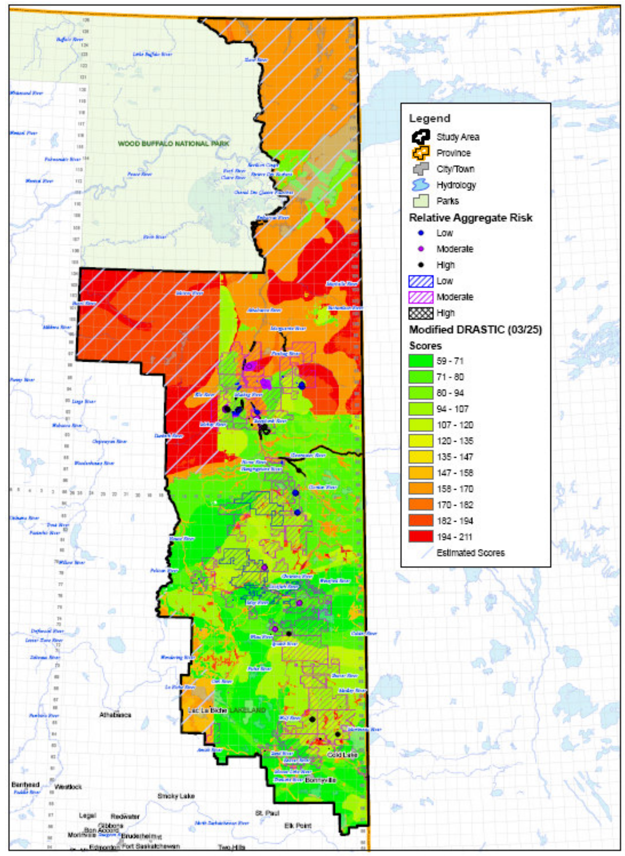

Figure 6. Overall risk

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