Geographical Analysis of Cumulative Threats to Prairie Water Resources: *Mapping water availability, water quality, and water use stresses*

Richard. E. Grosshans, Henry D. Venema, and Stephan Barg

International Institute for Sustainable Development (IISD)
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2005
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Acknowledgements

We would like to thank the gang from Prairie Farm Rehabilitation Administration, Agriculture and Agri-Food Canada, here in Winnipeg, Manitoba for working with us on this study: Jarrett Powers, John Fitzmaurice, Conrad Wyrzykowski, and Chuck Swain, for data assistance, GIS technical wizardry, and providing important survey and spatial data layers. Several pieces that were provided were essential to carrying out this study. Thanks also goes out to a number of other Agriculture and Agri-Food Canada people for methodology ideas and being pointed in the right direction to find publicly available datasets and datalayers: Jim Hiley, Gord Bell, Phil Adkins, and Bob Eilers. And lastly to the GIS gurus of Ducks Unlimited Canada, out in Stonewall, Manitoba, for yet more GIS troubleshooting and brainstorming: Andrew Pratt and Bill Tedford.
1. Executive Summary

Despite the vast abundance of freshwater available in Canada, human induced impacts and stresses combined with agricultural pressures and the effects of global climate changes have caused significant freshwater problems across the country. The objective of this study was to gain a watershed perspective on water vulnerability across the Canadian Prairie provinces, with a focus on water quality, water use, and water availability stresses and their compounding effects across the prairie agro-region. Water related stresses and issues combine to produce “hotspots” or areas of concern that are more prone to the combined effects of water related stress, and therefore have a much higher degree of vulnerability with regards to shortages and contamination. By calculating a composite index of water vulnerability and mapping where these various water resource stresses compound, areas were identified that may require greater and more immediate attention for policy and management. Areas of greatest concern with the highest cumulative stresses appear throughout the prairie agro-region, most concentrated around the heavily populated areas of south central Alberta, the boreal plain fringes of Saskatchewan, and the entire Red River valley of Manitoba.

Rationale for mapping cumulative stresses is that the areas with the highest concentration of water resource stresses will have the highest vulnerability rating, and therefore the highest level for concern. GIS datasets include indicators of water use demands, water quality stresses, and water availability. Indicators include: domestic, commercial, industrial, agriculture, and energy sector demands on water resources; availability of water resources due to existing water sources, climate, and soil characteristics; pollution sources and their potential impacts to water quality; existing agriculture conservation practices, and government policies and programs; as well as additional stresses on water supply and consumption such as climate variability and possible future climate change impacts.

2. Introduction

Freshwater is one of the most important natural resources on our planet, and is essential to human populations (Naiman et al. 1995), and yet water resources across the globe continue to be heavily impacted by human activity. Despite the vast abundance of freshwater available in Canada (Natural Resources Canada 2002), human induced impacts and stresses such as urban expansion, development, resource extraction, industry, and increased agricultural pressures have caused significant freshwater problems across this country (McRae et al. 2000). The concept of water stress is fairly simple: either there is not enough water for all uses, or the water is polluted so that it is unfit for human consumption. Schindler (2001) warns that most freshwaters in southern Canada will suffer from the cumulative effects of stresses at some level, including unacceptable levels of pathogens, over allocation of water, and climate warming. Many rivers, streams, and lakes across the Canadian prairies are already significantly affected by over allocation of water and serious nutrient enrichment (Schindler 2001). Stresses to Canadian water resources range from increased energy demands for water by agriculture, domestic growth, and industry; nutrient contamination of water sources from agricultural runoff and sewage effluents; industrial and domestic pollution of water ways; severe erosion and silting of waterways from production and extraction; to significantly reduced flows in major rivers of the western prairies anywhere from 20-50% of their historic flows as a result of human withdrawals and climate warming.
Drinking water contamination and water shortages are typically thought of as problems occurring elsewhere or in developing countries. However, water related events, boil water advisories in local communities, and continued ecological decline of lakes and rivers reported in the media across Canada has significantly raised public awareness and concern of how precious and fragile Canada’s fresh water supply is. With population growth, industrialization, expansion of agriculture, increased demand for hydroelectric power, and other water use activities, the demand for water in the future will greatly increase globally and in Canada (Postel 1998, Climate Change Impacts and Adaptation Directorate 2002). Additionally, predicted global climate change effects and uncertainty of water resource supply will only compound the impacts of these stresses. Problems are most likely to arise where the resource is already under stress, because that stress would be exacerbated by changes in supply or demand associated with climate change (Climate Change Impacts and Adaptation Directorate 2002). One simply needs to examine current climate trends to preview the drastic variability of weather conditions and water resources that could occur as a result of global climate change. For example, the unusually severe drought conditions and resulting water shortages and crop failures experienced across Canada in 2003 and 2004, followed by record precipitation levels and water levels in south central Manitoba in 2004 and 2005 (Environment Canada).

Proper watershed management and water resource planning at all levels is critical to maintaining water quality and sustainability (Naiman et al. 1995, Gabor et al. 2001, 2004), as are improved policies and programs from decision makers. Water contamination, overuse of water, and global climate change are significant problems facing Canada, and stresses contributing to these problems are only going to increase locally, nationally, and across the globe (WBCSD 2005).

Figure 1. Stresses to our water resources are occurring across the globe as well as in our own backyard.
2.1. Goals and Objectives

The objective of this study was to gain a watershed perspective on water resource issues across the Canadian Prairies, with a focus on water quality, water use, and water availability stresses and their compounding effects across the prairie agro-region. This was accomplished by calculating composite indices and mapping existing water resource stresses to identify the areas where various water related stresses combine to produce “hotspots” or areas more prone to combined effects of stress. These areas of concern would have a much higher degree of vulnerability with regards to water shortages and contamination and will identify regions that may require greater and more immediate attention for policy and management. Rationale for mapping cumulative stresses is that the areas with the highest concentration of water resource stresses will have the highest vulnerability, and therefore the highest level for concern.

One of the goals of this prairie-wide water resource analysis was to gain baseline information at the soil landscape polygon level (Soil Landscapes of Canada Working Group 2005) on water resource stresses, and develop a framework for further efforts into examining water resource stresses on the prairies to better manage our water resources. Baseline data is one of the key pieces of information needed to base public policy decisions concerning the use and management of prairie water resources. This report describes the various data sources used, analytical framework, normalization, and aggregation of spatial data and databases, and GIS mapping methods for combining water stresses and presentation of final data.

2.2. Water Vulnerability, Vulnerability Mapping, and Risk Assessment

An important aspect of environmental vulnerability assessment and mapping is to identify areas on the landscape that require immediate policy implementation or management. This type of vulnerability assessment can help lead to prevention strategies aimed at avoiding a dangerous combination of factors and stresses. Definitions of vulnerability vary, but the common underlying definition is the understanding that vulnerability expresses the degree or susceptibility to a hazard or stress, either as a result of exposure to that stress, or because of variations in the ability to cope with its impacts (Ramachandran and Eastman 2005). Essentially, areas that have high exposure and high concentrations of stresses combined with low coping abilities would have the highest vulnerability. Several studies have mapped water resource stresses in Canada (McRae et al. 2000, Jones and Armstrong 2001, Bourne et al. 2002, Agriculture and Agri-Food Canada 2003, Bell et al. 2004, de Loe et al. 2005) however, only a few assess and identify cumulative stresses and water vulnerability.

Various methods for assessing and mapping vulnerability from other disciplines can be applied to mapping water resource stress and vulnerability. O’Brien et al. (2004) mapped India’s agricultural vulnerability to the two stressors of climate change and economic globalization. Detailed methodology used to construct their vulnerability profiles are described in Leichenko et al. (2004), specifically use of the UNDP’s Human Development Index (HDI) (UNDP 2002), to normalize and aggregate datasets measuring different variables. Several methods to construct composite vulnerability indices are also outlined in Ramachandran and Eastman (2005), many of which similarly aggregate and normalize indicator data. They discuss the use of GIS for food security mapping - a form of vulnerability assessment that examines the degree to which a population or region is susceptible to a range of hazards that threaten food supplies, and for
which food assistance is required. Bell et al. (2004) assessed the vulnerability of water from agricultural production in Saskatchewan by combining several geo-referenced databases to produce a composite water priority indicator map for Saskatchewan. This map was developed by combining three agri-Environmental Stressors of manure production, sales of inorganic fertilizers, and bulk sales of agro-chemicals with four agri-Environmental issues of potential for contamination by water erosion, and susceptibility of wetlands, streams, and groundwater within a landscape.

By combining various methods intended for risk assessment and development of vulnerability indices used for identifying areas of concern, a methodology could be developed to identify areas of cumulative water stresses and therefore highlight areas of concern and vulnerability.

2.3. Study Area

The study area was contained within the prairie watershed boundaries as defined by the Prairie Farm Rehabilitation Administration (PFRA) Watershed Project (Prairie Farm Rehabilitation Administration 2005), defined as the effective drainage area of the prairies. The spatial extent covers all of Alberta, Saskatchewan and Manitoba, and portions of adjacent areas into which Prairie watersheds extend (includes: British Columbia, the Northwest Territories, Nunavut, Ontario, and the United States). The PFRA Watershed project information and digital data is available on the internet (http://www.agr.gc.ca/pfia/main_e.htm).

![Figure 2](image-url)
3. General Approach

A common approach to measure vulnerability is to calculate an index from a combination of variable scores (O’Brien et al. 2004, Leichenko et al. 2004, Ramachandran and Eastman 2005). In most cases variable scores are scaled to a common standardized or normalized scale, or are assumed to follow a normal distribution and are expressed as standard deviates (z-scores). This “normalizing” allows indicators measuring different things and expressed in different units of measure to be compared. Standardized indicator scores can be assigned a weight, but because of uncertainties in applying weights to variables, equal weights are often used. All indicator data used in this study was standardized by normalization for aggregation, and to allow comparisons between data sources and GIS boundary layers.

Stresses were identified by combining existing spatial data sources and calculating their compounding effects. Stresses identified include: urbanization; agricultural, and energy sector demands on water resources; the varied stresses on water quality from non-point source contamination including human and livestock; stresses affecting the availability of water and existing water resources; and ultimately where these various water resource stresses compound. Secondary analysis included effects on water supply and water consumption from precipitation variability, and the possible climatic change impacts on water supply.

Methods for normalization and aggregation of datasets vary. Bell et al. (2004) used a standardized 5 category rating convention for defining degree of impact, and classified all datasets using Jenks’ natural breaks; described as either: negligible, low, moderate, high, and very high priority, respectively. The Canadian Biodiversity Index (Murray and Pinter 2004) utilizes a method where all indicators are “normalized” to a common scale from 0-100, and divided into five 20-point subcategories. O’Brien et al. (2004) described in Leichenko et al. (2004) utilized the UNDP’s Human Development Index (HDI) normalization method (UNDP 2002). The HDI was determined to be ideal for combining and comparing water resource stress data for this analysis. All datasets were normalized following the HDI to a common scale of 0-100 (UNDP 2002), while final maps for presentation were classified using Jenks’ natural breaks (Bell et al. 2004).

For aggregation and creation of compounding stress maps, all final normalized indicator data layers were subsequently converted to Soil Landscapes of Canada (SLC version 3.0) polygons (boundaries) (Soil Landscapes of Canada Working Group 2005), where boundary errors were assumed to balance out. The SLC classification system is based on soil survey data from Agriculture Canada (Publication 5243/B). SLC boundaries were used because it is an ecosystem level boundary layer, fairly fine scale, and is typically used for this type of analysis. Database files were then combined together in an Excel spreadsheet in one of the 3 major themes of 1) water use, 2) water quality, or 3) water availability stresses. Each set of theme indicators were combined and subsequently re-normalized to give a set of final index scores for each of the 3 themes. This data, converted to a database DBF file, was joined to the SLC version 3.0 polygon GIS data layer and displayed in ESRI’s ArcGIS 9.1 (ESRI 2005) based on a 10 Jenks natural breaks classification for display purposes. Datasets, indicators of water resource stress, aggregation framework, normalization methodology and calculations, and final mapping and Jenk’s classification in ESRI’s ArcGIS are described in further detail below.
3.1. Boundary layers (all indicator data sets are linked to a GIS boundary layer):

- **Census Divisions (CD), Census Subdivisions (CSD), and Census Consolidated Subdivisions (CCS)**
  Digital boundary files portray the official boundaries used for Statistics Canada census collection (Statistics Canada. 2001). For comparisons to be made between census divisions, polygon area was calculated. Existing geographic datasets were reprojected to North American Datum (NAD) 83 Universal Transverse Mercator (UTM) zones for the purpose of calculating polygon areas in km$^2$. Each UTM zone was treated separately (UTM zones 10-15, [http://www.dmap.co.uk/utmworld.htm](http://www.dmap.co.uk/utmworld.htm)). Polygon area estimates were calculated for each boundary layer (CD, CSD, CCS). An “area in km$^2$” data column (field) was added to each original boundary layer’s GIS database file.

- **Ecodistricts in Canada**
  EcoDistricts are ecosystem level boundary layers characterized by relatively homogeneous biophysical and climatic conditions. The differentiating characteristics of EcoDistricts are: regional landform, local surface form, permafrost distribution, soil development, textural group, vegetation cover/land use classes, range of annual precipitation, and mean temperature (Agriculture and Agri-Food Canada 1999, 2005).

- **Soil Landscapes of Canada (SLC version 3.0) polygon boundaries**
  The SLC classification system is based on soil survey data from Agriculture Canada (Publication 5243/B). Compiled at a 1:1 million scale soil landscapes are the product of soil forming factors acting on surficial geological deposits over time (Soil Landscapes of Canada Working Group. 2005). SLC boundaries were used because it is an ecosystem level boundary layer, fairly fine scale, and is commonly used for this type of analysis.

- **Base layer used for all maps was the North America Shaded Relief** (National Atlas of the United States 2005). This image file shows depth and elevation ranges using colors and relief enhanced by shading. The image was derived from GTOPO30 elevation data with a resolution of 1 km. Each grid cell represents average height above sea level. The image was created by grouping elevation values into ranges and assigning colors to elevation ranges. The three-dimensional appearance was achieved by shading image as if a light source was in the northwest. Image is intended for visual purposes only. Original GTOPO30 elevation data is needed for analysis and elevation values. Associated world file is included as part of the GeoTIFF (National Atlas of the United States 2005).

3.2. Data Sources and base datasets

Stresses were identified from already existing spatial data sources as listed below. Indicators of stress to water resources in the prairie watershed region (Figure 2) were selected from these datasets that best represented primary stresses to water resources. Stresses fall into one of three themes: 1) water use demands, 2) water quality stresses, and 3) factors relating to water availability. Additional datasets were considered for analysis, but were not made available or were not in the proper format or not available spatially to be used in this mapping study.
Datasources utilized for cumulative water stress mapping:

- **2001 Agricultural Census Data** (Statistics Canada 2001) provided by producers, and is the principal source of information about agricultural inputs on Canadian farms. Due to data limitations some areas do not have survey data, or are simply based off the few producers that answered the survey (CD and CCS boundary data).

- **2001 Municipal Water Use Data** (Environment Canada 2001), which is the primary source of information regarding municipal use of water by residential, industry, commercial and institutions (CCS boundary data).

- **Ecodistrict data** (Agriculture and Agri-Food Canada 2001, 2005), climate and ecological data is included with the ecodistrict GIS boundary layer. Canadian ecodistrict climate normals (1961-1990) are available as GIS databases for the ecodistricts GIS boundary layer (Ecodistrict boundary data).

- **Soil Landscapes of Canada** (SLC version 3.0, Soil Landscapes of Canada Working Group 2005) data describing water related conditions based on soil survey data from Agriculture Canada (Publication 5243/B) included with the SLC GIS boundary layer (SLC boundary data).

It is important to stress that the obtained indicator data is only as good as the surveys and data sources they come from, and in some cases are estimates based on averages. Due to data limitations some areas do not have data, or are based off the producers, landowners, government sectors, etc. that completed the survey questions.

### 3.3. Water Resource Stress Themes and Indicators

**Theme 1 - Water Use Stresses** (Table 2)

Water use demands on water resources from domestic, commercial, and industrial water use; agricultural water use (irrigation and livestock); and energy sector demands (Figure 3). The Water Use Stress Map was developed using primarily 2001 Agricultural Census (Statistics Canada 2001) and Municipal Water Use data (MUD) 2001 (Environment Canada 2001).

- **Percent of Total hectares of seeded land with irrigation**
  Data from 2001 Agricultural Census (Statistics Canada 2001). Percentage of the cropped land that is irrigated for crop production. Was standardized to % of cropped land area (CSD polygons boundary layer) and normalized.

- **Total human water flow per km$^2$ (domestic, industrial, commercial)**
  Includes total well flow, residential water use, and industrial, commercial, and institution water use from the Municipal Water Use data (MUD) 2001 (Environment Canada 2001).
  - Municipal water use data includes: domestic water use m$^3$ per year, industrial/commercial/institution water use m$^3$ per year, and population with wells.
  - Well flow was estimated using the value from (Southam et al. 1997). Population with wells multiplied by an average estimate for use of 159 L/day per person.
Total absolute water use was calculated to per unit area (km$^2$) for comparisons between municipalities (CCS polygon boundary layer) and normalized.

**Total Livestock water use per km$^2$**

Coefficients of water use were adapted from values from the literature (Ontario Ministry of Agriculture Food and Rural Affairs 1992, Prairie Agricultural Machinery Institute 1996, Prairie Farm Rehabilitation Administration 2003, Saskatchewan Agriculture and Food 2004). Coefficients of water use are not given for all livestock found in Canada, so livestock water use values could under-estimate actual quantity of water used in Canada by livestock. Coefficients of water use were calculated as per km$^2$ and normalized.

**Theme 2 - Water Quality Stresses (Table 2)**

Stress and potential impacts to the quality of water resources from domestic, commercial, industrial, and agricultural water contamination non-point sources (Figure 3). The Water Quality Stress Map was developed using primarily 2001 Agricultural Census data (Statistics Canada 2001).

**Total Livestock Animal Units per km$^2$**

Data based on livestock populations as of 2001, when the Census of Agriculture was conducted. For purposes of this study total livestock was: dairy cows, beef cattle, calves, hogs, horses, sheep, pullets, broilers, layhens, turkeys, and "other poultry". Livestock densities (number of animals in the landscape) were converted to standardized Animal Units (AUs) based on animal equivalents. Animal units are a means of equally measuring farm animals of different sizes based on feed input and manure output. They are used in regulations, codes of practice and municipal bylaws related to livestock production (Beaulieu and Bedard 2003). AUs were totaled and converted to per unit area in Km$^2$ for a given CCS. This provided a standardized unit of total livestock AUs per km$^2$.

**Percent total cropped land with agricultural Chemical Units applied**

Data based on percent of total cropland as of 2001, when Census of Agriculture was conducted. For the purposes of this study, total hectares of cropland with applications of: fertilizer, herbicide, insecticide, and fungicide were used. A Chemical Unit in a CCS is the total of all the normalized values of each of these. Each chemical (fertilizer, herbicide, insecticide, and fungicide) was calculated as a percent of total hectares of cropland that received application of the chemical and then normalized. All four normalized values were added for each CCS polygon and renormalized. This represented a value of total cropped land in a CCS polygon with agricultural Chemical Units applied.

**2001 Population - people per km$^2$**

Based on Municipal Water Use data (MUD) 2001 (Environment Canada 2001). Human density calculated as people per unit area (per km$^2$) for each CSD, and normalized.
Theme 3 - Water Availability Stresses (Table 2)

Stresses on availability of water from existing water sources. Calculated from climate and landscape influences, and soil water holding characteristics (Figure 3). The Water Availability Stress Map was developed using primarily Ecodistrict climate data (Agriculture and Agri-Food Canada 2001, 2005) and Soil Landscapes of Canada data (SLC version 3.0 Soil Landscapes of Canada Working Group 2005) data.

• Precipitation surplus/deficit
  Data from the Canadian ecodistrict climate normals (1961-1990) available as a GIS database for the Ecodistricts in Canada GIS boundary base layer (Agriculture and Agri-Food Canada 2001). A precipitation surplus/deficit was computed by subtracting the potential evapotranspiration (PE) from total precipitation (P) (i.e. TOTALP-PE) using the Penman PE calculations.

• Soil available water holding capacity (AWHC)
  Data from the Soil Landscapes of Canada (SLC version 3.0, Soil Landscapes of Canada Working Group 2005). A soil's water storage characteristics are very important for irrigation management. Since the size and number of pores in soils are directly related to soil texture (particle sizes), soil texture is the indicator for the amount of water a soil can hold. This is its available water capacity. Sand and clay have the lowest AWHC, while silt loams and organic soils have the highest (Appendix 1).

• Percent Area of Fresh Water
  Data from the Soil Landscapes of Canada (SLC version 3.0, Soil Landscapes of Canada Working Group 2005). Amount of area on the landscape that is water.

3.4. Supplementary theme layers

Theme 1 - Water and Soil Agricultural Practices (Table 2)

This layer of water and soil conservation practices was compared to the final Compounding Stress or “Hot Spots” map. It included existing agriculture conservation practices that are beneficial to soil and water conservation (Figure 4). Unfortunately it only includes the conservation practices included in the 2001 Agricultural Census data so the analysis is fairly limited.

• Percent of seeded land with No/zero tillage
  Data from 2001 Agricultural Census (Statistics Canada 2001). Total cropped land that is under conservation tillage. Was standardized to % of cropped land area (CSD polygons boundary layer) and normalized.

• Percent of Farms with cropland having Grass Waterways
  Data from 2001 Agricultural Census (Statistics Canada 2001). Total farms surveyed that have cropland with grassed waterways. Was standardized to % of cropped land area (CSD polygons boundary layer) and normalized.
**Percent of Farms with cropland having Windbreaks or shelterbelts**

Data from 2001 Agricultural Census (Statistics Canada 2001). Total farms surveyed that have cropland with windbreaks and shelterbelts. Was standardized to % of cropped land area (CSD polygons boundary layer) and normalized.

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**Figure 3.** The three water resource stress themes (water availability, use, and quality stresses) and associated indicators for each theme.

**Figure 4.** Additional overlay analysis themes of agricultural soil and water conservation practices, and water conservation policy programs and associated indicators for each theme. Climate change impacts are also given, represented by precipitation variability.
Theme 2 - Water Conservation Policies (Table 2)

Policy layer includes municipal government water conservation policies and programs. This GIS layer was applied to the final Compounding Stress or “Hot Spots” map with the Water and Soil Agricultural Practices layer included. Unfortunately it only includes the water conservation policies included in the Municipal Water Use data (MUD) 2001 (Environment Canada 2001). This is limited boolean data (i.e. Yes or no – whether a given CSD has policies in place) and is only intended as a preliminary analysis of comparing water stresses and policy. For comparison and normalization, these were summarized to the Census Division (CD) boundary level.

- Industrial, commercial advice of water conservation
- Public advertisements on water conservation in rural municipality
- Installation of water efficiency equipment
- Lawn watering bylaws in effect
- other water conservation programs underway

Theme 3 - Climatic variability and Climate Change impacts (Table 2)

Stresses on future water supply and consumption are determined from precipitation variability calculating a coefficient of variability from existing precipitation maps, and predicted average annual precipitation deficit in 2050 under climate change.

- Precipitation variability
  Growing season total accumulated precipitation maps (April 1 to August 31) of the prairie provinces from 1960 to 2002 were used to calculate and construct a precipitation variability map. Coefficients of variability for each pixel area was calculated using the software program Matlab®. Coefficient of variability data was imported into ArcGIS to display areas of highest precipitation variability over the 42 year period. Reasoning is that the areas that are most variable might be more susceptible to the effects of global climate change. In other words, increases in temperatures and decreased precipitation leads to increased evapotranspiration, and therefore greater precipitation deficits.

- Predicted potential evapotranspiration (PE) on the Canadian prairies in 2050
  Predicted global climate change effects and uncertainty of water resource supply will only compound the impacts of existing stresses. Problems are most likely to arise where the resource is already under stress. Climate change precipitation changes were forecasted by PFRA in Winnipeg (unpublished data).
### Table 1. Water vulnerability datasets – base GIS layers and GIS boundary layers.

<table>
<thead>
<tr>
<th>Base Maps and Boundary Layers</th>
<th>Source</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America shaded relief base map</td>
<td>National Atlas of the United States</td>
<td>___</td>
</tr>
<tr>
<td>Lakes</td>
<td></td>
<td>___</td>
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<tr>
<td>Rivers</td>
<td></td>
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</tr>
<tr>
<td>Populated Places</td>
<td></td>
<td>___</td>
</tr>
<tr>
<td>Provincial boundaries</td>
<td>National Scale Frameworks</td>
<td>___</td>
</tr>
<tr>
<td>PFRA Watershed Boundaries</td>
<td>PFRA - AAFC</td>
<td>___</td>
</tr>
<tr>
<td>Soil Landscapes of Canada Version 3.0</td>
<td>CanSIS - AAFC</td>
<td>SLC</td>
</tr>
<tr>
<td>Ecodistricts of Canada</td>
<td>National Ecological Framework for Canada</td>
<td>Ecodistricts</td>
</tr>
<tr>
<td>Municipal/Census SubDivision boundaries</td>
<td>National Scale Frameworks</td>
<td>CSD</td>
</tr>
<tr>
<td>Census Consolidated Subdivisions</td>
<td>Stats Canada</td>
<td>CCS</td>
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<tr>
<td>Census Divisions</td>
<td>Stats Canada</td>
<td>CD</td>
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<tr>
<td>Road Network</td>
<td>National Scale Frameworks &amp; Atlas of Canada</td>
<td>___</td>
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<tr>
<td>Rail Network</td>
<td>National Scale Frameworks &amp; Atlas of Canada</td>
<td>___</td>
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</tbody>
</table>

### Table 2. Water vulnerability datasets – Indicators of stresses to water availability, use, and quality to the water resources of the Canadian prairie provinces. Given is the indicator, GIS boundary layer, source, and what indicates a high stress.

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Boundary</th>
<th>Source</th>
<th>High Stress?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water Availability Stress Indicator layers</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precipitation surplus/deficit (total Precip-PE)</td>
<td>Ecodistrict</td>
<td>National Ecological Framework for Canada - AAFC</td>
<td>High deficit (less surplus)</td>
</tr>
<tr>
<td>Soil available water holding capacity (AWHC)</td>
<td>SLC</td>
<td>CanSIS - AAFC</td>
<td>Low available water</td>
</tr>
<tr>
<td>% of total area that is Fresh Water</td>
<td></td>
<td>CanSIS - AAFC</td>
<td>Less water area</td>
</tr>
<tr>
<td><strong>Water Use Stress Indicator layers</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of total hectares of seeded land with irrigation</td>
<td>CCS</td>
<td>2001 Census of Agriculture - Stats Canada</td>
<td>More land under irrigation</td>
</tr>
<tr>
<td>Total human water flow (m3 per year) per km2 (dom., indus., comm.)</td>
<td>CSD</td>
<td>Municipal Water Use - Env. Canada (MUDD 2001)</td>
<td>More m3 of water used per year</td>
</tr>
<tr>
<td>Total Livestock water use (m3 per year) per km2</td>
<td>CCS</td>
<td>2001 Census of Agriculture - Stats Canada</td>
<td>More m3 of water used per year</td>
</tr>
<tr>
<td><strong>Water Quality Stress Indicator layers</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Livestock Animal Units (AU) per km2</td>
<td>CCS</td>
<td>2001 Census of Agriculture - Stats Canada</td>
<td>More AUs per km2</td>
</tr>
<tr>
<td>Total cattle, pigs, horses, sheep, goats, bison, poultry, etc per km2</td>
<td>CCS</td>
<td>2001 Census of Agriculture - Stats Canada</td>
<td>Higher percent of land with chemical applied</td>
</tr>
<tr>
<td>% total land with agricultural Chemical Units applied</td>
<td></td>
<td>Municipal Water Use - Env. Canada (MUDD 2001)</td>
<td>Higher human population per km2</td>
</tr>
<tr>
<td>% and with FERTILIZER, HERBICIDE, INSECTICIDE, FUNGICIDE applied</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2001 Population - people per km2</td>
<td>CSD</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Agricultural Soil and Water Conservation programs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% seeded land with No/zero tillage</td>
<td>CCS</td>
<td>2001 Census of Agriculture - Stats Canada</td>
<td>Less land under low till practices</td>
</tr>
<tr>
<td>% Farms with cropland having Grass Waterways</td>
<td>CCS</td>
<td>2001 Census of Agriculture - Stats Canada</td>
<td>Less % of farms with no buffers on land</td>
</tr>
<tr>
<td>% Farms with cropland having Windbreaks or shelterbelts</td>
<td>CCS</td>
<td>2001 Census of Agriculture - Stats Canada</td>
<td>Less % of farms with no buffers on land</td>
</tr>
<tr>
<td><strong>Water conservation policy in use</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industrial, commercial advice of water conservation</td>
<td>CSD</td>
<td>Municipal Water Use - Env. Canada (MUDD 2001)</td>
<td>No policy program in effect</td>
</tr>
</tbody>
</table>
3.5. Normalization

In order to make comparisons and combine datasets indicators were scaled to a common standardized or normalized scale, allowing indicators measuring different things and expressed in different units of measure to be compared. Each indicator dataset was normalized prior to aggregation, and again renormalized following aggregation. All of the indicators in each of the water resource stress themes are normalized based on the method in the UNDP’s Human Development Index (UNDP 2002). The HDI has been used in several studies of vulnerability (O’Brien et al. 2004). Following the HDI index, the value of each variable is normalized to the range of values in the dataset, based on a 0-100 scale by applying the following general formula:

\[
\text{Index value} = \frac{\text{actual value} - \text{minimum value}}{\text{maximum value} - \text{minimum value}} \times 100
\]

In this type of normalization, each value is relative to each other ranked on the 0-100 scale. By normalizing each indicator, any combination of indicators could be made. Standardized indicator scores can be assigned a weight, but most studies use equal weights. For the purposes of this study all indicators were weighted equally. A normalized composite index was calculated for each of the three sets of water resource stress themes: stresses of 1) water use, 2) water quality, and 3) water availability. Each theme’s set of indicators (Figure 3) was combined based on the associated boundary layer information for the dataset (i.e. CSD for the 2001 Agricultural data, CCS for the Municipal water data, etc. see Table 2 for details) to produce composite index scores for the theme. Each theme’s set of total scores was renormalized to a scale of 0-100 following the formula above. Therefore, each of the three water resource stress indices is the average value of its set of normalized indicators based on a 0-100 scale. For example, total normalized AU/km², percent CU, and human density were added and renormalized to determine a composite Water Quality stress score for each CCS in the PFRA watershed area. Depending on the theme, high index values indicate either high stress, such as total amount of land with fertilizer applied and total animal units per km² (i.e. more is bad), or low stress, such as total area of freshwater or total farms practicing various conservation practices (i.e. more is better). Each indicator was evaluated in this manner prior to aggregation, normalization, and calculation of composite indices. A final total composite index of water resource stress or vulnerability was calculated by combining all three theme indices and again renormalized to a scale of 0-100 for the final composite index. This normalized dataset identifies water stress “Hotspots”, or areas of greatest cumulative stresses, and therefore considered of highest concern.
3.6. Aggregation

As described, each individual indicator dataset was normalized prior to aggregation and again following aggregations of composite index scores. Normalizing allowed comparison and combinations between all indicators and themes. (Figures 5, 6). Composite index scores were calculated for each water stress theme by aggregating normalized indicator datasets and renormalizing the final total values. Themes of (A) water use stresses, (B) water quality stresses, and (C) water availability stresses, were aggregated following the aggregation framework in Figure 5 to create datasets of compounding water stress. All database calculations and aggregations were done in Microsoft Excel, including the normalization calculations. Final normalized datasets were exported as DBF files and linked to GIS boundary layers for display in ArcGIS. The three final composite indices were combined and renormalized to calculate a set of final variable scores. These identify “hotspots” or areas of highest cumulative stress (Figure 6).

An additional gap analysis overlaid the Agricultural Soil and Water Conservation Programs layer (D) on the “hotspots” map to determine whether our agricultural conservation practices are concentrated in areas where they are most needed (Figure 5, 6). The 25% highest stressed areas or hotspots were identified across the prairies. The areas of 25% most and least conservation practices were identified at a municipal level based on the 2001 Agricultural census data. Agricultural conservation practices were identified and limited to the 2001 Agricultural census data. This includes: percent of seeded land with No/zero tillage, percent of farms with cropland having Grass Waterways, and percent of farms with cropland having windbreaks or shelterbelts. This was followed by overlaying the Water Conservation Policy datalayer (E) to identify where policies may be in place in relation to high stressed areas (Figure 5, 6).

1. \((A + B)\) = water use stresses + water quality stresses
2. \((A + B) + C\) = (water use stresses + water quality stresses) + water availability stresses
3. \([A + B] + C \text{ } D = \text{ (water use stresses + water quality stresses) + water availability stresses} \text{ } D\) Agr soil and water conservation practices
4. \([A + B] + C \text{ } D + E = \text{ (water use stresses + water quality stresses) + water availability stresses} \text{ } D + E\) Agr soil and water conservation practices + Water conservation policies
5. \((2) + F\) = Possible Climate Change effects (Precipitation Variability)

**Figure 5.** Aggregation framework.
3.7. Thematic and Composite Maps

Thematic maps of individual water stress indicators, composite maps of water stress themes, and compounding stress maps were created to identify areas of highest stress and areas of highest compounding stresses of water quality, water use, and water availability (Figure 7). Each thematic map and composite map presented throughout the report was created based on a standardized 10 category rating convention. Ranks were classified following aggregation and normalization of datasets for mapping and presentation purposes (Bell et al. 2004). Classification of thematic maps was done using Jenks’ natural breaks as calculated in ESRI’s ArcGIS 9.3 GIS software. Natural Breaks is a common method for classification that creates classes through the groupings and patterns in the data. This type of classification can run into difficulty when used for comparison of different maps since each map’s classification scheme is based on its own dataset’s characteristics (Leichenko et al. 2004). However, since all aggregations and analysis was calculated prior to classification, this method was used simply to contrast and highlight highly stressed areas, and create maps for presentation of normalized datasets. For descriptive purposes, qualitative labels were substituted ranging from “negligible” to “very high” for maps of normalized data, while maps using actual data values included legends representing these values.
Figure 6. Combination of stress layers to produce maps of compounding stresses, the composite stress or “hotspots” map, conservation and policy overlays, and precipitation variability which indicates potential climate change impacts.

4. Mapping Results – Cumulative threats to prairie water resources

4.1. Thematic and Composite Maps

Composite maps of compounding Water Use stresses (Figure 7), Water Quality stresses (Figure 8), and/or Water Availability stresses (Figure 9) identify areas of greatest concern with regards to potential future water shortages or contamination problems to water resources. The Water Use stress map (Figure 7) identifies areas of high water demand within the south central and southern area of Alberta and the Red River valley of Manitoba, with some clustering of stresses in south central Manitoba as well. High water use stressed areas of Alberta are located around heavily populated areas with high livestock intensification, primarily cattle (Figure 12), and high rates of irrigation. Similarly with Manitoba, these are areas with high numbers of livestock, primarily pigs (Figure 12), and high human densities.

The Water Quality stress map (Figure 8) indicates areas of greatest concern, with the highest cumulative water contamination stresses, occur throughout a large portion of the prairie agro-
region. Most concentrated water quality stresses occur around heavily populated areas of south and central Alberta, the boreal plain fringes of Saskatchewan, and the entire south western and Red River valley region of Manitoba. Not all that surprising, since these are all areas of combined intense livestock operations (Figure 12), heavy uses of chemical applications to croplands, and the highest densities of human populations.

The Water Availability Stress map (Figure 9) identifies areas as expected within the drier Palliser triangle of southeast Alberta all the way to southeastern Saskatchewan, an area of traditionally high deficits of precipitation resulting from low annual precipitation and high potential evapotranspiration (Figure 10). Areas of high water availability stress are also identified in northeastern Alberta near the Fort McMurray oil sands area, as well as the Red River valley of Manitoba. The Red River valley is a region of dense clay soils that are low in available water holding capacity, with less waterbodies and wetland areas.

Combined water use stresses and water quality stresses are identified in Figure 11, again highlighting areas in south central Alberta, south central Saskatchewan, and the Red River valley of Manitoba. All of these regions have higher population densities, large livestock operations, and are areas of intense agriculture that experience heavy fertilization of agricultural fields.

The final Composite Water Resources Stress Map, or “Hotspots” Map, created from the combined stresses of all three water stress themes, again identifies highest stressed areas are concentrated around the heavily populated areas of south and central Alberta, the boreal plain fringes of Saskatchewan down to southeastern Saskatchewan, and the entire south western and Red River valley region of Manitoba (Figure 13). These areas experience the most cumulative stresses and could be the most prone to water shortages, water contamination, and future impacts from additional stresses.

4.2. Supplementary Analysis Maps

Agricultural Soil & Water Conservation Practices Overlay

Agricultural soil and water conservation practices were combined and normalized for the CCS boundary layer (Figure 14), and as would be expected are focused within the agricultural region of the prairie provinces. A water management gap analysis was accomplished by overlaying the CCS regions that had the most and least agricultural conservation practices in effect (as identified by the 2001 Agricultural Census data) over the areas with the 25% highest cumulative water stresses identified from the Water Resources Stress Map or “Hotspots” Map. This addresses the question whether active agricultural water and soil conservation practices such as grassed waterways, buffer zones, shelterbelts, and zero tillage (which help keep moisture in the soil and on the landscape while reducing erosion and runoff of sediment and contaminants into water ways), are being practiced where they are most needed. Overlaying of these data layers in ArcGIS shows that conservation practices may not necessarily be concentrated in areas of highest concern. Most notably the Red River Valley which is highly stressed, and portions of southern Alberta. Unfortunately, only a few of the surveyed conservation practices on the land are identified in the surveys, and so preliminary analysis is fairly incomplete. Wetland conservation and riparian buffer zone management, for example, while extremely important conservation
practices, were not included in the 2001 Agricultural Census. But an initial discussion with other managers indicates additional survey information might be found elsewhere and incorporated into future spatial water management analysis. Regardless, it clearly identifies that more effort must be taken into focusing water and soil conservation practices where they are most needed.

**Policy and Management**

Water conservation policies (as identified from the Municipal Water Use Data (MUD) 2001), were overlayed onto the Water Management Gap Analysis Map to identify whether water conservation policies are in place within areas of highest stress or concern. Based on the available policies, some areas of greater policy implementation do overlap with areas of highest concentration of water resource stresses and therefore the areas of greater concern. The high stressed areas of south central Alberta and Manitoba’s Red River valley do occur within Census Divisions (CD boundary level data) with more policies in place. Nevertheless, some areas of higher stress do have very few policies in place. Once again, this preliminary water conservation policy analysis is limited to survey data that was available, and any conclusions that could be made is limited. Nevertheless, it does once again suggest more effort is needed to focus water conservation policies within areas of high cumulative water stress. Additionally, more attention is needed to further identify where current water related policies do exist. Policies to promote water conservation, programs, research, and technology; recognition of management and conservation practices; education about our natural systems and their ability to store and filter water; and installing and providing water conserving equipment to residential and commercial.

**Climatic variability and Climate Change impacts**

Stresses on future water supply and consumption were assessed by calculating and constructing a coefficient of precipitation variability map from existing growing season precipitation maps (Figure 17), as well as a map of predicted average annual precipitation deficits in 2050 under climate change (Prairie Farm Rehabilitation Administration unpublished data).

The coefficient of variability map (Figure 17) identifies several areas of high precipitation variability in and around the Palliser triangle region of the southwestern prairies, central Saskatchewan, northern Manitoba, and north western Alberta. Rationale is that area of high variability could be more vulnerable to predicted variable climate conditions predicted under global climate change.

Not only could precipitation become much more variable and unpredictable in some areas, but average annual precipitation deficits (P-PE) predicted for 2050 under global climate change (Figure 18) highlight several areas already under high cumulative water resource stresses that could become even more prone to water shortages as a result of climate change associated supply or demand impacts. For example, higher precipitation deficits are predicted in a much greater area of south western Manitoba by 2050; areas that are already experiencing high cumulative water resource stresses. Although direct overlay and aggregation was not carried out with the cumulative stress maps, direct comparisons can be made between areas of cumulative water stress and the predicted impacts on precipitation in the presence of global climate change.
Figure 7. Water Use stress Map. Combined water use stresses across the Prairie region, including: percent of total cropland under irrigation, total human water use ($m^3/\text{year}$) per $\text{km}^2$, and total Livestock water use ($m^3/\text{year}$) per $\text{km}^2$. 

Figure 8. Water Quality Stress Map. Combined water quality stresses across the Prairie region, including: total livestock animal units per $\text{km}^2$, percent of total cropland with agricultural chemical units applied, and human population density (people per $\text{km}^2$).
Figure 9. Water Availability Stress Map. Combined water availability stresses across the Prairie region, including: Annual precipitation surplus/deficit (mm) (P-PE), Soil available water holding capacity (AWHC), and percent of total area that is fresh water.

Figure 10. Average Annual Precipitation Deficit (P-PE). Calculated from average annual Precipitation – Potential Evapotranspiration.
Figure 11. Composite stress map of Water Use and Water Quality.

Figure 12. Total livestock animal units per km².
Figure 13. Composite Water Resource Stress Map, or “Hotspots” Map.

Figure 14. Agricultural Soil and Water conservation practices map.
Figure 15. Water conservation Gap Analysis Map. The 25% highest stressed areas (red) or “Hotspots”, overlayed with the areas of 25% least (purple) and 25% most (green) conservation practices in place. Identifies whether conservation efforts are being applied where most needed.

Figure 16. Water conservation Gap Analysis Map identifying if conservation efforts are being applied where most needed, overlayed with Water Conservation Policy programs that are in effect within respective Census Divisions (CD). Identifies whether policies are in highly stressed areas. Legend indicates the number of policy programs in effect.
Figure 17. Precipitation variability map - Coefficients of variability calculated from average precipitation data (1960-2002).

Figure 18. Predicted Average Annual Precipitation Deficit (P-PE) in 2050 under global climate change (source data from PFRA, 2005).
5. Significance of the geographical water resource stress analysis

Cumulative mapping of water resource stresses clearly identified areas of high stress, and compounding stresses, across the prairie agro-region. Stresses are concentrating around regions of greater human populations, combined with large livestock operations and intense agriculture. Additionally, preliminary water management gap analysis and policy overlays with the water stress maps suggest that more effort must be taken into focusing water and soil conservation practices where they are most needed and further developing policies in highly stressed areas. It is important to note that the cumulative water resource stress maps created in this study do not show actual impacts and do not show areas of actual problems, but only identify the areas of cumulative stresses to water resources, using data that was obtained from the most recent available survey and spatial datasets. Areas of greatest concentrations of stresses are regarded as the areas with the greatest potential for water shortages due to high water demands, contamination to surrounding water resources, and reduced availability of water sources because of global climate change impacts.

While a composite dataset of normalized vulnerability index scores and accompanying cumulative stress and water stress “Hotspots” maps as a final output are a useful description and tool to identify the areas of potentially greatest water resource concern, this method of presentation does lose the original individual values in the data. For example, a composite vulnerability score of water quality in one area identified as highly stressed may be due to agriculture while the same score in another area may be due to excessive nutrient inputs from populated places. Composite scores and the accompanying maps in the report are unable to distinguish the different contributions of different variables. An example of this is clearly shown for the high water availability stressed areas along the mountain region of western Alberta (Figure 9). Although this area has high precipitation rates and a precipitation surplus (Figure 10), it scores as a highly water stressed area compared to other areas due to its low available water holding capacity and percent of water on the landscape. This is a result of the indicators used to calculate cumulative water availability stresses. Different factors will contribute to the vulnerability of an area or region, for instance livestock intensification, human use, industrial discharge, nutrient contamination, and irrigation rates, do not necessarily correlate with each other, but as these stresses compound in an area we assume that vulnerability is increased and compounded (Leichenko et al. 2004). Regardless, the primary objective of this study was to identify where the greatest cumulative water resource stresses occur within the prairie region, and therefore the areas of greatest concern with regards to water resources. Regions were also identified where soil and water conservation programs should be better promoted, as well as areas that may need to improve their water conservation policies. This preliminary management and policy analysis clearly illustrates that more focus needs to be made on highly stressed areas.

Regions of cumulative water resource stresses as identified in this study agrees with results obtained from a study conducted by Statistics Canada on the impacts of manure production across Canada (Statistics Canada 2004). The main objective of that study was to estimate and map the quantity of livestock manure produced in Canada, and the annual quantity of nitrogen, phosphorus, total coliform bacteria and fecal coliform bacteria found in livestock manure. To estimate these variables, 1996 Census of Agriculture livestock populations by enumeration area was multiplied by daily manure quantity coefficients derived from the 1997 American Society of Agricultural Engineers (ASAE) Manure Production and Characteristics Standard. Data was
aggregated to the sub-sub-basin watershed level, normalized by sub-sub-basin area, and then mapped (Statistics Canada 2004). Hotspots of Phosphorous (Figure 19) and Nitrogen contamination (Figure 20) in the south central Alberta plains, across south central Saskatchewan, and the Red River Valley of Manitoba were identified. This also lends support to the inputs of agricultural nutrient loads to the Red River and ultimately into Lake Winnipeg, Manitoba (Bourne et al. 2002, Lake Winnipeg Stewardship Board 2005, Lake Winnipeg Implementation Committee 2005).

**Figure 19.** Estimated Phosphorous production in livestock manure by sub-sub-basin, 1996. (Source: Statistics Canada 2004).

**Figure 20.** Estimated Nitrogen Production in Livestock Manure by sub-sub-basin, 1996. (Source: Statistics Canada 2004).
5.1. Local Issues: Red River valley and Lake Winnipeg

The high cumulative water quality stresses within Manitoba’s Red River valley region (Figure 8) corresponds to the high nutrient levels recorded from the Red River by Manitoba Conservation (Jones and Armstrong 2001, Bourne et al. 2002). The Red River is the largest source of nitrogen and phosphorous entering Lake Winnipeg, contributing almost 60% of the phosphorous entering the lake; 14% of which comes from agriculture and 11% from wastewater effluent from Manitoba sources (Figure 21) (Lake Winnipeg Stewardship Board 2005). High nutrient levels in the lake cause massive algal blooms to occur, which have serious health risks to humans and the lake fishery (Figure 22). The Red River and its watershed has been recognized as a serious source of nutrient loading to the lake (Lake Winnipeg Stewardship Board 2005, Lake Winnipeg Implementation Committee 2005). Regions surrounding the Red River are areas of high livestock intensification (i.e. hog operations), heavy fertilizer use, and a high precipitation deficit due to low precipitation rates and low available water holding capacity of the clay soils in the region. This translates to high levels of contamination from many nonpoint sources, that all eventually ends up in Lake Winnipeg.

Figure 21. Phosphorous loading to the Red River.
Source: Manitoba Water Stewardship

Figure 22. Algal bloom in Lake Winnipeg North Basin, source: McCullough (2001). Image is derived from AVHRR satellite imagery from September 26, 2001. Brown in the lake shows the chlorophyll (less phytoplankton) green in the lake indicates more chlorophyll (more phytoplankton).
Results of this current cumulative water resource stress analysis emphasizes concerns regarding the nutrification of Lake Winnipeg in Manitoba. Regions of high cumulative water quality stresses identified within this study (Figure 8) are almost completely contained within the large Lake Winnipeg watershed (Figure 23). The significance of this is that the results of high contamination stressed areas upstream all ends up downstream in Lake Winnipeg. This only emphasizes the concept that upstream management is critical for maintaining the health and quality of downstream water resources (Gabor et al. 2001, 2004). Watershed level management is critical to addressing the water quality problems facing Lake Winnipeg in Manitoba.

Figure 23. The Lake Winnipeg Watershed stretches across Alberta, Saskatchewan, and Manitoba, as well Ontario, and into the United States. Inset shows the cumulate Water Quality Stress Map from Figure 8 for comparison.
5.2. Application for other datasources and derived maps

The cumulative water stress maps from this study could provide a firm foundation for any future water stress mapping and analysis. Additionally, all spatial data and results of analysis can be readily applied to other derived maps, and accordingly datasets and derived maps can be applied to these maps as they would become available.

Analysis of Agricultural Water Supply Issues: National Summary

The National Water Supply Expansion Program (NWSEP) is an Agriculture and Agri-Food Canada (AAFC) investment in secure water supplies for agriculture (Agriculture and Agri-Food Canada 2003). The intent of the program is to improve the capacity of agricultural producers to deal with drought and other agriculturally related water supply constraints through the development and expansion of water supply systems on a cost-shared basis. Water supply constraints to agricultural production were evident in all provinces except Newfoundland/Labrador. The reports identified four main priorities for agricultural water supply expansion, including:

- Improved knowledge of our surface water and groundwater resources, specifically in terms of the available supply and the demand placed upon them by all sectors.
- Encouragement of more efficient use of available water.
- Improved planning and communication among all parties responsible for aspects of water supply development and withdrawal.
- Additional water supply and distribution infrastructure to support sustainability and growth of the agricultural sector.

http://www.agr.gc.ca/pfra/water/natsupply_e.htm

The first goal of the NWSEP program will improve the dataset available for water resource stress mapping, while the second will potentially build water policy and management where they are most needed. The last priority, however, with regards to additional water distribution to agriculture could increase the strain on already stressed water resources and should take into consideration highly stressed areas on the landscape.

Canada’s National Agri-Environmental Health Analysis and Reporting Program (NAHARP)

Canada’s National Agri-Environmental Health Analysis and Reporting Program (NAHARP) was formed to examine agricultural water concerns on the prairie provinces. Has an agriculture focus to it, but also focuses on general water and soil related stresses and impacts. Apparently they have already mapped N and P levels based on ecodistricts across the prairie provinces. This was accomplished by using census data, fertilizer sales data, and crop insurance data. Exactly what has been mapped and what is available still needs to be investigated and was not made available during this cumulative water stress analysis.

http://www.agr.gc.ca/env/naharp-pnarsa/
Water Contamination Sources – Non-Spatial data

Various nonspatial datasets that exist could be converted to spatial data and incorporated into the analysis. Particularly point sources of pollution that can be quite easily mapped spatially.

- **Pulp and Paper Industry**
  In 2000, the Canadian pulp and paper industry consisted of approximately 125 pulp and paper mills widely distributed across Canada. The pulp and paper process produces large volumes of waste effluent, with a typical mill (700 tonne/d capacity) generating approximately 90 to 130 million liters per day.

- **Petrochemical Industry**
  Onshore drilling for oil and gas – industrial waste discharges into Canadian waterways.

- **Mining**
  There are approximately 900 mining sites across Canada where base metals, gold, potash, coal, and iron ore have been or are being extracted (AETE 1995). Although many of these sites are presently closed or abandoned, the number of operating mines in Canada ranges between 100 and 170. Most facilities are adjacent to freshwater systems in remote areas away from other industrial and urban developments. Most wastewaters are discharged into waterways.

  *Source: Threats to Sources of Drinking Water and Aquatic Ecosystem Health in Canada (Environment Canada. 2001).*

Climatic variability

Analyzing long term climate trends and changes that would affect water supply and availability on the prairies can help identify potential future pollution sources and stresses on water supply and consumption.

- Flood maps and flood history give indication of climatic variability
- Historical water levels in lakes, such as Lakes Manitoba and Winnipeg, are a surrogate for historical changes in water variability and supply
- Period of thaw and spring runoff could be compared to fertilizer and manure applications, general agricultural conservation practices, drainage, wetlands, etc.
- Heavy rain events during times of agricultural fertilization, manure applications can also lead to ground water and watershed contamination.

Watershed boundaries

Watershed boundaries are available at different basin levels for the prairie watershed region, defined as the effective drainage area of the prairies, as defined by the Prairie Farm Rehabilitation Administration (PFRA) Watershed Project (Prairie Farm Rehabilitation Administration 2005). The Watershed Project is a long-term PFRA undertaking that has entailed the creation and maintenance of a drainage area database (based on hydrometric gauging stations) for the Canadian Prairies. It consists of hydrometric gauging stations and watershed boundaries,
tabulated gross and effective drainage areas, and digital products generated for use in hydrological mapping and analysis. The GIS database is the authoritative source for the gross and effective drainage areas in the Prairie Provinces. It is composed of more than a dozen derivative output products that are available over the internet at [http://www.agr.gc.ca/pfra/main_e.htm](http://www.agr.gc.ca/pfra/main_e.htm).

The cumulative stress maps from this study can be readily applied at the watershed level to aid in watershed planning (Figure 24). More specifically in Manitoba where the current Conservation District program is currently considering moving to a watershed boundary rather than a political municipal boundary, which has been the case since the creation of the CD program.

![Cumulative stress maps](image)

**Figure 24.** Cumulative water use and water quality stresses across the prairie watershed region. Watershed boundary overlay is the Environment Canada 4-Character Sub-basins as defined by the PFRA Watershed Project (Prairie Farm Rehabilitation Administration 2005).

### 6. Conclusions and Recommendations

By calculating a composite normalized index and mapping where water resource stresses compound, regions were identified that may require greater and more immediate attention for policy and water resource management. Cumulative mapping of water resource stresses clearly identified areas of high stress and combined to produce cumulative stress “hotspots” or areas of concern across the prairie agro-region. GIS datasets include indicators of water use demands, water quality stresses, and water availability stresses. Rationale for mapping cumulative stresses is that the areas with the highest concentration of water resource stresses are regarded as the most
vulnerable, and have the greatest potential for water shortages due to high water demands, contamination to surrounding water resources, and reduced availability of water sources.

Regions of greatest cumulative water resource stresses, as identified in this analysis, appear throughout the prairie agro-region, most concentrated around the heavily populated areas of south central Alberta, the boreal plain fringes of Saskatchewan, and the entire Red River valley of Manitoba. Cumulative stresses are concentrated around regions of greater human populations, combined with large livestock operations and intense agriculture, as well as areas with agriculture and industry. Preliminary water management gap analysis and policy overlays with the cumulative water stress maps suggest existing agricultural soil and water conservation practices and local municipal level government policies may not be focused where they are most needed.

Additional stresses on water supply and consumption from climate variability and possible future climate change impacts are evident. Precipitation variability and climate change predictions highlight several areas that are already under cumulative water resource stress, which could be even more prone to reduced water availability and water shortages because of supply or demand impacts associated with climate change. Although direct overlay and aggregation was not carried out with the cumulative stress maps, direct comparisons can be made between areas of cumulative water stress and the predicted impacts on precipitation in the presence of global climate change.

It is important to note that the cumulative water resource stress maps created in this study do not show actual impacts and do not show areas of actual problems, but only identify the areas of cumulative stresses to water resources, using data that was obtained from the most recent available survey and spatial datasets. Nonetheless, the cumulative water stress maps created in this study provide a firm foundation for any future water stress mapping analysis. This was only a preliminary look at cumulative water resource stresses and there is potential to apply further existing spatial data layers and data bases, as well as other datasets and derived maps as they become available, for further analysis. Additionally, the spatial data and results of this study can be readily applied to future studies.

Additional data from the datasets used in this analysis could also be used for additional analysis and cumulative mapping. For example, the current water survey data also includes information on the percent of residents using private well systems as well as private sewer systems, the total amount of water coming from surface and ground water sources, and the percent of populations with no water treatment as well as no sewage treatment. This information can be combined with the Water Resource stress maps to improve local policies and promotion of management and conservation programs.

Based on the maps developed in this study, recommendations can be made for improvements to soil and water conservation programs and to promote better management and policy where they are most needed. Regions can also be identified that are already under water resource stress, which could be more prone to further stress in the presence of global climate change.
7. Literature Cited


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http://sis.agr.gc.ca/cansis/nsdb/ecostrat/gis_data.html


http://adaptation.nrcan.gc.ca/perspective_e.asp


http://www.esri.com/software/arcgis/about/desktop.html


8. WEB RESOURCES

Canadian Geospatial Data Infrastructure (CGDI): GeoConnections.  
http://www.geoconnections.org/CGDI.cfm/fuseaction/aboutGcs.welcome/gcs.cfm

GeoConnections Discovery portal  
http://geodiscover.cgdi.ca/gdp/index.jsp?language=en

GeoGratis. Natural Resources Canada  
http://geogratis.cgdi.gc.ca/clf/en

National Scale Framworks 1:1 maps:  

GeoGratis - National Scale Frameworks can access  

GeoBase collections of data:  
http://geobase.ca/geobase/en/

Atlas of Canada basemaps:  
http://geogratis.cgdi.gc.ca/clf/en?action=entrySummary&entryId=138&entryType=productCollection&keymap=outlineCanada

North American atlas base maps:  

Natural Resources Canada listing of data products and download location on the internet.  
Includes Base Maps of Canada, ecosystem maps, Canada 3D DEMs  
http://ess.nrcan.gc.ca/prod_e.php?c=pt_map_e
Appendix 1 - Other potential derived maps, data layers, and data sources

Mapping of large livestock operations

Source: Canadian Agriculture at a Glance. Statistics Canada (Beaulieu 1996).

Risk of soil salinization on cropland in the Prairie Provinces in 1996

Proposed National Groundwater Inventory

Proposed by the federal government. In the next five to ten years at least ten recognized regional aquifers will have been mapped. Source: *Water and the future of life on Earth – proceedings from a workshop.* (Gallaugher and Wood 2002).

Nutrient Monitoring – long-term stream water quality stations in Manitoba

Estimates of total nitrogen and total phosphorus loading to streams in Manitoba (Bourne et al. 2002).
**Threats to Canada’s Ecosystems**

**Industrial discharge sites**
Industrial activities generate waste that is discharged into water bodies, the air or ends up in landfill sites. Air is the most common release medium. Ammonia, methanol, sulfur dioxide, and nitrogen dioxide are by far the most common industrial pollutants released in Canada. Industrial discharge sites are concentrated in southern Ontario and Quebec, and around major cities in British Columbia and the Prairies (Natural Resources Canada 2004).

*Source: The Atlas of Canada. Natural Resources Canada*

**Number of industrial discharge sites**

<table>
<thead>
<tr>
<th>Number of Sites</th>
<th>Percentage</th>
</tr>
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<tr>
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<td>1 - 10</td>
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<tr>
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<tr>
<td>121 - 295</td>
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</table>

**Future climate change predictions**
Future climate change predictions can be readily applied to the analysis.

*Source: Climate Change Impacts on Prairies Region. C-CIARN Prairies (Sauchyn 2005).*