THE Prairie Climate Resilience PROJECT

Indicators of Adaptive Capacity to Climate Change for Agriculture in the Prairie Region of Canada

An analysis based on Statistics Canada's Census of Agriculture

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Executive Summary

In 2003, the Canadian Senate Committee on Agriculture and Forestry published a report entitled, *Climate Change: We Are at Risk*, concluding that Canadian agriculture will be affected by climate change and noting that more frequent and widespread drought on the Prairies is expected.

The twentieth century has been punctuated by at least eight droughts lasting from one to three years. And recent analysis of the 2001–2002 drought indicates losses of CDN$3.6 billion in agricultural productivity and $5.8 billion in gross domestic product with a loss of 41,000 jobs in the Canadian agricultural sector (Wheaton *et al.,* 2005). With the Prairie region being home to 80 per cent of all farms and total farm area in Canada, and acknowledging that the Prairie agricultural region is historically a drought-sensitive area, the adaptive capacity of Prairie agriculture to future climate variability and longer-term change is of fundamental importance to the Prairie Provinces and to Canada.

The Prairie Climate Resilience Project, a collaborative project of the International Institute for Sustainable Development (IISD), the Prairie Farm Rehabilitation Administration (PFRA) and the University of Manitoba, is motivated by the above historic and present accounts. The hypothesis for this research project is that rural agro-ecosystems with high exposure to historic climatic change differ in their vulnerability and resilience. By developing a method to identify these areas, we can investigate those characteristics associated with successful adaptive capacity.

This paper outlines the development and analysis of a geographic information system (GIS)-based indicator of the adaptive capacity to climate change of agriculturally-based communities in the Prairie region. A valuable array of existing socio-economic and environmental data is leveraged to:

- advance our understanding of the vulnerability and adaptive capacity of Prairie agriculture to climate variability and longer-term change;
- guide the selection of sites for farm-level study of successful adaptive behaviours;
- identify the types of policy interventions that support farm- and community-level adaptation to climate variability and change; and
- help identify Prairie locations that are most vulnerable to climate variability and change.

Twenty indicators representative of adaptive capacity were derived for Census Divisions across the Prairies from Statistics Canada sources, most notably the 2001 Census of Agriculture from which 17 of the indicators were derived. The indicators were organized into six determinants (based on Smit *et al.*, 2001), namely: (1) economic resources; (2) technology; (3) infrastructure; (4) information, skills and management; (5) institutions and networks; and (6) equity. Comparison of adaptive capacity across Census Divisions required that scores for each indicator be normalized, aggregated to a determinant value and then aggregated into an overall index of adaptive capacity for each of the 53 Census Divisions.

As illustrated in Figure ES-1, Census Divisions exhibiting the highest adaptive capacity were clustered near large urban centres in three main corridors. From east to west, these areas were: Winnipeg extending west to Brandon and south to the United States border; Saskatoon extending south in a band from the Saskatchewan-Alberta border to Regina; and Calgary extending southeast to the United States border. Census Divisions exhibiting the lowest adaptive capacity were typically along the northern boundaries of the Prairie agricultural region.

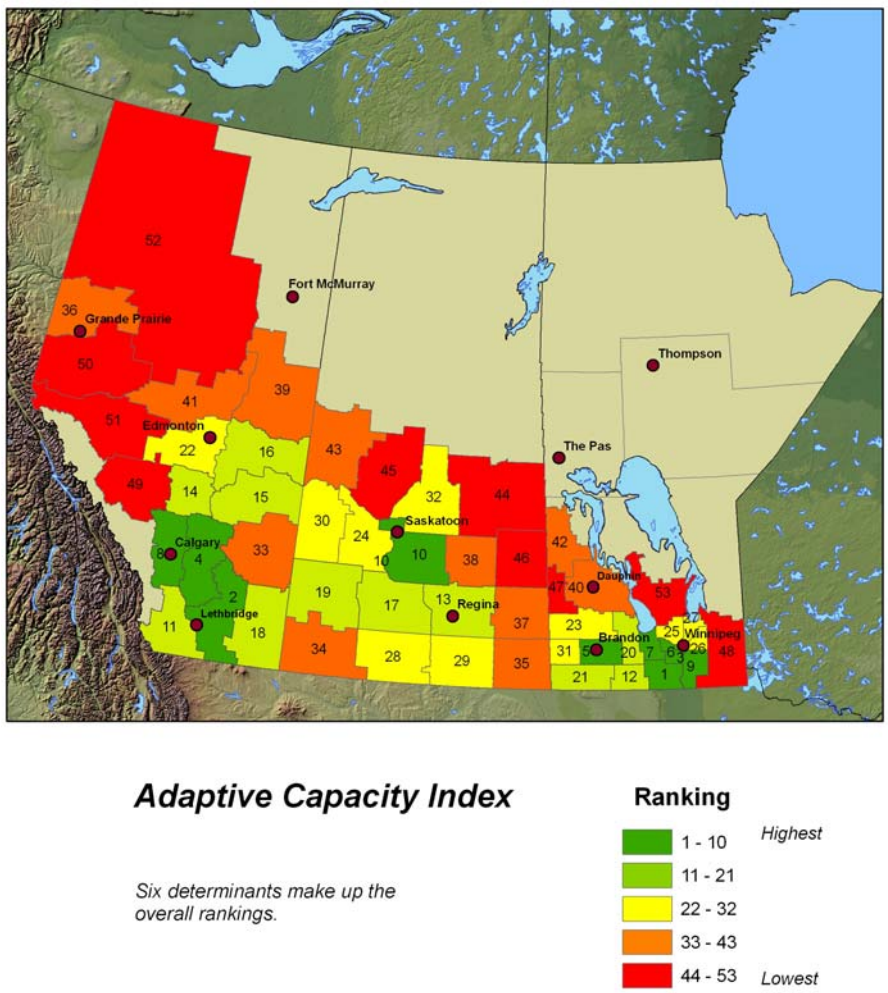

Figure ES-1. Ranking of adaptive capacity using aggregate indicators for Census Divisions in the Prairie agricultural region.

Census Divisions exhibiting higher rankings were associated with the following: proximity to major urban centres; higher off-farm earnings; greater diversity of employment opportunities; greater use of computer technology; more use of computers in farm management; a higher density of transportation networks; more e-mail and use of the World Wide Web; and closer proximity to agricultural education institutions. Census Divisions along the northern extent of agriculture ranked much lower on these indicators of adaptive capacity.

In the near term, these results have positive implications for agriculture in the Prairie region; in particular the Census Divisions exhibiting lower capacity lie north of areas historically stressed by drought. However, global climate model projections indicate that over the longer term, moisture deficits in the central Prairies could increase in magnitude and extend to regions further north—to those regions that currently exhibit lower adaptive capacity.

Ongoing farm- and community-level surveys to study adaptive behaviours will help assess how important the indicators are to understanding adaptive capacity on the ground. The primary contribution of this desk study to policy development is the application of a methodology for using existing statistical data to quantify spatial differences in overall adaptive capacity, as well as bringing attention to specific aspects of adaptive capacity.

In terms of policy guidance, this spatial analysis of adaptive capacity based on existing census data suggests the following:

- To build the adaptive capacity of remote rural areas, attention should be paid to policy interventions that contribute positively to indicators of adaptive capacity not highly correlated with proximity to urban centres. These indicators include:
    - ensuring agricultural commodity prices are sufficient to maintain adequate farm incomes;
    - ensuring access to irrigation and associated equipment;
    - promoting sustainable soil management practices;
    - discouraging farming on marginal land; and
    - investment in farm machinery and equipment versatile enough to adjust production decisions to variable climatic conditions.
- Other policy interventions to increase the adaptive capacity of producers, regardless of proximity to urban corridors, could include:
    - more opportunities to increase off-farm earnings;
    - enhanced employment prospects through diversification within the agricultural and agri-food sector as well as in other sectors of the economy;
    - improved access to and use of computer technology in general and, in particular, for farm management;
    - increased density of transportation networks;
    - improved use of e-mail and the World Wide Web to keep abreast of climate trends and innovative farming practices; and
    - greater access to agricultural education institutions.

Policy interventions such as those described above are best focused on the most vulnerable areas—that is, those areas with the greatest exposure to climate shocks/stresses and having the lowest adaptive capacity. These areas of greatest exposure can be anticipated using a combination of historic record and projections of future climate variability from global and regional climate models. But the future is inherently unknowable. Therefore, it will be important for policy-makers to continually monitor trends in climate and hydrologic parameters that signal climate shocks and stresses (e.g., temperature, precipitation, evapo-transpiration and soil moisture) and trends in those determinants most important in building the capacity of farm families and communities to adapt to climate change in an area.

Significant data gaps were documented that prevented us from understanding certain determinants of adaptive capacity. Shortcomings were documented in equity (as measured by the distribution of wealth within Census Divisions); infrastructure (as measured by the extent of surface and groundwater resources); and institutions and networks (as measured by social capital). Improvement in data availability for these aspects would be beneficial for future studies of adaptive capacity.

In addition to this study of adaptive capacity, the Prairie Climate Resilience Project is undertaking farm-level studies to better understand the actual actions farm families have taken to adapt to past climate shocks and stresses. Additionally, the project is mapping areas of acute historic climate variability on the Prairies. Through these integrative efforts, we endeavour to help farm families and policy-makers better understand which areas in the Prairie region are most vulnerable to climate variability and which aspects of adaptive capacity are most important for building resilience to a future certain to be full of surprise, change and uncertainty.

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1.0 Introduction

In 2003, the Canadian Senate Committee on Agriculture and Forestry published a report entitled *Climate Change: We Are at Risk*, concluding that Canadian agriculture will be affected by climate change, and noting that more frequent and widespread drought on the Prairies is expected. Schindler and Donahue (2006) warned of an impending water crisis in Canada's western Prairie Provinces. They stated that "in the near future climate warming, via its effects on glaciers, snowpacks, and evaporation, will combine with cyclic drought and rapidly increasing human activity in the western Prairie Provinces to cause a crisis in water quantity and quality with far-reaching implications." This is a troubling scenario for the future of Canada given that the Prairies are home to 80 per cent of the farms in Canada (AAFC, 2005) and produce almost half of the total value of Canadian agri-food exports (AAFC, 2006).

A consistent theme in the vulnerability and adaptation literature, both in Canada and internationally, is that our current knowledge of the nature of adaptive capacity is insufficient to reliably predict adaptation responses or devise appropriate government policy frameworks (Smit *et al.*, 2001). Furthermore, implementing successful adaptation policies will require a better understanding of the potential options, existing farm-level risk-management practices and government decision-making frameworks (Smit and Skinner, 2002).

The Prairie Climate Resilience Project, a collaborative initiative of the International Institute for Sustainable Development (IISD), Prairie Farm Rehabilitation Administration (PFRA) and the University of Manitoba, endeavours to help address this policy gap. The hypothesis for this research is that rural agro-ecosystems with high exposure to historic climatic stress differ in their vulnerability and resilience, and by investigating these differences we can learn valuable lessons about the nature of adaptive capacity.

This paper outlines the development and analysis of a geographic information system (GIS)-based indicator of adaptive capacity of agriculturally based communities to climate change on the Prairies. A valuable array of existing socio-economic and environmental information available across the Prairies is leveraged to advance:

- understanding of the vulnerability of Prairie agriculture to climate change;
- a systematic approach to direct further research to locations where farm- and community-level adaptation has met with success or failure;
- knowledge of key factors that have affected the adaptive capacity of farms and communities at these locations; and
- development of public policies that vary with the particular suite of key factors in a given area of the Prairie region so as to increase the adaptive capacity and reduce the vulnerability of farms and communities to climatic variability.

1.1 Socio-economic and ecologic context

The Prairie region stretches across 550,000 square kilometres, spanning the provinces of Manitoba, Saskatchewan and Alberta. Prairie agriculture takes place in a physiographic region known as the Western Interior Basin that includes the northern portion of the Great

Plains "ecozone," essentially the northern geographic limit of arable land in North America (see Figure 1-1).

Within the last millennium, there were two broad climate phases: the Medieval Warm Period, ending around the twelfth century, followed by the Little Ice Age.[1] The paleo-climatic record for the past 1,000 years indicates that periodic and severe drought episodes are common and that drought conditions prior to Euro-Canadian settlement far exceed anything experienced in the last century (Sauchyn and Beaudoin, 1998). The most severe drought of the past 500 years is thought to have occurred between approximately 1791 and 1800 (Harrington *et al.*, 1997). Historically, drought has been found to occur every 30 to 50 years, a pattern repeated in the twentieth century. The potential for greater climatic variability is very high based on historical records and scenarios of future conditions. Taken separately or together, a naturally dryer cycle with greater variability in precipitation produced via climate change leaves agricultural production on the Prairies in an extremely vulnerable position. It may be that future growing conditions will be unlike any that modern farming has yet experienced.

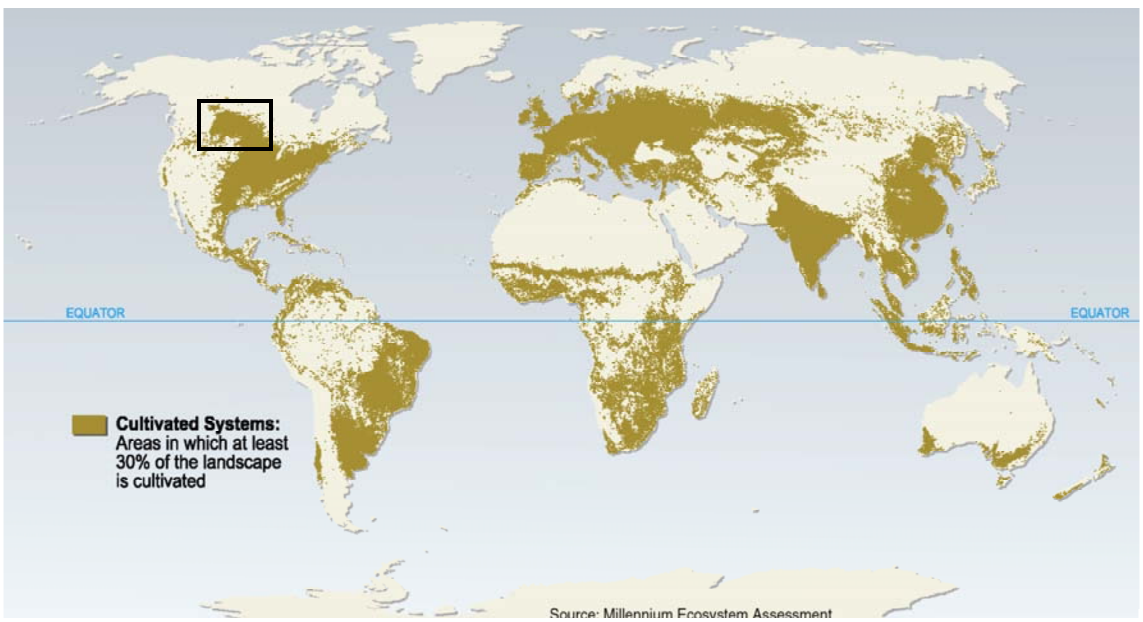


Figure 1-1. The Prairie agricultural zone of Canada in the international context (Reid et al., 2005).

Based upon the period of instrumental record-keeping, the available growing degree-days[2] average about 1,700–1,800 in Manitoba, with Saskatchewan and Alberta receiving on average 100–300 fewer days. Annual precipitation during the period of instrumental record has

[1] A cold period that lasted from about AD 1550 to about AD 1850 in Europe, North America and Asia. This period was marked by rapid expansion of mountain glaciers, especially in the Alps, Norway, Ireland and Alaska. There were three maxima, beginning about 1650, about 1770 and 1850, each separated by a slight warming interval.

[2] Growing degree-days (GDDs) are determined as follows: "heat accumulated each day is determined by adding together the maximum and minimum temperatures and dividing the total by two to obtain a daily average" (Manitoba Agriculture, Food and Rural Initiatives: www.gov.mb.ca/agriculture/climate/waa01s01.html)

ranged from 400 to 600 mm for Manitoba, whereas Saskatchewan (300–500 mm) and Alberta (300–500 mm) tend to receive slightly less rainfall. Most of the precipitation falls during the growing season and typically during the month of June when field crops can best use the moisture for the early stages of plant development. Moisture deficits, however, tend to exist in most agricultural regions, ranging between 150 and 250 mm, and are particularly high in the central and southern parts of the region.

The soils of the interior plains reflect development under different vegetative cover, indicative of long-term cycles of wet and dry conditions over the past 10 thousand years. They are divided into the black, dark brown and brown soil zones (Watts, 1967). Zonal differences are attributable to long-term differences in soil-forming factors, with blacker soils showing higher organic matter levels derived from development under cooler, moister conditions and occasional forest cover. Dark brown soils are found in transition to the brown soils of southern Saskatchewan and Alberta, the latter having formed under short grasses indicative of hotter, dryer conditions. The soils are generally quite fertile for annual and perennial crops, subject to available heat and moisture in a growing season.

The earliest scientific assessment of the Prairie region challenged the notion of viable agriculture in the area. From 1857 to 1860, Captain John Palliser led a group of scientists into what was then the virtually unknown (to Europeans) territory lying west of what is now Manitoba. Palliser's group, known as the British North American Exploring Expedition, was charged by the government of the day with exploring, studying and mapping the plains between the North Saskatchewan River and the American border (see Figure 1-2). They identified a triangular region roughly bounded by the lines adjoining Cartwright, Manitoba; Lloydminster, Saskatchewan; and Calgary, Alberta. This area has become known as the Palliser Triangle, an arid region unsuitable for settled cultivation. Palliser warned that disaster would befall those who tried to settle the region. A subsequent Prairie expedition by Henry Youle Hind in 1858–1859 had a more modest geographic scope and reached different conclusions from those of Palliser.

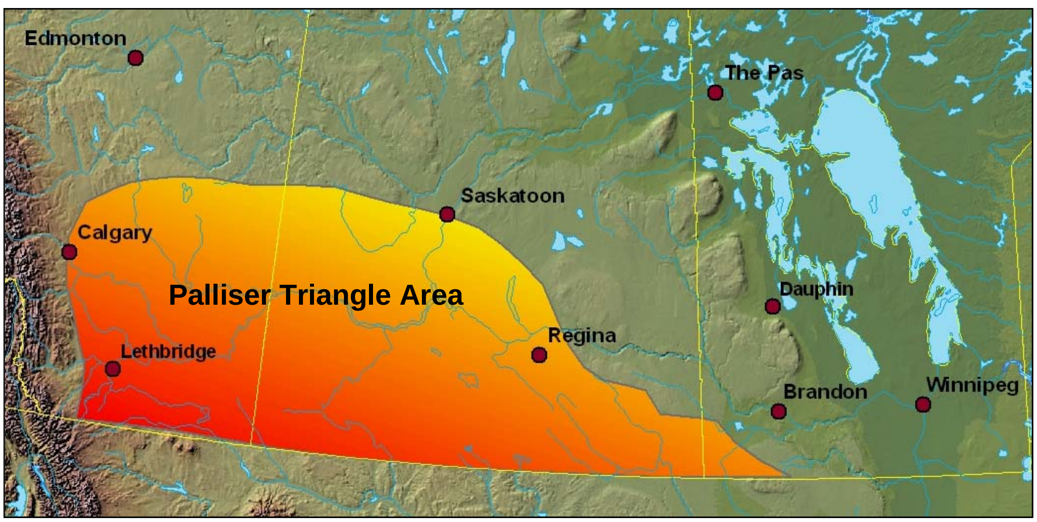


Figure 1-2. The Palliser Triangle within the Prairie agricultural region (from Spry, 1968, in Lemmen et al., 1997).

Government policy followed Hind's recommendations and the early settlement of the Prairies coincided with an unusual sustained run of moist years from the late 1890s to the early 1900s. In fact, 12 years of average or above-average precipitation were recorded during that period of settlement. Enhanced soil moisture reserves and other favourable conditions in the growing season (i.e., frost-free days, etc.) produced good crop yields with bumper harvests in 1905 and 1915. These early successes encouraged further agricultural expansion and population increases. Despite the initial promise of prosperous farming, the twentieth century has been punctuated by frequent and prolonged drought, such as those in 1906, 1936–38, 1961, 1976–77, 1980, 1984–85, 1988 and 2001–2003 (Godwin, 1986; Gan, 2000; Wheaton *et al.*, 2005).

The combination of fertile soils and—on average—adequate precipitation, have generally been favourable to agricultural production since the original settlement. The region is home to approximately 170,000 farm operators (Statistics Canada, 2001), representing 80 per cent of all farms and total farm area in Canada. Red meats, grains and oilseeds typically account for over 80 per cent of market receipts (Statistics Canada, 2001).

Although grain production has historically been associated with agriculture in the Prairie region and continues to account for the majority of production by total area, in recent years the portfolio of commodities produced on the Prairies has diversified. Farmers now produce the traditional range of crops and livestock along with specialty crops such as mustard seed, dry peas and lentils, and less conventional types of livestock including bison and elk. In addition, irrigation systems are now extensive in the southern part of the Prairie region with 630,000 hectares currently irrigated (PFRA, 2000), almost 500,000 hectares of which are in southern Alberta, where agriculture produces a wide variety of cash and feed crops including grains, oilseeds, pulses and forages as well as corn, sugar beets and vegetables.

Prairie agricultural producers have gained considerable experience in adapting their production systems in the face of climatic variability in the past 100 years. Recent challenges to the Prairie socio-ecological systems have included stagnant commodity prices, input price shocks (particularly energy and commercially produced fertilizer), loss of market access and income due to closure of the American border to beef exports, declining access to health and education services in rural areas, an increasing income gap between urban and rural residents, and large annual variations in the quantity and quality of available surface water. The latter point merits examination as it demonstrates the inherently challenging setting for agriculture in the region.

Measures of precipitation variability provide an indication of the inherent risk of drought in the Prairie region. Precipitation is the major factor controlling the onset and duration of drought. Inter-annual variability of precipitation and, to a lesser extent, temperature, determines the frequency and intensity of drought. Precipitation variability can be a useful indicator of the extent to which an area is prone to drought, with the coefficient of variation (the ratio of the standard deviation to the mean) being the most stable measure of precipitation variability (Longley, 1952 in Maybank *et al.*, 1995). Furthermore, a consensus opinion of the Intergovermental Panel on Climate Change is that increased climate variability is a very likely short-term manifestation of climate change (IPCC, 2001). For example, precipitation variability in the Palliser Triangle of the Prairie region is currently in the order of 30–40 per cent. How to manage this already highly variable climate becomes the critical policy challenge in the face of climate change not just in the Prairie region but elsewhere in the world experiencing similar conditions.

In a special issue of *IDS Bulletin on Climate Change and Development*, Ian Scoones (2004) emphasizes the historical disconnect between the biophysical reality of fragile agro-ecosystems and the techniques and policies intended to manage them. Scoones focuses specifically on the pastoral rangelands of Africa. He describes these as regions "where systems are not at equilibrium, where sometimes chaotic, often stochastic, dynamics prevail and where predictability and control are false hopes." Regions where equilibrium conditions do not apply are described by Ellis (1998) as existing in very large swaths of Africa, where the coefficient of variation of rainfall is more than 30 per cent.

Scoones (2004) recognized that if increased climatic variability becomes more evident—creating non-equilibrium conditions such as is currently the situation in the pastoral dryland regions of Africa—then "we must shed our blinkered equilibrium views and solutions and search for alternatives that allow for living with uncertainty." We argue here that Scoones' insights also resonate on the Canadian Prairies. First, although the underlying social and economic conditions in the rangelands of Africa and the Canadian Prairies differ greatly, the ecological conditions, particularly precipitation variability, exert a comparable influence on decisions related to agricultural production. A history of the key federal agency charged with soil and water conservation on the Canadian Prairies is simply entitled *Men Against the Desert* (Gray, 1967). Second, the longer paleo-climatic record also reveals high variability.

The history of Prairie agriculture shows a mixed record with regard to adaptation to climate variability. Successful adaptations since European settlement include the development of drought- and frost-tolerant crops, soil conservation techniques and long-term crop rotations. Whether these adaptations are sufficient under conditions of increased climate variability (due to a return to paleo-climatic norms or driven by climate change) is an open and pressing policy question. Targeted policies to increase coping capacity may be required. The dust-bowl years of the Great Depression provide a classic example of maladaptation; the response to the onset of drought was a continued reliance on monoculture wheat production and land management that left soil extremely vulnerable to erosion. The 1930s drought affected 7.3 million acres and forced the distress migration of a quarter of a million people (Goodwin, 1986).

This mass exodus did catalyze major institutional responses from the Government of Canada—that being the formation of the Prairie Farm Rehabilitation Administration (PFRA) and the Canadian Wheat Board (CWB). PFRA was established through an act of Parliament to assist Prairie farmers recover ecological resilience that had been lost through inappropriate land-management practices that left the Prairies extremely vulnerable to the wind and water erosion during the extreme droughts of the 1930s. The CWB was also established by an act of Parliament to buffer Prairie farmers from extreme fluctuations in international commodity prices by aggregating and marketing all Prairie wheat and barley production for single desk selling to global markets.

The economic impacts of subsequent droughts have largely been absorbed by a much larger, more diverse national economy with less direct dependence on agriculture.[3] The 1984–85 drought affected most of the southern Prairies and cost Canada at least a billion dollars of GDP (Ripley, 1988). In the severe drought year of 1988, agricultural export losses topped $4 billion. Despite assistance payments of over $1.3 billion, Manitoba showed net farm income losses of 50 per cent and Saskatchewan 78 per cent, and an estimated 10 per cent of farmers and farm workers left the agricultural sector that year alone (Arthur and Chorney, 1989; Harrington *et al.*, 1997). Even in 1991, a year of record-high wheat production, emergency payments (i.e., above regular assistance and insurance programs) were still in excess of $700 million (Sauchyn and Beaudoin, 1998). Recent analysis of the 2001–2002 drought (Wheaton *et al.*, 2005) indicates losses of $3.6 billion and $5.8 billion in agricultural productivity and gross domestic product respectively and manifest as the loss of 41,000 jobs in the agricultural sector.

The prospect of more frequent and severe droughts afflicting the entire Prairie region, further compounding a multitude of economic, social and physical shocks and stressors noted previously, underscores the urgency of addressing our limited knowledge on adaptive capacity and its potential contributions to policy development.

1.2 Navigating this report

The next section of the report (Section 2) presents the relevant theoretical and conceptual background necessary for understanding vulnerability and adaptive capacity. Section 3 outlines the analytical framework and approach used to develop the adaptive capacity indicators, including the six individual determinants of adaptive capacity and the overall aggregated adaptive capacity index. Section 4 presents the results of the adaptive-capacity analysis for each of the Census Divisions across the Prairie agricultural region, first, examining the individual determinants of adaptive capacity and, second, examining Census Divisions exhibiting the highest and lowest adaptive capacity across the Prairies. Finally in Section 5 we discuss these results in terms of the underlying characteristics of the data and in Section 6 we highlight the policy implications of our research.

2.0 Vulnerability and Adaptive Capacity: Theoretical and conceptual background

The *vulnerability* of a socio-economic and environmental system to climate change is conceptualized as a function of a system's *exposure* to climate change effects and its *adaptive capacity* to deal with those effects. The more exposed a system is to a particular climate stimulus, the greater the system vulnerability; conversely, the greater the adaptive capacity of the system to a given climate event, the lower its vulnerability. Smit and Pilifosova (2003) express this relationship formally as:

[3] In 1999 about two per cent of Canada's GDP was derived directly from agriculture, www.wd.gc.ca/rpts/audit/wdp/3_e.asp.

$$V_{it}^{s} = f(E_{it}^{s}, A_{it}^{s}) \quad (1)$$

Where

V_{it}^{s} = vulnerability of system i to climate stimulus s in time t

E_{it}^{s} = exposure of system i to stimulus s in time t

A_{it}^{s} = adaptive capacity of system i to deal with stimulus s in time t

The emergence of the vulnerabilities approach coincides with the realization that experiences and lessons learned building resilience to existing climate stresses are important pre-requisites for future adaptation (Red Cross, 2002; ISDR, 2002). Regions with high historic climatic variability can be particularly important examples of adaptive capacity and climate resilience (or lack thereof). Polsky and Easterly (2001), for example, studied agricultural adaptation to climate variability in the U.S. Great Plains using a Ricardian approach that included an index of historic climatic variability. They concluded that farmers and institutions in districts with high historic climate variability had adapted and were more resilient to climate variability, but that the underlying reasons and sustainability of these adaptations were unclear, varied spatially and needed to be investigated with field-level study of individual farms, farmers and the institutions affecting agriculture.

The Prairie Climate Resilience Project uses both climate exposure and adaptive capacity metrics in the construction of a conceptual understanding of regions that are climatically stressed and have a range of adaptive capacity. Further, using a variant of the "double exposure framework" proposed by O'Brien and Leichenko (2001) and applied in India by O'Brien *et al.* (2003), locations within a region will be selected to study adaptive capacity through targeted stakeholder narratives (on-farm and off-farm). This approach will help document why some regions are resilient to climate stress and some not. From this understanding, the project will consider those policies and practices found in these regions that are critical for building resilience.

For the Prairie Climate Resilience Project, a GIS-based climate-exposure indicator, E, is being developed using a weighted metric of inter-annual and intra-annual precipitation and temperature variability for the 1961–1990 period. Precipitation and temperature are the most fundamental determinants of climate stress on the Prairies; the underlying data is maintained by PFRA and is used to continuously monitor drought conditions on the Prairies and to generate the Drought Watch maps available on the PFRA Web site.[4] The output at this analytical stage will be GIS-based maps that will identify areas with historically high climate stress in the Prairie region.

In terms of the Prairie Climate Resilience Project's approach to adaptive capacity, we believe it to be based on diverse endowments including technology, knowledge, wealth and socio-ecological attributes (Bohle *et al.*, 1994). A number of research studies for indicators of adaptive capacity (related to climate change and other stressors) have attempted to provide a conceptual framework and operational method to measure adaptive capacity. Smit *et al.* (2001) identified six determinants of adaptive capacity in the context of climate change as a

[4] www.agr.gc.ca/pfra/drought/prgrowing_e.htm.

contribution to the third assessment report for the Intergovernmental Panel on Climate Change (Table 2-1). While not specific indicators themselves, the rationale associated with each determinant does provide guidance for the development of indicators.

Table 2-1. Determinants of adaptive capacity from Smit *et al.* (2001).

Determinant	**Rationale**
Economic resources	Greater economic resources increase adaptive capacity
	Lack of financial resources limits adaptation options
Technology	Lack of technology limits range of potential adaptation options
	Less technologically advanced regions are less likely to develop and/or implement technological adaptations
Information and skills	Lack of informed, skilled and trained personnel reduces adaptive capacity
	Greater access to information increases likelihood of timely and appropriate adaptation
Infrastructure	Greater variety of infrastructure can enhance adaptive capacity, since it provides more options
	Characteristics and location of infrastructure also affect adaptive capacity
Institutions	Well-developed social institutions help to reduce impacts of climate-related risks and therefore increase adaptive capacity
	Policies and regulations may constrain or enhance adaptive capacity
Equity	Equitable distribution of resources increases adaptive capacity
	Both availability of and entitlement to resources are important

Starting from a much broader perspective recognizing uncertainty, change and surprise as inherent characteristics of the complex world in which we live, an international network of sustainable development researchers and practitioners called the Resilience Alliance (www.resalliance.org), put forth an approach for achieving sustainable development to the Swedish Government leading into the 2002 World Summit on Sustainable Development. In doing so they posed the following question: "are there elements that sustain adaptive capacity of social-ecological systems in a world that is constantly changing?" In responding to this question, the Resilience Alliance noted that "addressing how people respond to periods of change, and how society reorganizes following change, is the most neglected and the least understood aspect in conventional resource management and science" (Gunderson and Holling, 2002).

Their central recommendation, based on the concept of resilience, is to *build adaptive capacity*—to shift from policies that aspire to control change to *managing the capacity of social-ecological systems to cope with, adapt to and shape change* (Folke *et al.*, 2002). They identify four critical factors that *interact across temporal and spatial scales* and that seem to be required for dealing with natural-resource dynamics during periods of change and reorganization (Berkes *et al.*, 2003): learning to live with change and uncertainty; nurturing diversity for reorganization and renewal; combining different types of knowledge for learning; and creating opportunity for self-organization. Berkes and Seixas (2005) used these factors as an initial step toward developing surrogates of resilience for lagoon social-ecologic systems. The initial step involved considering clusters of factors for building resilience from the local perspective and their applicability in analyzing different lagoon systems. These clusters of factors are summarized in Table 2-2.

Table 2-2. Clusters of factors for building resilience from the local perspective in lagoon social-ecological systems (from Berkes and Seixas, 2005; categories based on Folke *et al.*, 2003).

Resilience Clusters	**Resilience Factors**
Learning to live with change and uncertainty	▪ Learning from crises ▪ Building rapid feedback capacity to respond to environmental change ▪ Managing disturbance ▪ Building a portfolio of livelihood activities ▪ Developing coping strategies
Nurturing diversity for reorganization and renewal	▪ Nurturing ecological memory ▪ Nurturing a diversity of institutions to respond to change ▪ Creating political space for experimentation ▪ Building trust among users ▪ Using social memory as source of innovation and novelty
Combining different kinds of knowledge	▪ Building capacity to monitor the environment ▪ Building capacity for participatory management ▪ Building institutions that frame learning, memory and creativity ▪ Creating cross-scale mechanisms to share knowledge ▪ Combining local and scientific knowledge
Creating opportunity for self-organization	▪ Building capacity for user self-organization ▪ Building conflict management mechanisms ▪ Self-organizing for equity in resource access and allocation ▪ Self-organizing in response to external drivers ▪ Matching scales of ecosystem and governance ▪ Creating multi-level governance

In a study conducted in Ontario, Canada, Wall and Marzall (2004) reported on the early phases of a project designed to assess adaptive capacity in rural communities for meeting climate and weather risks. In their research they interpreted that adaptive capacity depends in part on the available social, human, institutional, natural and economic resources. They identified a set of indicators for each of these resources (Table 2-3) and applied these indicators in an assessment of the adaptive capacity of the community of Tweed, Ontario. A rank was developed for each indicator to define in quantitative or qualitative terms the lowest and highest ranks. A score was then given to each indicator based on actual data collected in the community. The results were then presented on a spider plot (Figure 2-1) to illustrate overall adaptive capacity (i.e., the more area covered by the plot, the higher the overall adaptive capacity).

Table 2-3. Resource types for assessing the adaptive capacity in rural communities for meeting climate and weather risks (from Wall and Marzall, 2004).

Resource Type	Rationale	Indicators
Social resources	• Fewer people left stranded or without care • Networks between communities get the word out and assistance in • People who care about their community will ensure it recovers	• Community attachment (AB) • Voluntary involvement (V) • Number of community events (E)
Human resources	• Response to climate impacts is enhanced with residents who have: ➢ strong skills and ingenuity; and ➢ good physical and mental health	• School availability measure (SA) • Dependency ratio (DR) • Years of schooling completed (SC)
Institutional resources	• The quality of utilities infrastructure affects severity of impact • Political connections may enhance community access to assistance • Effective communications services guarantee faster response from within and without	• Elected representation (ER) • Age and condition of utilities (U) • Number of emergency programs available (EP) • Community health and services measure (HS) • Radio/TV (C)
Natural resources	• Better quality/higher quantity of affected resources mean greater ability to withstand climate impacts	• Frequency of water contamination (WC) • Frequency of water shortage (WS) • Quality/quantity assessment of surface water (WQ)
Economic resources	• Greater financial assets mean greater ability to recover from material loss • Diverse employment opportunities provide more options if climate affects particular type of occupation	• Job diversity (JD) • Employment rates (ERS) • Income level (IL) • Home ownership (HO) • Local business ownership (LB)

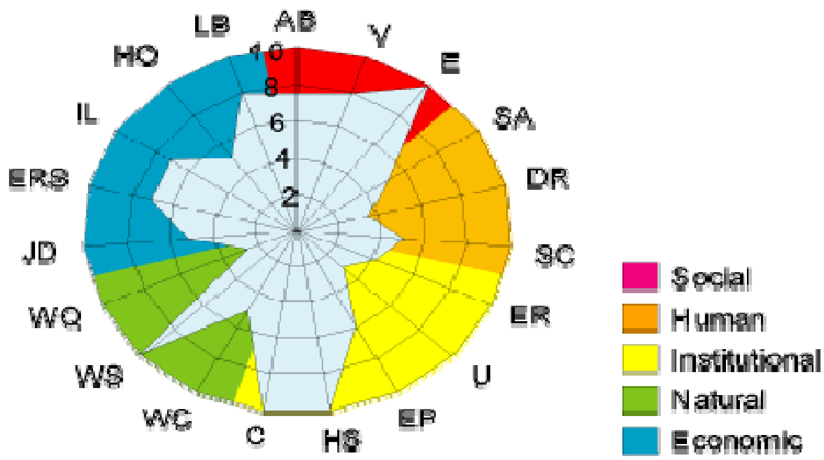


Figure 2-1. Profile of adaptive capacity for Tweed, Ontario (from Wall and Marzall, 2004; see Table 2-3 for definition of indicators).

We also gleaned insight from two Canadian studies on community development. The first is a community-capacity model reported by Beckely *et al.* (2002) and elaborated by Tiepoh and Reimer (2004) for the New Rural Economy project of the Canadian Rural Revitalization Foundation. The model is illustrated in Figure 2-2 and depicts the "ability of a group of people to collectively combine and mobilize different forms of capital within institutional and relational contexts to meet challenges and create beneficial outcomes for the community" (Beckely *et al.*, 2002). What makes this work relevant to adaptive capacity is that these researchers note that "specific skills are needed to adapt and deal with the significant changes and stresses currently facing rural areas" and the community-capacity model was developed to elucidate such skills.

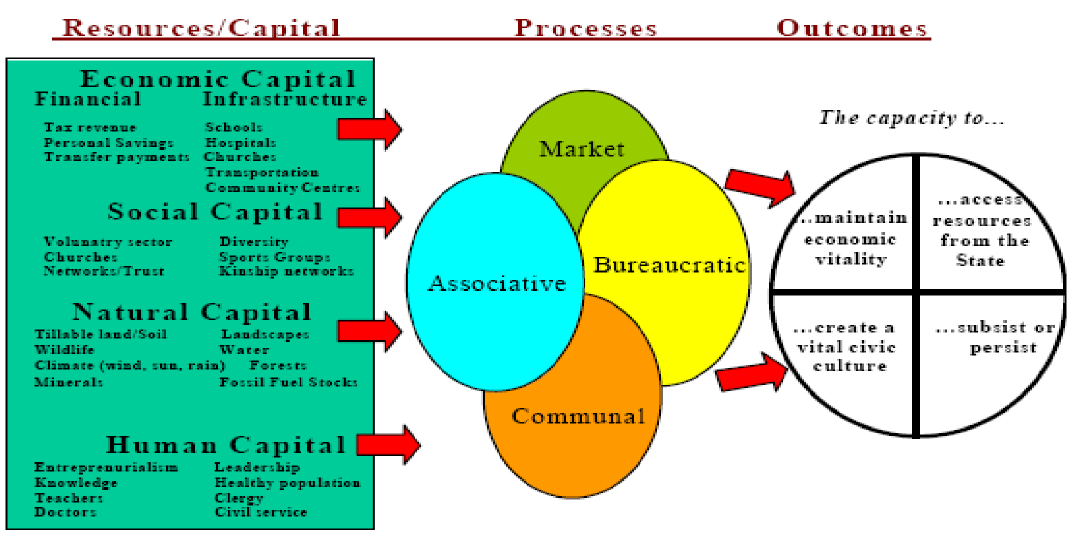


Figure 2-2. Community capacity model (Beckley et al., 2002)

Tiepoh and Reimer (2004) applied this model to a cross-community analysis of social capital, information flows and income creation in rural Canada. They proposed that "social capacity, defined as the ability of people to organize and use their social capital, does influence their level of income, and that this is because social-capital use facilitates the flow of income-related knowledge and information between economic agents." Despite the focus on income in this study, it does provide considerable insight into the potential role of social capital in adaptive capacity. The model describes market relations as those relations "based on the exchange of goods and services within a relatively free and information-rich context." The second component, bureaucratic relations, are described as formal relationships and structured authority through formal principles and rules. The study notes that experience with bureaucratic-based social capital "has become increasingly important over the last 50 years as states and corporate organizations have come to dominate economic and social life." For example, they elaborate by saying "knowing how to find a job, access transfer payments, expand trade, or avoid taxes requires familiarity with bureaucratic modes of relating and negotiation."

Associative relations, the third type, are characterized as those "primarily based on shared interests and characterized by focused objectives, informal structures, and short-term life span (e.g., voluntary associations, clubs, and informal groups)." Finally, communal relations are those "founded on strongly shared identity, in which rights and obligations of members are largely determined by custom (e.g., family, clan, or close friendship networks…)" and can be a source of income through remittances, preferred transfers, jobs and special entitlements.

The study considers a number of indicators of the availability of social capital under the four types of relations, and these are illustrated in Table 2-4.

Table 2-4. Indicators for the availability of social capital (from Tiepoh and Reimer, 2004).

Type of Relation	Indicator
Market-based	▪ Number of businesses within 30 minutes of site ▪ Number of market-based services within 30 minutes of site (e.g., banks, ATM machines, insurance offices) ▪ Number of market communication services (e.g., cable, Internet, national newspaper) ▪ Commercial shopping code (Stabler *et al.*, 1992) ▪ Total of business and market services for site ▪ Density of enterprises and market services
Bureaucratic-based	▪ Number of bureaucratic services within 30 minutes of site (e.g., schools, hospital, employment office) ▪ Number of bureaucratic communication services (e.g., Internet, national newspaper) ▪ Number of bureaucratic access services within 30 minutes (e.g., school, hospital, employment office) ▪ Density of bureaucratic services
Associate-based	▪ Number of associative-based services within 30 minutes of site (e.g., food bank, rink, community centre) ▪ Number of associative communication services (e.g., community newspaper, local radio station) ▪ Number of associative access services within 30 minutes ▪ Density of associative services

Communal-based	▪ Average of number of people in census families ▪ Number of communal-based services in site (e.g., daycare, retirement home) ▪ Index of communal relations – basic ▪ Density of communal index

As a final example of a framework for adaptive capacity-related indicators, the Centre for Community Enterprise in British Columbia, Canada, developed in 1999 a Community Resilience Manual that was designed to help rural communities "assess their own state of resilience and establish priorities for strengthening it"—to "strengthen their ability to respond to, and influence the course of social and economic change." They cite the community decline as a significant threat to many Canadian towns, but at the same time recognize that many communities have taken steps that have "enabled them to survive crisis, influence change, and become healthy, vital places for their citizens. They are resilient."

The Community Resilience Manual identifies a number of resilience indicators under the categories of resources in the community, people in the community, organizations in the community and community process. These indicators are summarized in Table 2-5.

From review of the example conceptual models and indicators described above, a number of key points become apparent. The first is that there is clearly a substantive interest in Canada to better understand the capacity of communities to adapt to surprise and longer-term change, be it to climate change or other socio-economic conditions affecting community development. A comprehensive conceptual approach covering social, economic and environmental dimensions of community well-being is emerging under different cultural situations. The notion of resilience is receiving much attention from several streams of research in Canada, some mainly from the socio-economic perspective of community development (e.g., CCE, 1999; Tiepoh and Reimer, 2004), while others from the integrated ecologic and socio-economic perspective (Berkes and Seixas, 2005; Wall and Marzall, 2004; Smit *et al.*, 2001). In all examples, the importance of maintaining and building forms of social capital is emphasized as a critical element for building adaptive capacity.

While the diversity of perspectives being brought to bear on the concept of adaptive capacity and resilience is most certainly a positive trend, it brings with it some difficulties, particularly in relation to a lack of standardized approach and common language and terms.

Table 2-5. Community resilience indicators (CCE, 1999).

Cateogry	Aspect	Indicator
People in the community	1. Leadership, both the formal elected and informal organizational, is diversified and representative of the age, gender and cultural composition of the community.	a. Breakdown of formal and informal leaders by gender, age and culture compared to representation in the community as a whole. b. Degree to which people perceive formal and informal leadership to be diversified and representative of the population. c. Degree to which people perceive that the community has been successful at involving youth, women, marginalized groups and ethnic groups in decision-making.
	2. Community elected leadership is visionary, shares power and builds consensus.	Degree to which people perceive that the formal, elected leadership: a. guides the community in the crafting and use of a clear vision; b. shares decision-making and executive power with community members; and c. works to find consensus on issues that affect the community.
	3. Community members are involved in significant community decisions.	a. Meetings are advertised, open to the public and well attended. b. Public input into decisions has been pro-actively encouraged and solicited. c. Degree to which people perceive that public input has influenced major decisions in the community.
	4. The community feels a sense of pride.	a. Degree to which people describe feelings of pride in their community. b. Number of local celebrations/festivals in the last year. c. Number of community beautification initiatives in the last year. d. Number of complaints to town re: litter, poorly kept yards, etc.
	5. People feel optimistic about the future of the community.	Relative level of optimism expressed by community people.
	6. There is a spirit of mutual assistance and cooperation in the community.	Degree to which people perceive that mutual assistance and cooperation exist in the community.
	7. People feel a sense of attachment to their community.	a. In/out-migration from census data. b. Degree to which people perceive there to be a sense of attachment to community. c. Degree to which people perceive that seniors are attached to the community (relative to attachment of population in general). d. Degree to which people perceive that youth are attached to the community (relative to attachment of population in general).
	8. The community is self-reliant and looks to itself and its own resources to address major issues.	a. Degree to which people perceive that there is openness to new ideas. b. Degree to which people in the community believe they can influence their future.
	9. There is a strong belief in, and support for, education at all levels.	a. Percentage of population by education level. b. High-school drop-out rate. c. Number of adults registered in all continuing or adult-education courses in the last year, per capita. d. Number of new skills training programs developed in response to a local need in the last year. e. High-school provincial scholorship rate
Organizations in the community	10. There is a variety of CED organizations in the community such that the five key CED functions are well-served: access to equity; access to credit; human-resource development; planning/research/advocacy; and infrastructure.	a. Number of organizations in each CED function area. b. Degree to which people perceive that they are well served, in all areas, by CED organizations.
	11. Organizations in the community have developed partnerships and collaborative working relationships.	a. Number and quality of relationships. b. Degree to which people perceive that there are good working relationships between organizations. c. Degree to which people perceive that conflict between organizations is well managed.
Resources in the community	12. Employment in the community is diversified beyond a single, large employer.	Percentage of total working population employed in top five private-sector employer companies
	13. Major employers in the community are locally owned.	Percentage of top five private sector employers that are locally owned.
	14. The community has a strategy for increasing independent, local ownership.	a. The municipality, regional district and/or CED/economic development organizations include local ownership as a goal in their plan. b. There is a community strategy to assist with local business succession planning. c. The community has a strategy to identify and assist businesses in danger of closing.
	15. There is openness to alternative ways of earning a living and economic activity.	a. The community owns a major asset for the economic and social benefit of the community, e.g., a community-owned forest licence. b. Degree to which people perceive an openness to alternative forms of earning a living. c. Degree to which people perceive that the community is open to alternative forms of economic diversification.
	16. The community looks outside itself to seek and secure resources (skills, expertise, finance) that will address identified areas of weakness.	Degree to which people perceive that outside resources have been accessed in order to address gaps or achieve goals.
	17. The community is aware of its competitive position in the broader economy.	a. The community has a buy-local campaign. b. The amount of economic leakage out of the community has been identified and analyzed. c. Niche markets (in which unique opportunities exist) have been identified in the community that take advantage of community strengths.
Community process	18. The community has a community economic development (CED) plan that guides its development.	a. A community-wide economic-development plan exists. b. The CED plan reflects all aspects of good planning practice: (community vision, mission, community values, SWOT analysis, goals and objectives, operational/action plan, evaluation measures/implementation plan, is inclusive of all aspects of the community).
	19. Citizens are involved in the creation and implementation of the community vision and goals.	a. Number of participants attending community visioning meetings. b. Number of mechanisms for public input into community vision or goals. c. Number of volunteers who participate in groups/committees/etc. that are implementing initiatives in the CED plan. d. Degree to which people perceive that the public was involved in the creation and implementation of a community vision and goals.
	20. There is ongoing action towards achieving the goals in the CED plan.	a. Number of initiatives from the CED plan that have been acted on in the last year. b. Degree to which there is a perception in the community that the plan is being realized.
	21. There is regular evaluation of progress against the community's strategic goals.	Evaluation of accomplishments against the goals has been conducted in the last year.
	22. Organizations use the CED plan to guide their actions.	a. Percentage of organizations who work from the CED plan and integrate it into their own planning process. b. Degree to which oragnizations are perceived to be working toward achieving the goals in the CED plan.
	23. The community adopts a development approach that encompasses all segments of the population.	a. The degree to which people perceive that the CED plan addresses the needs of marginalized people in the community. b. Number of organizations/groups in the community that address the economic interests of low-income people. c. The degree to which people perceive that there is an ongoing, structured dialogue between economic-development and social-service agencies.

3.0 Framework and Analytic Approach

From the literature just described, we identified a suitable framework of adaptive capacity, assessed a suite of indicators within this framework in the context of the study area and quantified each measure from federal census data sources and other inventories with complete coverage of the Prairie region. The method is elaborated below in two sub-sections. First, we elaborate the indicator framework and define the indicators. Second, we present the analytical approach used to calculate the overall indices of adaptive capacity for each Census Division in the Prairie agricultural region.

3.1 Framework and indicator definition and development

We adopted the determinants of adaptive capacity as put forth by Smit *et al.* (2001) as a framework for identifying indicators in this study. As the focus of our work is applied research, we based our framework on just one study rather than create a new framework based on a synthesis of the literature.

Our selection of a framework was also constrained by the availability of data. Many of the studies cited in the literature review, such as the community capacity model and Community Resilience Manual, involved primary data collection to produce information necessary to complete the indicator. This type of primary data collection was not an option for the Prairie Climate Resilience Project given that we were interested in analyzing adaptive capacity across all communities on the Prairies. Our selection of indicators was therefore constrained by data that already existed for all communities on the Prairies. Fortunately, Canada has a world-renowned census system and we were therefore able to mine Canada's censuses of agriculture and population for data relevant to adaptive capacity. But in order to mine this available data, we had to first be clear in what we wanted to measure.

With some slight modification on our part, as noted in italicized text, the framework of Smit *et al.* (2001) contains six determinants:

- economic resources;
- technology;
- *information, skills and management*;
- infrastructure;
- *institutions and networks*; and
- equity.

We renamed two of the determinants to note our expansion of the scope of coverage therein. The information determinant includes *skills and management* to reflect our broader view of the human abilities required to effectively use information. In addition, we included in the institutions determinant a *networks* component to reinforce our view that institutions include social connections or social capital (Putnam, 2001).

For each of the six determinants we developed a list of aspects that defined the span of each determinant. The aspects presented in our study were a compromise between those referenced in the literature (our wish list) and data available for the Prairies. Data sources with Prairie-wide spatial coverage included the Census of Agriculture (2001), Census of Population (2001), and environmental, transportation and other topical information sets of variable vintage.

Compilation of these data sources to a common spatial unit facilitated the analysis of adaptive capacity across the study area. As Statistics Canada's censuses of population and agriculture were the principal data sources, the chosen base units were the federal agency's Census Divisions (CDs) and Census Sub-divisions (CSDs). There are 60 CDs in the three Prairie Provinces as illustrated on Figure 3-1, of which 53 are located in the Prairie agricultural region. These divisions are used by Statistics Canada to carry out its Census of Population every five years. CSDs are municipalities or areas treated as municipal equivalents. Summation of other data sources to CDs and CSDs was accomplished through overlay in a geographic information system (GIS) using a common geographic coordinate and projection. While the availability of data for each indicator at the CSD level was assessed for finer resolution analysis, this paper presents an application of the method at the CD level.

The data were compiled within a GIS using digital boundary files for Statistics Canada census collection (Statistics Canada, 2001). Census Division polygons were calculated by projecting the digital data to North American Datum (NAD) 83 Universal Transverse Mercator (UTM) zones for each square kilometre. Each UTM zone was treated separately.[5] Area estimates were calculated for the Census Divisions. The base layer for the GIS projections was the North America shaded relief map (National Atlas of the United States, 2005).

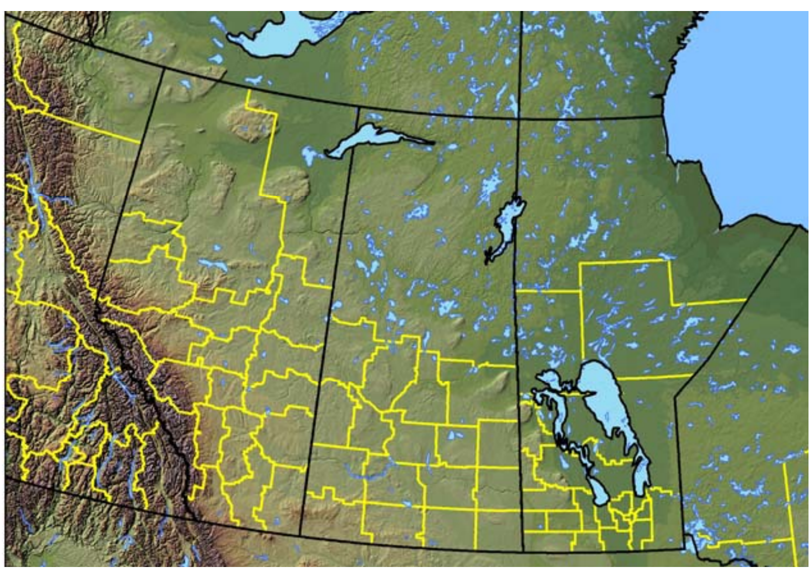


Figure 3-1. Census divisions in the Prairie agricultural region.

Within this chosen spatial framework, we identified 24 aspects of adaptive capacity (four for each determinant) for which we anticipated that relevant data could be summarized (Figure

[5] UTM zones 10–15, www.dmap.co.uk/utmworld.htm.

3-2). The selection of a consistent number of aspects denoted our view that each determinant made an equal contribution to the concept of adaptive capacity. In that the literature provided no definitive direction to the topic of weighting, we deemed this decision to be prudent.

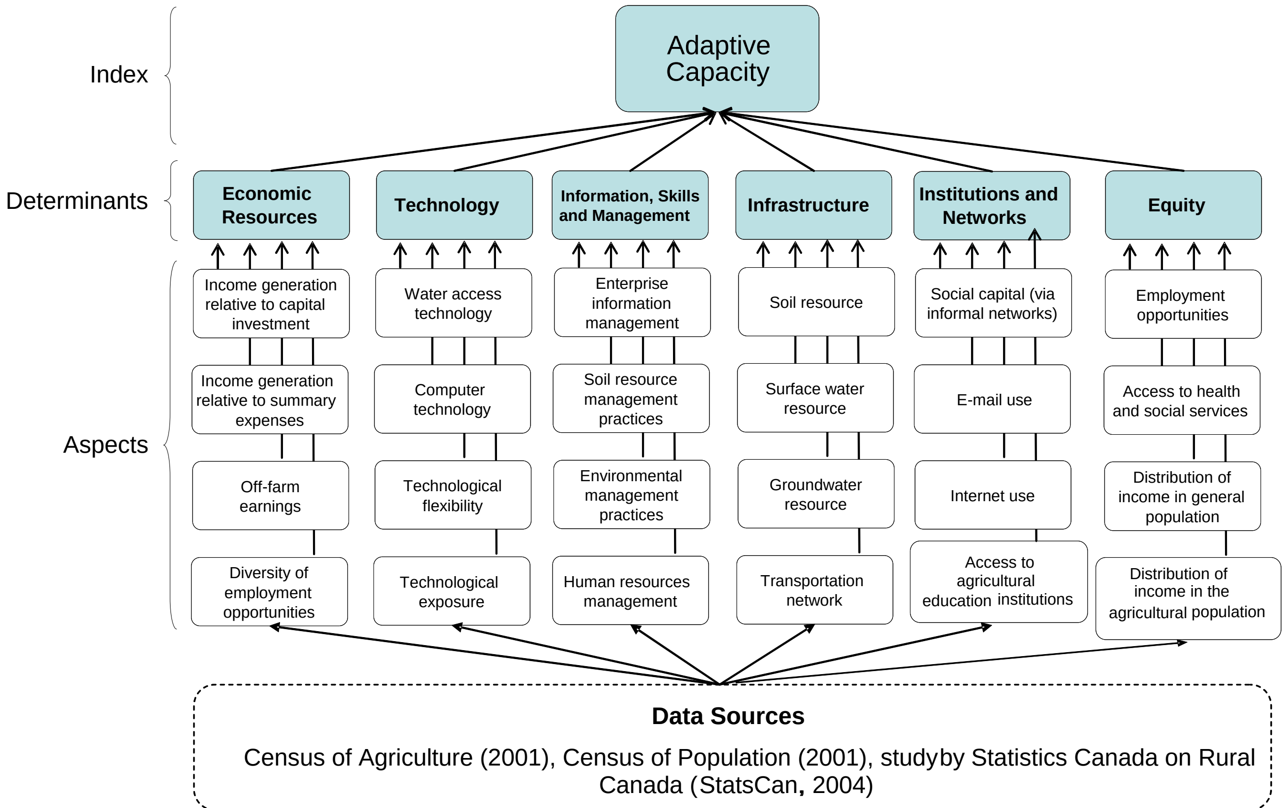


Figure 3-2. Framework for adaptive capacity to climate change on the Canadian Prairies.

We identified an indicator for each aspect that was specific, measurable and time-bound. These indicators are summarized in Table 3-1 and are described below.

Economic Resources

Smit *et al.* (2001) highlight that greater economic resources increase adaptive capacity, while a lack of financial resources limits adaptation options. We developed four aspects of interest to producers in times of climate stress.

- Income generation relative to capital investment. More income generated per dollar of capital investment is interpreted as an indication that further efficiencies in production may be realized more likely relative to less efficient areas. The indicator was the *ratio of gross farm receipts to total capital investment* (unless otherwise noted, the Census of Agriculture is the data source). The signal for this indicator is that higher is better.
- Income generation relative to summary expenses. More income generated per unit of expense means further efficiencies in production may be more likely than less

efficient areas of production. The indicator was the *ratio of income to expenses,* with higher values being better.

- Income from off-farm sources. More of total income coming from non-agricultural sources suggests a capability to manage production through difficult years via different income sources. The indicator was *off-farm earnings as a percent of total family income* where families have at least one farm operator. Higher is better.
- Diversity of employment opportunities. More opportunities to gain non-agricultural employment will help to sustain their enterprise in difficult years for agricultural production. A desirable indicator for this aspect, based on the Census of Agriculture, would have been the *ratio of off-farm contribution of time to on-farm contribution of time*. However, this indicator was not available with the current dataset. As an alternative, the indicator was the *ratio of employment in agriculture to employment in other industries*. Lower is better.

Table 3-1. Indicators identified for the aspects of adaptive capacity.

Determinant	Aspect	Indicator
Economic resources	Income generation relative to capital investment	Ratio of gross farm receipts to total capital investment. Higher is better.
	Income generation relative to summary expenses	Ratio of income to expenses. Higher is better.
	Off-farm earnings	Off-farm earnings as a per cent of total family income where families have at least one farm operator. Higher is better.
	Diversity of employment opportunities	Ratio of off-farm contribution of time to on-farm contribution of time. Not available with current dataset. Alternative was the ratio of employment in agriculture to employment in other industries within CD. Lower is better.
Technology	Water-access technology	Ratio of value of irrigation equipment to value of all other farm equipment. Higher is better.
	Computer technology	Ratio of farms reporting use of computer to all other farms. Higher is better.
	Technological flexibility	Ratio of value in tractors under 100 hp to total value of all other tractors. Lower is better.
	Technological exposure	Ratio of technologically demanding to less demanding farm types. Higher is better.
Information, skills and management	Enterprise information management	Ratio of farms reporting computer livestock and crop record keeping to all other farms. Higher is better.
	Sustainable soil resource-management practices	Ratio of area of no-till or zero-till seeding to tilled area. Higher is better.
	Sustainable environmental-management practices	Ratio of farms reporting windbreaks and shelter belts to all other farms. Higher is better.
	Human-resources management	Ratio of total farms reporting paid agricultural labour to all other farms. Higher is better.
Infrastructure	Soil resources	Proportion of area in dependable agricultural land. Higher is better.
	Surface-water resources	Ratio of surface-water area to total land area. Higher is better.
	Groundwater resources	No. and/or yield of wells. Higher is better.
	Transportation network	Ratio of high-capacity to low-capacity roads. Higher is better.
Institutions and networks	Informal operating arrangements	Ratio of total farms reporting formal agreements to total no. of farms reporting sole proprietorships and partnerships without written agreement minus miscellaneous category. Lower is better.
	E-mail use	Ratio of total farms reporting e-mail use to all other farms. Higher is better.
	Internet access	Ratio of farms reporting Internet use to all other farms. Higher is better.
	Opportunity to access agricultural-education institutions	Distance between centroids of each Census Division and the nearest regionally significant agricultural education institution. Lower is better.
Equity	Employment opportunities	Unemployment rate from Statistics Canada's 2001 Census of Population 20% Sample Data for Population of 15 years and over. Lower is better.
	Opportunity to access health and social services	Ratio of labour force in health and social-service occupations to all other occupations. Statistics Canada 2001 Census of Population 20% Sample data for Population. Higher is better.
	Distribution of income – general population	Rating by Alessandro's work as published in Catalogue no. 21-006-X1E (Rural/urban divide is not changing; income disparities persist).
	Distribution of income – agricultural producers	Ratio of farms reporting sales in excess of $250,000 to all other farms. Lower is better.

Technology

Smit *et al.* (2001) highlighted that a "lack of technology limits the range of potential adaptation options" and that "less technologically advanced regions are less likely to develop and/or implement technological adaptations." We identified four specific aspects that would be of benefit in times of high climatic variability.

- Water access technology. Producers require technology to access supplementary water (represented by irrigation equipment) for crop production. We make the assumption that groundwater wells are a readily available technology; hence not a barrier to livestock production at the scale of CDs and CSDs within the region. The indicator was the *ratio of value of irrigation equipment to value of all other farm equipment*. Higher is better.
- Computer technology. Producers require computer technology to access, rapidly process and evaluate new data and information. The indicator was the *ratio of farms reporting use of computer to all other farms*. Higher is better.
- Technological flexibility. Noting that climate models forecast greater variability in the amount of precipitation, producers need flexibility when conducting field work under conditions of variable moisture levels in landscapes. Smaller rather than larger tractors increase options available to initiate and complete time-sensitive, seasonal field activities. The indicator was the *ratio of value in tractors under 100 hp to total value of all other tractors*. Lower is better.
- Technological exposure. A prevalence of technologically demanding farming systems shows that many producers have been exposed to how it may be used to control agricultural inputs. The indicator was the *ratio of technologically demanding to less demanding farm types*. Higher is better.

Information, Skills and Management

The rationale for this determinant is that a "lack of informed, skilled and trained personnel reduces adaptive capacity," while "greater access to information increases likelihood of timely and appropriate adaptation" (Smit *et al.*, 2001). We identified four aspects that would assist producers in adapting to challenging climatic conditions.

- Enterprise information management. Producers benefit from access to information and management software to more efficiently and effectively control their enterprise. The indicator was the *ratio of farms reporting computer livestock and crop record keeping to all other farms*. Higher is better.
- Sustainable soil management practices. Less physical disturbance of the land by tillage reduces environmental degradation and increases water-holding capacity. It also provides potential access to emerging carbon-trading markets where zero or reduced tillage serves as a carbon sequestration practice. The indicator was the *ratio of area of no-till or zero till seeding to tilled area*. Higher is better.
- Sustainable environmental management practices. More windbreaks and shelter belts provide protection to the soil, and help maintain higher water tables and habitat for wildlife. As with the previous indicator, the potential to access carbon-trading markets also exists. The indicator was the *ratio of farms reporting windbreaks and shelter belts to all other farms*. Higher is better.

- Human resources management. Previous experience in dealing with the hiring and management of people shows a producer's enhanced experience in adapting the factors of production, in this case labour. The indicator was the ratio of total farms reporting paid agricultural labour to all other farms. Higher is better.

Infrastructure

The rationale for this determinant as described by Smit *et al.* (2001) is that "greater variety of infrastructure can enhance adaptive capacity, since it provides more options." The characteristics and location of infrastructure also affect adaptive capacity. We identified four aspects that are relevant to an assessment of adaptive capacity in times of climatic variability.

- Soil resources. Higher-quality soil resources will increase adaptive capacity. The indicator was the proportion of area in dependable agricultural land. Higher is better.
- Surface water resources. More surface water will increase adaptive capacity; however, this aspect does not account for variable water quality. A possible indicator for this aspect is the *ratio of surface water area to total land area,* with higher being better. Unfortunately, at the time of our analysis, we could not identify a data source that would allow this calculation at the CD or CSD level.
- Groundwater resources. More groundwater will increase adaptive capacity. Similar to surface water resources, this aspect does not consider variable quantity or quality. A potential indicator for this aspect is *the number and/or yield of wells in the Census Division,* with higher being better. Also similar to surface water resources, data were not available to calculate such an indicator.
- Transportation network. The capacity of a transportation network to move goods, services and people increases the options for producers to adapt to unexpected or extreme social, economic and environmental conditions. The indicator was the *ratio of high capacity to low capacity roads* as calculated from the National Road Network database (www.geobase.ca/geobase/en/data/nrnc1.html). Higher is better.

Institutions and Networks

The rationale of Smit *et al.* (2001) for institutions as a determinant of adaptive capacity was that "well-developed social institutions help to reduce impacts of climate-related risks, and therefore increase adaptive capacity." Additionally, "policies and regulations can constrain or enhance adaptive capacity." We added the dimension of networks to this determinant to highlight the important contribution of social capital to developing adaptive capacity. We identified the following four aspects and indicators.

- Social capital. The opportunity to rely on a network of family, friends and close associates provides valuable assistance to producers in stressful times. Putnam (2000) defines this as social capital. Putnam (2001) in a survey of social capital across the United States and parts of Canada identified informal business relationships as one possible indicator of social capital. The rationale would be that informal business relationships require closer personal relationships as compared to more formal, contractual arrangements. Based on this rationale, the indicator was the *ratio of total farms reporting formal agreements to total number of farms reporting sole proprietorships and partnerships without written agreement minus miscellaneous category*. Lower is better.

- E-mail use. Producers need to communicate with many individuals and organizations to consider new and emerging viewpoints and information sources. This indicator is distinguished from the technology determinant, computer-use indicator on the basis of personal interaction as the latter indicator shows access to, rather than a specific use of, computer technology. The indicator was *ratio of total farms reporting e-mail use to all other farms*. Higher is better.
- Internet use. Producers use the Internet to seek out a diversity of viewpoints and information to expand their knowledge and understanding of current stresses (e.g., droughts) or shocks (e.g., floods, global market changes). This indicator is differentiated from the technology determinant, computer-use indicator on the basis of intended use and from the previous indicator on the basis of type of use—the seeking of information as opposed to communication of same. This indicator was the *ratio of farms reporting Internet use to all other farms*. Higher is better.
- Opportunity to access agricultural education institutions in person. Producers that are close to regionally significant agricultural education institutions have an opportunity to attend them with less social and economic costs compared to those at further distance. Personal attendance provides producers not only with the opportunity to interact with accredited agricultural educators but also cooperatively evaluate materials and advice with a network of like-minded producers. The indicator was the straight-line *distance between the centroids of each Census Division and the nearest regional, post-secondary educational institution providing agricultural courses*. Lower is better.

Equity

While the rationale for this determinant was based on an international development perspective, Smit *et al.* (2001) describe a determinant of adaptive capacity that is relevant in any setting. Their specific rationale stated that the "equitable distribution of resources increases adaptive capacity" and that "both availability of, and entitlement to, resources is important." We identified two aspects representative of this determinant while a third and fourth measure reflective of the distribution of wealth in the general population could not be derived at the CD level based on available data.

- Employment opportunities. Unemployment rates are an indication of labour demand. The indicator was the *unemployment rate* from Statistic Canada's 2001 Census of Population (20 per cent sample data for population of 15 years and over). Lower is better.
- Opportunity to access health and social services. Producers always need to access health and social services to sustain physical and mental health, but especially so in stressful times. The indicator was the *ratio of labour force in health and social service occupations to all other occupations* from Statistics Canada's 2001 Census of Population (20 per cent sample data for population). Higher is better.

3.2 Analytical approach

The primary purpose of the analysis was to identify CDs with relatively higher or lower adaptive capacity and describe those determinants and aspects therein that contributed to these findings. This information would then be combined with data on the degree of historic climate stress experienced to help identify regions with relatively higher or lower vulnerability to climate change. In the context of the Prairie Climate Resilience Project, this information provides general locations and broad insights for field-based researchers studying those factors that may contribute to adaptive capacity.

Comparison of adaptive capacity across CDs required, first, that the individual indicators for each determinant be aggregated to a determinant value and, second, that these determinant values be aggregated into an overall index of adaptive capacity. The main conceptual challenge in such an exercise is the disparate units for each of the individual indicators that make up each determinant.

There are myriad ways for normalizing values of disparate units. One of the most notable was the normalization procedure applied for the Human Development Index (HDI) reported annually by the United Nations Development Programme (UNDP). The HDI combines indicators of life expectancy, adult literacy and real GDP per capita into one overall index of development. Morse (2004) describes the HDI procedure as follows:

$$\text{Normalized Value} = \frac{(\text{Value for country} - \text{minimum value})}{(\text{Maximum value} - \text{minimum value})} \qquad \text{Eq 1}$$

In the context of the HDI, the maximum and minimum values have been determined in different ways over the years, including basing these values on the range seen in the list of countries included in the index, but also by employing values that would be expected as reasonable. Morse (2004) notes that there are advantages and disadvantages to each approach. For example, when basing the maximum and minimum on the range for the list of countries in the index, a country's index could change from one year to the next given changes in the maximum and minimum country values, while its own value actually remains constant.

Despite this disadvantage, this type of normalization process is used frequently due to its simplicity and relevance, particularly for indices whose purpose is to provide relative information. For example, Krajnc and Glavic (2005a, 2005b) describe such calculations for integrated assessment for sustainable development and how to compare different businesses on relevant dimensions of sustainability. In the context of climate change vulnerability assessment, such a normalization procedure was used in India by O'Brien *et al.* (2004).

In the context of our adaptive-capacity index, the normalization procedure used is based on the above citations and presented below as equations 2a and 2b.

Normalized Value = [where higher is better]

$$\frac{(\text{Value for CD to be normalized} - \text{minimum value for all CDs})}{(\text{Maximum value for all CDs} - \text{minimum value for all CDs})} \qquad \text{[Eq 2a]}$$

Normalized Value = [where lower is better]

$$\frac{1\text{- (Value of CD to be normalized} - \text{minimum value for all CDs})}{(\text{Maximum value for all CDs} - \text{minimum value for all CDs})} \qquad \text{[Eq 2b]}$$

Equation 2a and 2b were used to calculate normalized values for each of the determinant indicators relative across Census Divisions. Each indicator within a determinant was considered to be of equal importance. Based on this assumed weighting, a single aggregated value for the determinant was calculated as the average of the normalized indicator values. Each determinant was considered to be of equal importance in calculating the overall adaptive capacity index for each CD. Based on this assumed weighting, a single overall adaptive capacity index for each CD was calculated as the average of the aggregated determinant values.

4.0 Results

The capacity of farm families and communities to adapt to climate shocks and stresses is a critical part of sustainable development. It is this imperative that motivates us to study adaptive capacity across the Prairies using available census data. In this section we first present the results of the individual determinants to build our understanding of the contributors to adaptive capacity. Second, we present and analyze the results of the overall composite indices of adaptive capacity for each CD.

Analysis of the adaptive capacity index and the normalized scores for the determinants and individual indicators is best undertaken from a relative (i.e., ranking) perspective. In the context of the Prairie Climate Resilience Project, this analysis is designed to help select locations for field-level studies of the resilience of farm families and communities to climate variability and change. The ranking of Census Divisions (CDs) relative to each other for this data is helpful to see which areas appear to be fairing well with respect to adaptive capacity and which are not—a necessary precursor to better understanding the actual vulnerability of farm families and communities to climate stress.

The indicators represent information mined from existing census data that were deemed relevant to adaptive capacity. It is important to note that these indicators may not necessarily represent the most important components of adaptive capacity—this can only be revealed through field-level studies, and this research is ongoing at this time. Therefore, we cannot assert from Table 4-1 that those CDs having the highest overall rankings of adaptive capacity do indeed have sufficiently high capacity to adapt to climate shocks and stresses. Similarly, we cannot assert at this point in time whether the CDs ranking the lowest in fact do not have sufficiently high capacity to adapt to climate shocks and stresses.

It is also important to remember that the indicator values are normalized scores of the actual original indicator value—that is, they are scores which are relative to the value of the indicator in all other CDs. These scores are numbers between 0 and 1 with a score of 1 signifying that a CD has the highest value for this indicator compared to all other CDs, while a score of 0 signifies that a CD has the lowest indicator value compared to all other CDs. The characteristics of the underlying indicator data are discussed in Section 5.1 to provide a better understanding of what the normalized indicator values mean in real terms.

4.1 Results and analysis of the determinants of adaptive capacity

Mapping of the adaptive capacity results for each Census Division is the most effective and efficient means to analyze the data as it reveals the spatial associations underlying the range in adaptive capacity as represented by each determinant. In this section we present the ranking results for each of the six determinants as a foundation for understanding their respective contributors to the composite adaptive capacity index.

4.1.1 Economic resources

Normalized results for indicators making up the economic resources determinant are presented in Table 4-1. Mapping the census-division rankings shows at least three clustered areas in the Prairie region (Figure 4-1). The most extensive grouping of CDs exhibiting relatively high values for the economic resources determinant occurs in southern Manitoba in the vicinity of Winnipeg. The highest ranking CD in this cluster centred around Winnipeg (CD 460911000) and recorded top values in the Prairies for two of the four indicators which make up this aspect—income generation relative to capital investment and diversity of employment opportunities. Other high-ranking CDs also report high scores on the latter aspect as well as high scores on the off-farm earnings aspect.

There is a grouping of CDs exhibiting relatively low values for the economic resources determinant straddling the border between Saskatchewan and Manitoba as well as the southern borders of Saskatchewan and western Manitoba. This area presents consistently low scores for two aspects, namely income generation relative to capital investment and off-farm earnings.

The lowest rankings for the economic resources determinant are seen in a band running from southern Saskatchewan through to south-central Manitoba. The CDs in southwestern Saskatchewan report high to very high scores on the income generation relative to summary expenses aspect, however very low scores for all other economic resources aspects. The CDs in southeastern Saskatchewan show high scores on the same aspect as well as the diversity of employment opportunities aspect with very low scores on the remaining two aspects. The CDs in Manitoba consistently report low scores for the income generation relative to capital investment aspect but a variable pattern of lower scores on the remaining aspects.

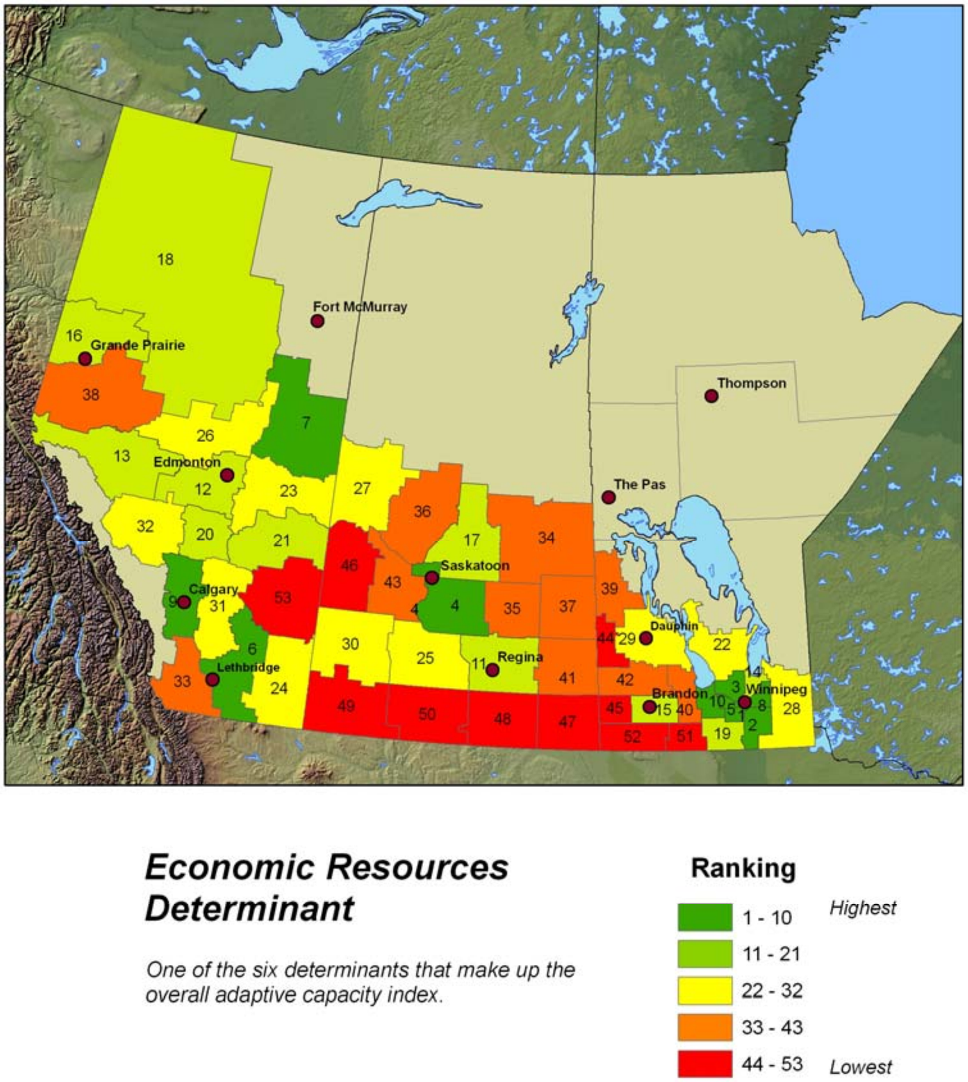


Figure 4-1. Relative ranking results for the economic resources determinant.

Table 4-1. Normalized indicator results for the economic resources determinant.

Census Division		Normalized Indicator Values: Economic Resources Determinant					
Census Division Code	Number of farms	Income generation relative to capital investment	Income generation relative to expenses	Off-farm earnings	Diversity of employment opportunities	Average (rank)	
460911000	170	1.000	0.028	0.875	1.000	.726	(1)
460902000	1,655	0.582	0.741	0.690	0.852	.717	(2)
461114000	830	0.276	0.544	0.824	0.800	.611	(3)
479911000	3,564	0.226	0.761	0.489	0.947	.606	(4)
460710000	455	0.315	0.903	0.410	0.641	.567	(5)
482002000	3,329	0.638	0.203	0.576	0.849	.567	(6)
486012000	2,830	0.109	0.319	0.912	0.897	.559	(7)
460912000	660	0.221	0.243	0.865	0.907	.559	(8)
483006000	4,941	0.057	0.325	0.859	0.988	.557	(9)
460709000	739	0.285	0.698	0.419	0.791	.548	(10)
479906000	3,901	0.174	0.488	0.541	0.948	.538	(11)
485011000	6,618	0.075	0.350	0.743	0.982	.538	(12)
486014000	904	0.199	0.000	1.000	0.942	.535	(13)
461113000	539	0.182	0.386	0.608	0.962	.534	(14)
460207000	1,246	0.244	0.373	0.596	0.915	.532	(15)
487019000	3,531	0.132	0.410	0.691	0.878	.528	(16)
479915000	4,382	0.194	0.630	0.460	0.820	.526	(17)
487017000	2,758	0.110	0.306	0.748	0.881	.511	(18)
460803000	1,830	0.292	0.576	0.369	0.767	.501	(19)
485008000	4,542	0.162	0.359	0.594	0.887	.500	(20)
484007000	3,316	0.172	0.718	0.458	0.652	.500	(21)
461218000	1,534	0.240	0.611	0.412	0.734	.499	(22)
484110000	5,694	0.150	0.531	0.562	0.746	.497	(23)
481001000	1,636	0.159	0.701	0.252	0.871	.496	(24)
479907000	2,795	0.191	0.792	0.198	0.784	.491	(25)
486013000	4,921	0.178	0.324	0.675	0.787	.491	(26)
479917000	2,460	0.126	0.505	0.538	0.772	.485	(27)
461001000	688	0.233	0.345	0.470	0.885	.483	(28)
460617000	1,812	0.207	0.500	0.531	0.675	.478	(29)
479908000	3,058	0.130	0.930	0.269	0.580	.477	(30)
482005000	2,875	0.235	0.580	0.433	0.639	.472	(31)
485009000	1,268	0.000	0.241	0.818	0.821	.470	(32)
483003000	2,043	0.153	0.443	0.590	0.690	.469	(33)
479914000	3,812	0.205	0.632	0.370	0.637	.461	(34)
479910000	2,534	0.344	0.550	0.424	0.495	.454	(35)
479916000	2,869	0.155	0.502	0.401	0.715	.443	(36)
479909000	3,118	0.200	0.404	0.453	0.711	.442	(37)
487018000	821	0.053	0.169	0.649	0.897	.442	(38)
460520000	885	0.215	0.432	0.343	0.727	.429	(39)
460708000	1,315	0.279	0.611	0.387	0.431	.427	(40)
479905000	3,231	0.213	0.348	0.518	0.609	.422	(41)
460315000	1,907	0.220	0.351	0.484	0.631	.421	(42)
479912000	2,377	0.199	0.771	0.211	0.487	.417	(43)
460416000	921	0.206	0.424	0.347	0.586	.391	(44)
460206000	892	0.303	0.268	0.352	0.625	.387	(45)
479913000	2,744	0.175	0.704	0.197	0.467	.386	(46)
479901000	2,651	0.165	0.415	0.250	0.704	.384	(47)
479902000	2,692	0.154	0.650	0.171	0.559	.383	(48)
479904000	1,790	0.124	1.000	0.217	0.000	.335	(49)
479903000	2,620	0.150	0.891	0.085	0.143	.317	(50)
460804000	1,191	0.286	0.711	0.066	0.188	.313	(51)
460105000	1,556	0.220	0.426	0.234	0.344	.306	(52)
481004000	1,487	0.174	0.436	0.000	0.271	.220	(53)

4.1.2 Technology

The technology determinant reveals four concentrations of CDs exhibiting high and low ranks (Figure 4-2). The CDs in the high-ranking areas of southern Alberta and southern Manitoba scored very high on the computer technology and technological flexibility aspects, with the Alberta grouping showing generally higher scores on the water access technology aspect, whereas the Manitoba group scored higher on the technological exposure aspect.

The lowest-ranking areas are also found in Alberta and Manitoba, but in the more northern locations of each province. In Alberta, the lower-ranking CDs score moderately high on the technological flexibility aspect, but low on all other aspects of this determinant. The Manitoba grouping presents a similar pattern of scores.

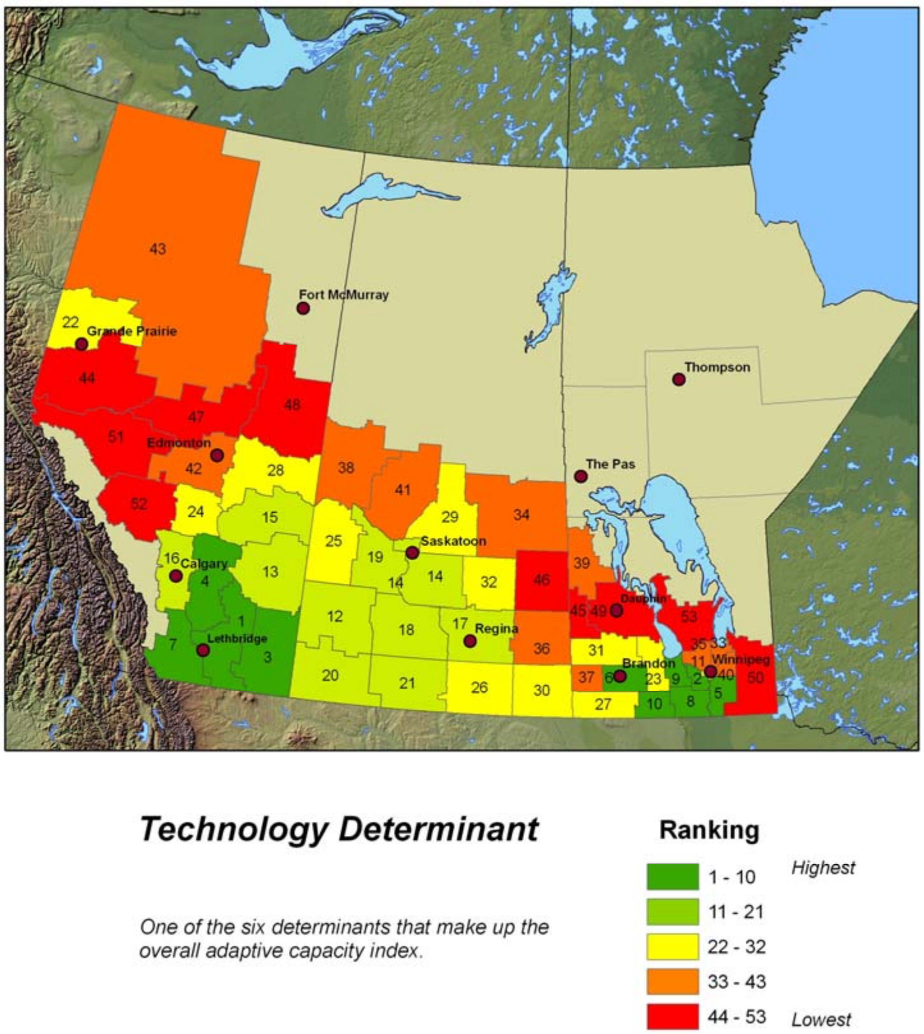


Figure 4-2. Results of relative rankings for the technology determinant.

Table 4-2. Normalized indicator results for the technology determinant.

Census Division		Normalized Indicator Values: Technology Determinant					
Census Division Code	Number of farms	Water access	Computer technology	Technological flexibility	Technological expeosure	Average (rank)	
482002000	3,329	1.000	.727	.902	.172	.700	(1)
460710000	455	.040	1.000	.902	.202	.536	(2)
481001000	1,636	.520	.559	.949	.094	.530	(3)
482005000	2,875	.200	.827	.938	.095	.515	(4)
460902000	1,655	.000	.420	.450	1.000	.468	(5)
460207000	1,246	.280	.470	.850	.144	.436	(6)
483003000	2,043	.280	.670	.720	.056	.432	(7)
460803000	1,830	.040	.429	.859	.288	.404	(8)
460709000	739	.120	.423	.774	.264	.395	(9)
460804000	1,191	.000	.377	.888	.256	.380	(10)
460911000	170	.000	.336	.561	.624	.380	(11)
479908000	3,058	.040	.456	.987	.003	.372	(12)
481004000	1,487	.080	.417	.955	.006	.365	(13)
479911000	3,564	.080	.356	.919	.088	.361	(14)
484007000	3,316	.000	.383	.952	.039	.344	(15)
483006000	4,941	.000	.682	.606	.084	.343	(16)
479906000	3,901	.000	.412	.921	.033	.341	(17)
479907000	2,795	.080	.309	.965	.011	.341	(18)
479912000	2,377	.040	.309	.969	.034	.338	(19)
479904000	1,790	.040	.333	.951	.000	.331	(20)
479903000	2,620	.000	.336	.974	.000	.327	(21)
487019000	3,531	.000	.392	.886	.025	.326	(22)
460708000	1,315	.080	.212	.844	.142	.319	(23)
485008000	4,542	.000	.474	.638	.163	.319	(24)
479913000	2,744	.000	.257	1.000	.013	.318	(25)
479902000	2,692	.000	.285	.969	.001	.314	(26)
460105000	1,556	.000	.284	.909	.053	.312	(27)
484110000	5,694	.000	.255	.881	.058	.299	(28)
479915000	4,382	.000	.182	.931	.068	.295	(29)
479901000	2,651	.000	.210	.937	.011	.290	(30)
460315000	1,907	.000	.255	.831	.053	.285	(31)
479910000	2,534	.000	.139	.960	.018	.279	(32)
461113000	539	.000	.227	.618	.260	.276	(33)
479914000	3,812	.000	.123	.939	.027	.272	(34)
461114000	830	.000	.280	.594	.213	.272	(35)
479905000	3,231	.000	.132	.897	.023	.263	(36)
460206000	892	.000	.245	.745	.047	.259	(37)
479917000	2,460	.000	.140	.889	.007	.259	(38)
460520000	885	.000	.109	.846	.066	.255	(39)
460912000	660	.000	.279	.512	.199	.247	(40)
479916000	2,869	.000	.053	.898	.018	.242	(41)
485011000	6,618	.000	.368	.420	.155	.236	(42)
487017000	2,758	.000	.145	.772	.020	.234	(43)
487018000	821	.000	.271	.631	.021	.231	(44)
460416000	921	.000	.122	.733	.030	.221	(45)
479909000	3,118	.000	.000	.833	.026	.215	(46)
486013000	4,921	.000	.192	.566	.076	.209	(47)
486012000	2,830	.000	.120	.647	.034	.200	(48)
460617000	1,812	.000	.021	.529	.032	.146	(49)
461001000	688	.000	.145	.073	.338	.139	(50)
486014000	904	.000	.177	.295	.055	.131	(51)
485009000	1,268	.000	.195	.050	.062	.077	(52)
461218000	1,534	.000	.044	.000	.071	.029	(53)

4.1.3 Information, skills and management

Mapping of the information, skills and management determinant shows three clusters, two of higher ranks and one with lower ranks (Figure 4-3). Of the higher-ranked areas, one is reported in a band running from southwestern Alberta through to west-central Saskatchewan. CDs in this area record very high to high scores on the enterprise information management, sustainable soil resource management practices and human resources management aspects. In the high-ranking areas in southern Manitoba, similar results are reported with the main difference being very high scores for the environmental management practices aspect and much lower scores for the sustainable soil resource management practices aspect.

The grouping of very low-ranking CDs is found in east-central Saskatchewan and the northern extent of the Prairie region in Manitoba. Generally, results show that scores for all aspects are low with some ranking amongst the lowest in the Prairie region, including scores for the enterprise information management and human resources management aspects.

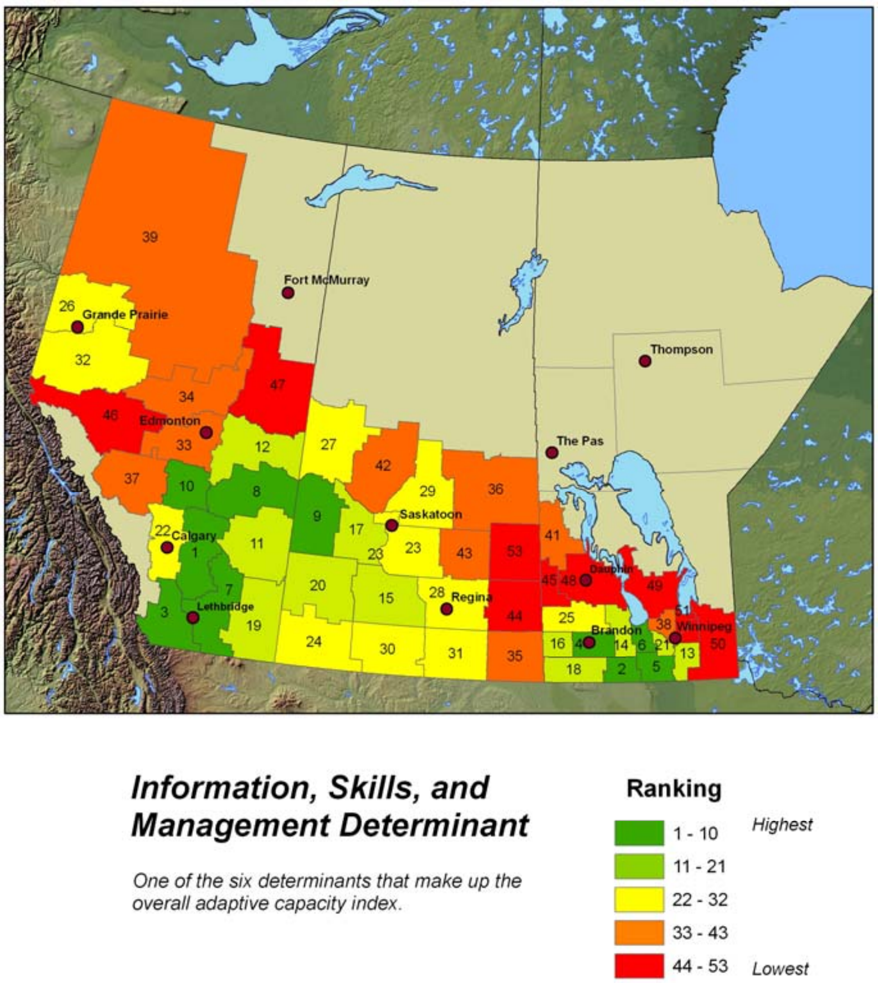


Figure 4-3. Results of relative rankings for the information, skills and management determinant.

Table 4-3. Normalized indicator results for the information, skills and management determinant.

Census Division		Normalized Indicator Values: Information, Skills and Management Determinant				
Census Division Code	Number of farms	Enterprise information management	Soil resource management practices	Environmental management practices	Human resources management	Average (rank)
482005000	2,875	.829	1.000	.218	.677	.681 (1)
460804000	1,191	.631	.161	.855	.796	.611 (2)
483003000	2,043	1.000	.640	.229	.441	.577 (3)
460207000	1,246	.750	.324	.698	.492	.566 (4)
460803000	1,830	.520	.053	.934	.717	.556 (5)
460709000	739	.556	.064	1.000	.596	.554 (6)
482002000	3,329	.812	.359	.002	1.000	.543 (7)
484007000	3,316	.517	.589	.403	.601	.528 (8)
479913000	2,744	.320	.549	.371	.832	.518 (9)
485008000	4,542	.725	.156	.685	.366	.483 (10)
481004000	1,487	.578	.384	.167	.734	.466 (11)
484110000	5,694	.429	.646	.419	.364	.464 (12)
460902000	1,655	.811	.068	.200	.761	.460 (13)
460708000	1,315	.372	.117	.841	.501	.458 (14)
479907000	2,795	.406	.565	.390	.464	.456 (15)
460206000	892	.475	.498	.368	.472	.453 (16)
479912000	2,377	.343	.669	.361	.411	.446 (17)
460105000	1,556	.412	.530	.449	.393	.446 (18)
481001000	1,636	.428	.444	.000	.879	.438 (19)
479908000	3,058	.383	.489	.108	.770	.438 (20)
460710000	455	.823	.007	.145	.743	.429 (21)
483006000	4,941	.839	.279	.366	.232	.429 (22)
479911000	3,564	.388	.682	.273	.368	.428 (23)
479904000	1,790	.346	.310	.352	.505	.378 (24)
460315000	1,907	.464	.301	.359	.384	.377 (25)
487019000	3,531	.353	.284	.418	.367	.356 (26)
479917000	2,460	.281	.544	.199	.379	.351 (27)
479906000	3,901	.404	.620	.117	.253	.348 (28)
479915000	4,382	.233	.562	.183	.350	.332 (29)
479903000	2,620	.244	.444	.233	.396	.329 (30)
479902000	2,692	.259	.488	.169	.398	.328 (31)
487018000	821	.457	.182	.552	.097	.322 (32)
485011000	6,618	.558	.159	.413	.149	.320 (33)
486013000	4,921	.375	.123	.528	.168	.298 (34)
479901000	2,651	.236	.463	.138	.258	.274 (35)
479914000	3,812	.151	.380	.215	.326	.268 (36)
485009000	1,268	.456	.000	.479	.072	.252 (37)
461114000	830	.606	.056	.188	.156	.252 (38)
487017000	2,758	.136	.160	.495	.195	.247 (39)
460911000	170	.342	.060	.260	.319	.245 (40)
460520000	885	.283	.071	.277	.337	.242 (41)
479916000	2,869	.175	.341	.189	.253	.239 (42)
479910000	2,534	.174	.396	.063	.313	.237 (43)
479905000	3,231	.220	.344	.093	.267	.231 (44)
460416000	921	.301	.146	.235	.177	.215 (45)
486014000	904	.353	.000	.467	.000	.205 (46)
486012000	2,830	.232	.193	.169	.184	.195 (47)
460617000	1,812	.163	.127	.258	.225	.193 (48)
461218000	1,534	.140	.136	.179	.221	.169 (49)
461001000	688	.381	.065	.152	.074	.168 (50)
461113000	539	.256	.111	.183	.120	.167 (51)
460912000	660	.394	.087	.059	.009	.137 (52)
479909000	3,118	.000	.179	.039	.165	.096 (53)

4.1.4 Infrastructure

Concentrations of high-ranked CDs on the infrastructure determinant are found in southern Manitoba and concentrations of low-ranked CDs in east-central Alberta into southwestern Saskatchewan. The CDs in southern Manitoba present distinctive results based on very high scores on either the soil resource aspect (e.g., CD 460803000), the transportation network aspect (e.g., CD 460911000) or moderately high scores on both aspects (e.g., CD 461113000). The results for the low-ranking CDs are unambiguous—very low scores on both aspects.

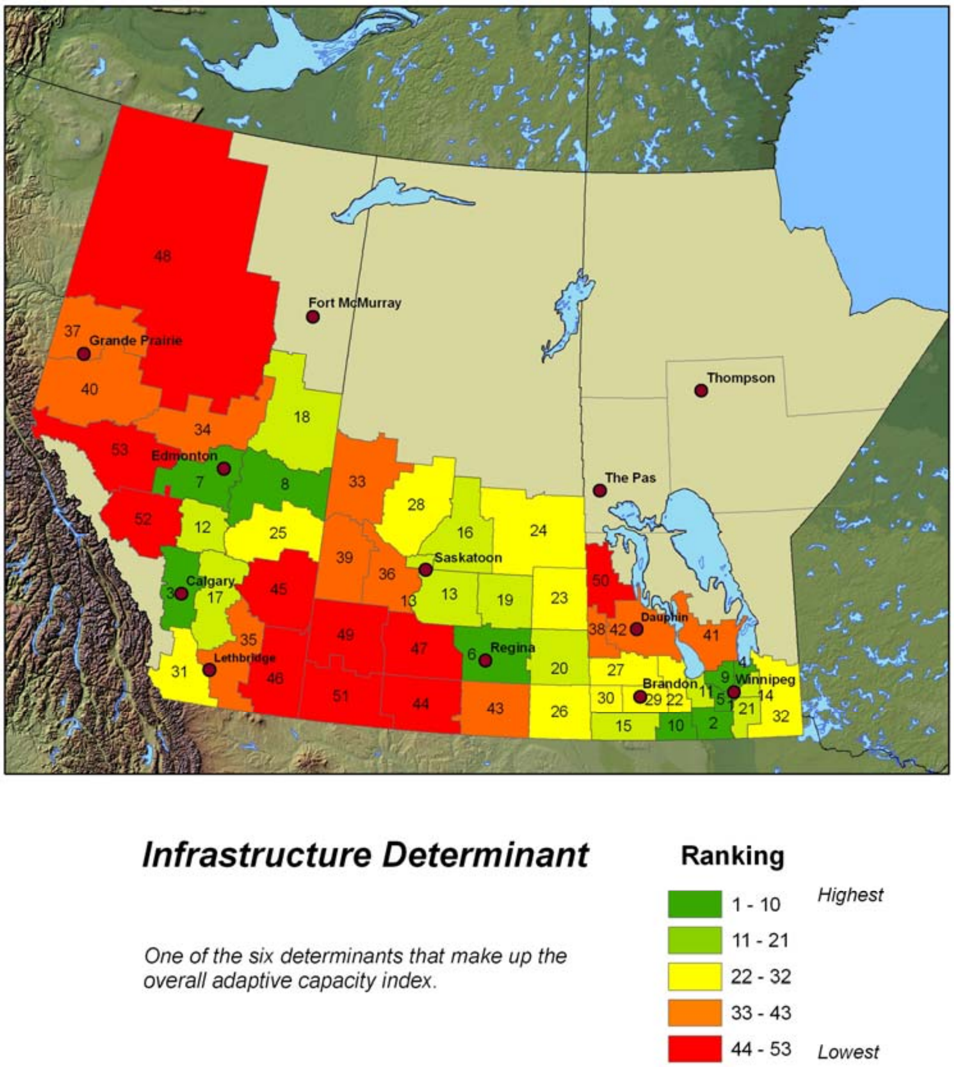


Figure 4-4. Results of relative rankings for the infrastructure.

Table 4-4. Normalized indicator results for the infrastructure determinant.

Census Division		Normalized Indicator Values: Infrastructure Determinant			
Census Division Code	Number of farms	Soil resource	Transportation network	Average (rank)	
460911000	170	.048	1.000	.524	(1)
460803000	1,830	1.000	.014	.507	(2)
483006000	4,941	.032	.223	.128	(3)
461113000	539	.090	.148	.119	(4)
460710000	455	.193	.017	.105	(5)
479906000	3,901	.187	.022	.104	(6)
485011000	6,618	.056	.153	.104	(7)
484110000	5,694	.142	.051	.096	(8)
461114000	830	.154	.037	.095	(9)
460804000	1,191	.164	.014	.089	(10)
460709000	739	.150	.027	.088	(11)
485008000	4,542	.067	.073	.070	(12)
479911000	3,564	.109	.026	.067	(13)
460912000	660	.080	.049	.065	(14)
460105000	1,556	.099	.016	.057	(15)
479915000	4,382	.101	.013	.057	(16)
482005000	2,875	.082	.031	.057	(17)
486012000	2,830	.014	.098	.056	(18)
479910000	2,534	.110	.000	.055	(19)
479905000	3,231	.100	.010	.055	(20)
460902000	1,655	.056	.053	.054	(21)
460708000	1,315	.100	.007	.054	(22)
479909000	3,118	.090	.008	.049	(23)
479914000	3,812	.092	.004	.048	(24)
484007000	3,316	.058	.035	.046	(25)
479901000	2,651	.089	.003	.046	(26)
460315000	1,907	.076	.012	.044	(27)
479916000	2,869	.076	.011	.043	(28)
460207000	1,246	.042	.043	.043	(29)
460206000	892	.056	.027	.042	(30)
483003000	2,043	.024	.057	.040	(31)
461001000	688	.000	.080	.040	(32)
479917000	2,460	.038	.042	.040	(33)
486013000	4,921	.032	.037	.034	(34)
482002000	3,329	.014	.052	.033	(35)
479912000	2,377	.051	.014	.032	(36)
487019000	3,531	.050	.014	.032	(37)
460416000	921	.057	.007	.032	(38)
479913000	2,744	.053	.008	.030	(39)
487018000	821	.050	.002	.026	(40)
461218000	1,534	.029	.018	.024	(41)
460617000	1,812	.027	.020	.023	(42)
479902000	2,692	.043	.004	.023	(43)
479903000	2,620	.043	.004	.023	(44)
481004000	1,487	.011	.035	.023	(45)
481001000	1,636	.013	.031	.022	(46)
479907000	2,795	.032	.012	.022	(47)
487017000	2,758	.030	.013	.021	(48)
479908000	3,058	.037	.000	.019	(49)
460520000	885	.011	.021	.016	(50)
479904000	1,790	.010	.007	.008	(51)
485009000	1,268	.000	.016	.008	(52)
486014000	904	.004	.003	.004	(53)

4.1.5 *Institutions and networks*

Two areas of high ranks and an extensive area of low ranks are observed for this determinant. One high-ranking area is in southern Alberta. For this area, all aspects scored well with the exception of the social capital aspect for which the results were more variable. A second area is located through south and central Saskatchewan exhibiting very high scores for the social capital and access to agricultural education institutions, with lower scores on the e-mail use aspect.

A band of low ranks exists on the north boundary of the Prairie region. In Alberta, very high scores for the social capital aspect are not sufficient to overcome much lower scores for the other aspects. In Manitoba, high scores on the social capital and access to agricultural education aspects do not overcome very low scores on the e-mail use and Internet use aspects. Low ranks extend through Saskatchewan on the northern fringe, however they present a more diffuse pattern.

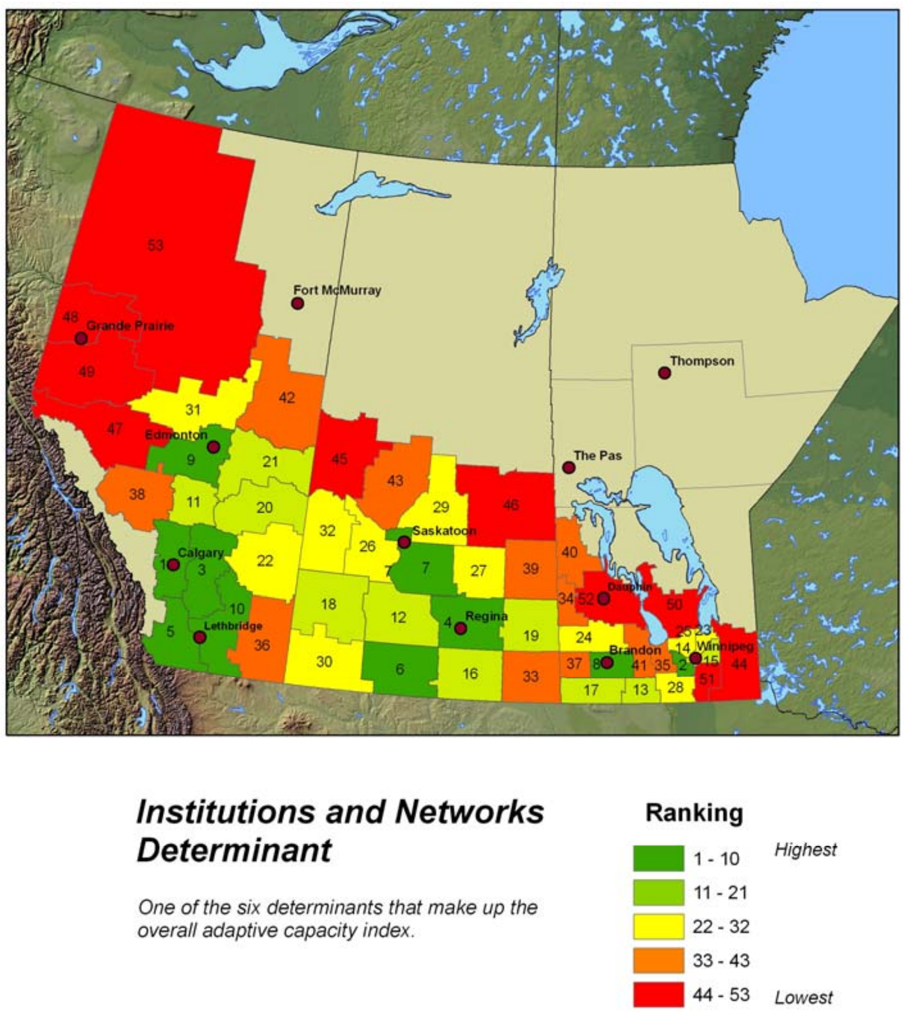


Figure 4-5. Results of relative rankings for the institutions and networks determinant.

Table 4-5. Normalized indicator results for the institutions and networks determinant.

Census Division		Normalized Indicator Values: Institutions and Networks Determinant					
Census Division Code	Number of farms	Informal operating arrangements	E-mail use	Internet access	Access to agricultural education institutions	Average (rank)	
483006000	4,941	.608	.895	.913	.980	.849	(1)
460710000	455	.348	.872	.983	.940	.785	(2)
482005000	2,875	.203	1.000	1.000	.838	.760	(3)
479906000	3,901	.900	.532	.597	.957	.746	(4)
483003000	2,043	.403	.736	.766	.884	.697	(5)
479903000	2,620	.834	.470	.509	.940	.688	(6)
479911000	3,564	.813	.499	.520	.866	.675	(7)
460207000	1,246	.533	.516	.599	.981	.657	(8)
485011000	6,618	.740	.477	.478	.907	.651	(9)
482002000	3,329	.155	.743	.817	.885	.650	(10)
485008000	4,542	.637	.597	.600	.725	.640	(11)
479907000	2,795	.799	.466	.503	.756	.631	(12)
460804000	1,191	.766	.431	.430	.786	.603	(13)
460911000	170	.547	.410	.427	1.000	.596	(14)
460912000	660	.849	.286	.316	.924	.594	(15)
479902000	2,692	.760	.387	.448	.777	.593	(16)
460105000	1,556	.670	.387	.427	.853	.584	(17)
479908000	3,058	.366	.676	.754	.534	.583	(18)
479905000	3,231	.965	.216	.241	.907	.582	(19)
484007000	3,316	.634	.450	.465	.776	.581	(20)
484110000	5,694	.799	.307	.304	.888	.574	(21)
481004000	1,487	.485	.589	.647	.540	.565	(22)
461113000	539	.741	.315	.288	.910	.564	(23)
460315000	1,907	.736	.320	.323	.870	.562	(24)
461114000	830	.803	.258	.260	.914	.559	(25)
479912000	2,377	.579	.336	.405	.831	.538	(26)
479910000	2,534	.938	.223	.226	.745	.533	(27)
460803000	1,830	.545	.360	.390	.834	.532	(28)
479915000	4,382	.862	.226	.255	.768	.528	(29)
479904000	1,790	.546	.457	.526	.566	.523	(30)
486013000	4,921	.792	.246	.257	.786	.520	(31)
479913000	2,744	.558	.408	.454	.634	.514	(32)
479901000	2,651	.844	.270	.275	.662	.513	(33)
460416000	921	.898	.178	.196	.761	.508	(34)
460709000	739	.402	.393	.379	.847	.505	(35)
481001000	1636	.000	.625	.671	.689	.496	(36)
460206000	892	.681	.197	.197	.852	.482	(37)
485009000	1,268	.765	.260	.253	.623	.475	(38)
479909000	3,118	1.000	.039	.047	.808	.474	(39)
460520000	885	.931	.186	.141	.624	.471	(40)
460708000	1,315	.703	.165	.169	.834	.468	(41)
486012000	2,830	.895	.149	.155	.667	.466	(42)
479916000	2,869	.944	.090	.100	.702	.459	(43)
461001000	688	.918	.066	.042	.801	.457	(44)
479917000	2,460	.784	.152	.162	.720	.455	(45)
479914000	3,812	.807	.204	.227	.496	.434	(46)
486014000	904	.687	.276	.280	.483	.432	(47)
487019000	3,531	.693	.440	.470	.122	.431	(48)
487018000	821	.776	.306	.334	.307	.431	(49)
461218000	1,534	.919	.040	.020	.715	.424	(50)
460902000	1,655	.265	.247	.251	.891	.414	(51)
460617000	1,812	.871	.000	.000	.700	.393	(52)
487017000	2,758	.822	.176	.168	.000	.291	(53)

4.1.6 Equity

Mapping of the equity determinant reveals that high-ranking CDs tended to represent areas with smaller urban centres. The high rankings are due to a combination of good employment opportunities and a larger portion of the population having access to health and social services (i.e., as represented by the portion of population involved in health- and social service-related jobs). CDs ranking low on the equity determinant tended to be in more remote areas of the Prairie agricultural region.

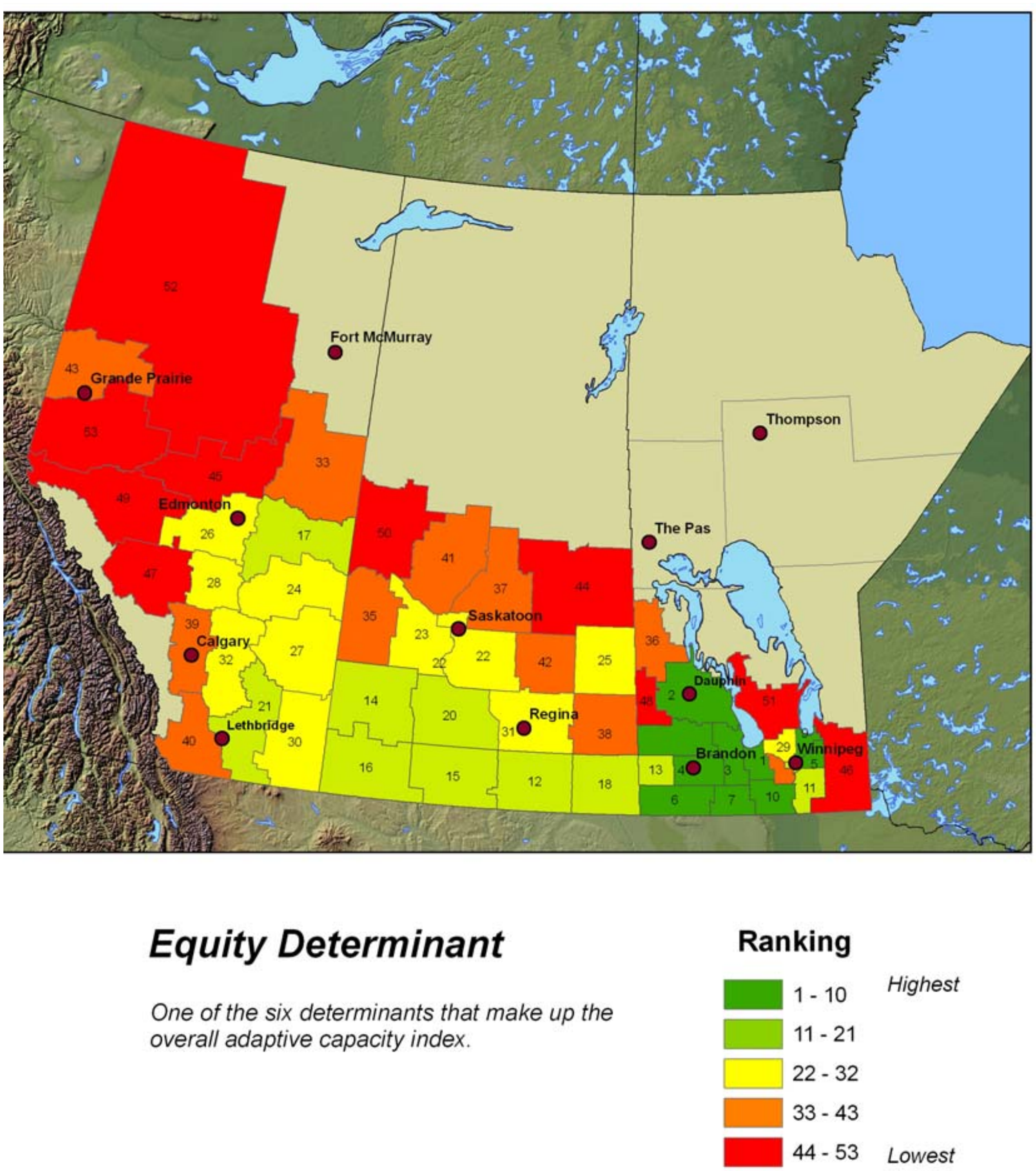


Figure 4-6. Results of relative rankings for the equity determinant.

Table 4-6. Normalized indicator results for the equity determinant.

Census Division		Normalized Indicator Values: Equity Determinant			
Census Division Code	Number of farms	Employment opportunities	Access to health and social services	Average (rank)	
460709000	739	.625	1.000	.813	(1)
460617000	1,812	.500	.946	.723	(2)
460708000	1,315	.750	.692	.721	(3)
460207000	1,246	.625	.815	.720	(4)
460912000	660	.875	.556	.716	(5)
460105000	1,556	.875	.521	.698	(6)
460804000	1,191	.875	.451	.663	(7)
460315000	1,907	.750	.574	.662	(8)
461113000	539	.625	.681	.653	(9)
460803000	1,830	.750	.537	.643	(10)
460902000	1,655	.750	.524	.637	(11)
479902000	2,692	.875	.381	.628	(12)
460206000	892	.625	.593	.609	(13)
479908000	3,058	.875	.336	.606	(14)
479903000	2,620	1.000	.202	.601	(15)
479904000	1,790	.875	.324	.599	(16)
484110000	5,694	.750	.438	.594	(17)
479901000	2,651	.875	.302	.588	(18)
460911000	170	.500	.660	.580	(19)
479907000	2,795	.500	.659	.579	(20)
482002000	3,329	.625	.517	.571	(21)
479911000	3,564	.375	.754	.564	(22)
479912000	2,377	.750	.375	.563	(23)
484007000	3,316	.875	.234	.555	(24)
479909000	3,118	.625	.483	.554	(25)
485011000	6,618	.625	.480	.552	(26)
481004000	1,487	.875	.225	.550	(27)
485008000	4,542	.625	.459	.542	(28)
461114000	830	.625	.436	.531	(29)
481001000	1,636	.625	.413	.519	(30)
479906000	3,901	.500	.533	.516	(31)
482005000	2,875	.750	.269	.510	(32)
486012000	2,830	.500	.507	.504	(33)
460710000	455	.750	.253	.501	(34)
479913000	2,744	.750	.249	.500	(35)
460520000	885	.375	.618	.497	(36)
479915000	4,382	.250	.655	.453	(37)
479905000	3,231	.500	.399	.450	(38)
483006000	4,941	.625	.269	.447	(39)
483003000	2,043	.250	.641	.446	(40)
479916000	2,869	.250	.627	.439	(41)
479910000	2,534	.500	.364	.432	(42)
487019000	3,531	.500	.319	.410	(43)
479914000	3,812	.375	.400	.387	(44)
486013000	4,921	.500	.259	.379	(45)
461001000	688	.375	.358	.366	(46)
485009000	1,268	.500	.232	.366	(47)
460416000	921	.375	.355	.365	(48)
486014000	904	.500	.138	.319	(49)
479917000	2,460	.250	.387	.319	(50)
461218000	1,534	.000	.539	.269	(51)
487017000	2,758	.125	.390	.257	(52)
487018000	821	.375	.000	.188	(53)

4.2 Index of adaptive capacity

Listed in Table 4-7 for each of the 53 Census Divisions in the Prairie agricultural region are the Census Division's geographic code, the overall adaptive capacity index and ranking relative to all other CDs, the values and rankings for each of the six determinants, and the normalized values for the indicators that are averaged to make up each determinant value. The results are organized according to ranking—the CD with the highest composite adaptive-capacity index is listed first, while the CD with the lowest overall ranking appears last in the table.

The adaptive capacity indices represent the average of the individual determinant values, while the determinant values are the average of the normalized indicator values. Of interest from a policy perspective are the locations of clusters of very high- and very low-ranking CDs and, additionally, which determinants are the principal contributors to these rankings. From such an analysis we can better understand potential areas and avenues for policy intervention.

The general pattern of overall adaptive capacity (Figure 4-7) as revealed by the census data shows clusters of very high (i.e., top quintile showing the top-10 CDs) and high (second-highest quintile) adaptive capacity near large urban centres in each province with progressively decreasing adaptive capacity to the northern periphery of agriculture in the Prairie region. This is perhaps not surprising considering that many of the individual indicators for the determinants favour proximity to urban centres—e.g., off-farm earnings, diversity of employment opportunities, transportation network, e-mail/Internet use, access to agricultural educational opportunities and employment opportunities.

The sections below provide a more detailed analysis of the areas exhibiting highest and lowest adaptive capacity in the Prairies.

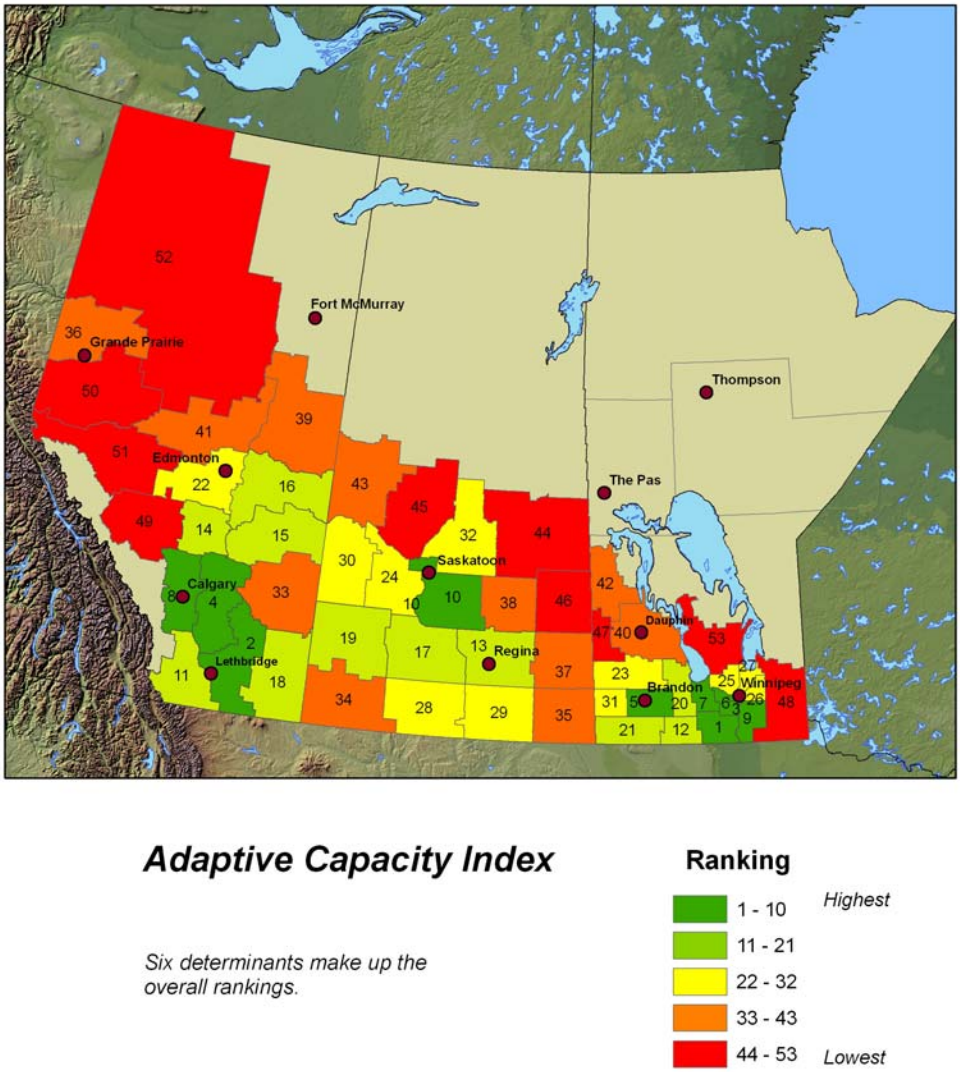


Figure 4-7. Map showing the rankings of the Prairie Census Divisions according to the adaptive capacity index.

Table 4-7. Adaptive capacity indices, determinant averages and normalized indicator values.

Census Division		Overall Adaptive Capacity Index (ranking in brackets)		Economic Resources						Technology						Information, Skills and Management					
Census Division Code	Number of farms			Income generation relative to capital investment	Income generation relative to expenses	Off-farm earnings	Diversity of employment opportunities	Average (rank)		Water access	Computer technology	Technological flexibility	Technological expeosure	Average (rank)		Enterprise information management	Soil resource management practices	Environmental management practices	Human resources management	Average (rank)	
460803000	1,830	.524	(1)	0.292	0.576	0.369	0.767	.501	(19)	.040	.429	.859	.288	.404	(8)	.520	.053	.934	.717	556	(5)
482002000	3,329	.511	(2)	0.638	0.203	0.576	0.849	.567	(6)	1.000	.727	.902	.172	.700	(1)	.812	.359	.002	1.000	543	(7)
460911000	170	.508	(3)	1.000	0.028	0.875	1.000	.726	(1)	.000	.336	.561	.624	.380	(11)	.342	.060	.260	.319	245	(40)
482005000	2,875	.499	(4)	0.235	0.580	0.433	0.639	.472	(31)	.200	.827	.938	.095	.515	(4)	.829	1.000	.218	.677	681	(1)
460207000	1,246	.492	(5)	0.244	0.373	0.596	0.915	.532	(15)	.280	.470	.850	.144	.436	(6)	.750	.324	.698	.492	566	(4)
460710000	455	.487	(6)	0.315	0.903	0.410	0.641	.567	(5)	.040	1.000	.902	.202	.536	(2)	.823	.007	.145	.743	429	(21)
460709000	739	.484	(7)	0.285	0.698	0.419	0.791	.548	(10)	.120	.423	.774	.264	.395	(9)	.556	.064	1.000	.596	554	(6)
483006000	4,941	.459	(8)	0.057	0.325	0.859	0.988	.557	(9)	.000	.682	.606	.084	.343	(16)	.839	.279	.366	.232	.429	(22)
460902000	1,655	.458	(9)	0.582	0.741	0.690	0.852	.717	(2)	.000	.420	.450	1.000	.468	(5)	.811	.068	.200	.761	.460	(13)
479911000	3,564	.450	(10)	0.226	0.761	0.489	0.947	.606	(4)	.080	.356	.919	.088	.361	(14)	.388	.682	.273	.368	.428	(23)
483003000	2,043	.443	(11)	0.153	0.443	0.590	0.690	.469	(33)	.280	.670	.720	.056	.432	(7)	1.000	.640	.229	.441	.577	(3)
460804000	1,191	.443	(12)	0.286	0.711	0.066	0.188	.313	(51)	.000	.377	.888	.256	.380	(10)	.631	.161	.855	.796	.611	(2)
479906000	3,901	.432	(13)	0.174	0.488	0.541	0.948	.538	(11)	.000	.412	.921	.033	.341	(17)	.404	.620	.117	.253	.348	(28)
485008000	4,542	.426	(14)	0.162	0.359	0.594	0.887	.500	(20)	.000	.474	.638	.163	.319	(24)	.725	.156	.685	.366	.483	(10)
484007000	3,316	.426	(15)	0.172	0.718	0.458	0.652	.500	(21)	.000	.383	.952	.039	.344	(15)	.517	.589	.403	.601	.528	(8)
484110000	5,694	.421	(16)	0.150	0.531	0.562	0.746	.497	(23)	.000	.255	.881	.058	.299	(28)	.429	.646	.419	.364	.464	(12)
479907000	2,795	.420	(17)	0.191	0.792	0.198	0.784	.491	(25)	.080	.309	.965	.011	.341	(18)	.406	.565	.390	.464	.456	(15)
481001000	1,636	.417	(18)	0.159	0.701	0.252	0.871	.496	(24)	.520	.559	.949	.094	.530	(3)	.428	.444	.000	.879	.438	(19)
479908000	3,058	.416	(19)	0.130	0.930	0.269	0.580	.477	(30)	.040	.456	.987	.003	.372	(12)	.383	.489	.108	.770	.438	(20)
460708000	1,315	.408	(20)	0.279	0.611	0.387	0.431	.427	(40)	.080	.212	.844	.142	.319	(23)	.372	.117	.841	.501	.458	(14)
460105000	1,556	.400	(21)	0.220	0.426	0.234	0.344	.306	(52)	.000	.284	.909	.053	.312	(27)	.412	.530	.449	.393	.446	(18)
485011000	6,618	.400	(22)	0.075	0.350	0.743	0.982	.538	(12)	.000	.368	.420	.155	.236	(42)	.558	.159	.413	.149	.320	(33)
460315000	1,907	.392	(23)	0.220	0.351	0.484	0.631	.421	(42)	.000	.255	.831	.053	.285	(31)	.464	.301	.359	.384	.377	(25)
479912000	2,377	.389	(24)	0.199	0.771	0.211	0.487	.417	(43)	.040	.309	.969	.034	.338	(19)	.343	.669	.361	.411	.446	(17)
461114000	830	.387	(25)	0.276	0.544	0.824	0.800	.611	(3)	.000	.280	.594	.213	.272	(35)	.606	.056	.188	.156	.252	(38)
460912000	660	.386	(26)	0.221	0.243	0.865	0.907	.559	(8)	.000	.279	.512	.199	.247	(40)	.394	.087	.059	.009	.137	(52)
461113000	539	.386	(27)	0.182	0.386	0.608	0.962	.534	(14)	.000	.227	.618	.260	.276	(33)	.256	.111	.183	.120	.167	(51)
479903000	2,620	.381	(28)	0.150	0.891	0.085	0.143	.317	(50)	.000	.336	.974	.000	.327	(21)	.244	.444	.233	.396	.329	(30)
479902000	2,692	.378	(29)	0.154	0.650	0.171	0.559	.383	(48)	.000	.285	.969	.001	.314	(26)	.259	.488	.169	.398	.328	(31)
479913000	2,744	.377	(30)	0.175	0.704	0.197	0.467	.386	(46)	.000	.257	1.000	.013	.318	(25)	.320	.549	.371	.832	.518	(9)
460206000	892	.372	(31)	0.303	0.268	0.352	0.625	.387	(45)	.000	.245	.745	.047	.259	(37)	.475	.498	.368	.472	.453	(16)
479915000	4,382	.365	(32)	0.194	0.630	0.460	0.820	.526	(17)	.000	.182	.931	.068	.295	(29)	.233	.562	.183	.350	.332	(29)
481004000	1,487	.365	(33)	0.174	0.436	0.000	0.271	.220	(53)	.080	.417	.955	.006	.365	(13)	.578	.384	.167	.734	.466	(11)
479904000	1,790	.363	(34)	0.124	1.000	0.217	0.000	.335	(49)	.040	.333	.951	.000	.331	(20)	.346	.310	.352	.505	.378	(24)
479901000	2,651	.349	(35)	0.165	0.415	0.250	0.704	.384	(47)	.000	.210	.937	.011	.290	(30)	.236	.463	.138	.258	.274	(35)
487019000	3,531	.347	(36)	0.132	0.410	0.691	0.878	.528	(16)	.000	.392	.886	.025	.326	(22)	.353	.284	.418	.367	.356	(26)
479905000	3,231	.334	(37)	0.213	0.348	0.518	0.609	.422	(41)	.000	.132	.897	.023	.263	(36)	.220	.344	.093	.267	.231	(44)
479910000	2,534	.332	(38)	0.344	0.550	0.424	0.495	.454	(35)	.000	.139	.960	.018	.279	(32)	.174	.396	.063	.313	.237	(43)
486012000	2,830	.330	(39)	0.109	0.319	0.912	0.897	.559	(7)	.000	.120	.647	.034	.200	(48)	.232	.193	.169	.184	.195	(47)
460617000	1,812	.326	(40)	0.207	0.500	0.531	0.675	.478	(29)	.000	.021	.529	.032	.146	(49)	.163	.127	.258	.225	.193	(48)
486013000	4,921	.322	(41)	0.178	0.324	0.675	0.787	.491	(26)	.000	.192	.566	.076	.209	(47)	.375	.123	.528	.168	.298	(34)
460520000	885	.318	(42)	0.215	0.432	0.343	0.727	.429	(39)	.000	.109	.846	.066	.255	(39)	.283	.071	.277	.337	.242	(41)
479917000	2,460	.318	(43)	0.126	0.505	0.538	0.772	.485	(27)	.000	.140	.889	.007	.259	(38)	.281	.544	.199	.379	.351	(27)
479914000	3,812	.312	(44)	0.205	0.632	0.370	0.637	.461	(34)	.000	.123	.939	.027	.272	(34)	.151	.380	.215	.326	.268	(36)
479916000	2,869	.311	(45)	0.155	0.502	0.401	0.715	.443	(36)	.000	.053	.898	.018	.242	(41)	.175	.341	.189	.253	.239	(42)
479909000	3,118	.305	(46)	0.200	0.404	0.453	0.711	.442	(37)	.000	.000	.833	.026	.215	(46)	.000	.179	.039	.165	.096	(53)
460416000	921	.289	(47)	0.206	0.424	0.347	0.586	.391	(44)	.000	.122	.733	.030	.221	(45)	.301	.146	.235	.177	.215	(45)
461001000	688	.276	(48)	0.233	0.345	0.470	0.885	.483	(28)	.000	.145	.073	.338	.139	(50)	.381	.065	.152	.074	.168	(50)
485009000	1,268	.275	(49)	0.000	0.241	0.818	0.821	.470	(32)	.000	.195	.050	.062	.077	(52)	.456	.000	.479	.072	.252	(37)
487018000	821	.273	(50)	0.053	0.169	0.649	0.897	.442	(38)	.000	.271	.631	.021	.231	(44)	.457	.182	.552	.097	.322	(32)
486014000	904	.271	(51)	0.199	0.000	1.000	0.942	.535	(13)	.000	.177	.295	.055	.131	(51)	.353	.000	.467	.000	.205	(46)
487017000	2,758	.260	(52)	0.110	0.306	0.748	0.881	.511	(18)	.000	.145	.772	.020	.234	(43)	.136	.160	.495	.195	.247	(39)
461218000	1,534	.236	(53)	0.240	0.611	0.412	0.734	.499	(22)	.000	.044	.000	.071	.029	(53)	.140	.136	.179	.221	.169	(49)

Table 4-7 (continued). Determinant averages and normalized indicator values.

Census Division		Overall Adaptive Capacity Index (ranking in brackets)		Infrastructure				Institutions and Networks						Equity			
Census Division Code	Number of farms			Soil resource	Transportation network	Average (rank)		Informal operating arrangements	E-mail use	Internet access	Access to agricultural education institutions	Average (rank)		Employment opportunities	Access to health and social services	Average (rank)	
460803000	1,830	.524	(1)	1.000	.014	.507	(2)	.545	.360	.390	.834	.532	(28)	.750	.537	.643	(10)
482002000	3,329	.511	(2)	.014	.052	.033	(35)	.155	.743	.817	.885	.650	(10)	.625	.517	.571	(21)
460911000	170	.508	(3)	.048	1.000	.524	(1)	.547	.410	.427	1.000	.596	(14)	.500	.660	.580	(19)
482005000	2,875	.499	(4)	.082	.031	.057	(17)	.203	1.000	1.000	.838	.760	(3)	.750	.269	.510	(32)
460207000	1,246	.492	(5)	.042	.043	.043	(29)	.533	.516	.599	.981	.657	(8)	.625	.815	.720	(4)
460710000	455	.487	(6)	.193	.017	.105	(5)	.348	.872	.983	.940	.785	(2)	.750	.253	.501	(34)
460709000	739	.484	(7)	.150	.027	.088	(11)	.402	.393	.379	.847	.505	(35)	.625	1.000	.813	(1)
483006000	4,941	.459	(8)	.032	.223	.128	(3)	.608	.895	.913	.980	.849	(1)	.625	.269	.447	(39)
460902000	1,655	.458	(9)	.056	.053	.054	(21)	.265	.247	.251	.891	.414	(51)	.750	.524	.637	(11)
479911000	3,564	.450	(10)	.109	.026	.067	(13)	.813	.499	.520	.866	.675	(7)	.375	.754	.564	(22)
483003000	2,043	.443	(11)	.024	.057	.040	(31)	.403	.736	.766	.884	.697	(5)	.250	.641	.446	(40)
460804000	1,191	.443	(12)	.164	.014	.089	(10)	.766	.431	.430	.786	.603	(13)	.875	.451	.663	(7)
479906000	3,901	.432	(13)	.187	.022	.104	(6)	.900	.532	.597	.957	.746	(4)	.500	.533	.516	(31)
485008000	4,542	.426	(14)	.067	.073	.070	(12)	.637	.597	.600	.725	.640	(11)	.625	.459	.542	(28)
484007000	3,316	.426	(15)	.058	.035	.046	(25)	.634	.450	.465	.776	.581	(20)	.875	.234	.555	(24)
484110000	5,694	.421	(16)	.142	.051	.096	(8)	.799	.307	.304	.888	.574	(21)	.750	.438	.594	(17)
479907000	2,795	.420	(17)	.032	.012	.022	(47)	.799	.466	.503	.756	.631	(12)	.500	.659	.579	(20)
481001000	1,636	.417	(18)	.013	.031	.022	(46)	.000	.625	.671	.689	.496	(36)	.625	.413	.519	(30)
479908000	3,058	.416	(19)	.037	.000	.019	(49)	.366	.676	.754	.534	.583	(18)	.875	.336	.606	(14)
460708000	1,315	.408	(20)	.100	.007	.054	(22)	.703	.165	.169	.834	.468	(41)	.750	.692	.721	(3)
460105000	1,556	.400	(21)	.099	.016	.057	(15)	.670	.387	.427	.853	.584	(17)	.875	.521	.698	(6)
485011000	6,618	.400	(22)	.056	.153	.104	(7)	.740	.477	.478	.907	.651	(9)	.625	.480	.552	(26)
460315000	1,907	.392	(23)	.076	.012	.044	(27)	.736	.320	.323	.870	.562	(24)	.750	.574	.662	(8)
479912000	2,377	.389	(24)	.051	.014	.032	(36)	.579	.336	.405	.831	.538	(26)	.750	.375	.563	(23)
461114000	830	.387	(25)	.154	.037	.095	(9)	.803	.258	.260	.914	.559	(25)	.625	.436	.531	(29)
460912000	660	.386	(26)	.080	.049	.065	(14)	.849	.286	.316	.924	.594	(15)	.875	.556	.716	(5)
461113000	539	.386	(27)	.090	.148	.119	(4)	.741	.315	.288	.910	.564	(23)	.625	.681	.653	(9)
479903000	2,620	.381	(28)	.043	.004	.023	(44)	.834	.470	.509	.940	.688	(6)	1.000	.202	.601	(15)
479902000	2,692	.378	(29)	.043	.004	.023	(43)	.760	.387	.448	.777	.593	(16)	.875	.381	.628	(12)
479913000	2,744	.377	(30)	.053	.008	.030	(39)	.558	.408	.454	.634	.514	(32)	.750	.249	.500	(35)
460206000	892	.372	(31)	.056	.027	.042	(30)	.681	.197	.197	.852	.482	(37)	.625	.593	.609	(13)
479915000	4,382	.365	(32)	.101	.013	.057	(16)	.862	.226	.255	.768	.528	(29)	.250	.655	.453	(37)
481004000	1,487	.365	(33)	.011	.035	.023	(45)	.485	.589	.647	.540	.565	(22)	.875	.225	.550	(27)
479904000	1,790	.363	(34)	.010	.007	.008	(51)	.546	.457	.526	.566	.523	(30)	.875	.324	.599	(16)
479901000	2,651	.349	(35)	.089	.003	.046	(26)	.844	.270	.275	.662	.513	(33)	.875	.302	.588	(18)
487019000	3,531	.347	(36)	.050	.014	.032	(37)	.693	.440	.470	.122	.431	(48)	.500	.319	.410	(43)
479905000	3,231	.334	(37)	.100	.010	.055	(20)	.965	.216	.241	.907	.582	(19)	.500	.399	.450	(38)
479910000	2,534	.332	(38)	.110	.000	.055	(19)	.938	.223	.226	.745	.533	(27)	.500	.364	.432	(42)
486012000	2,830	.330	(39)	.014	.098	.056	(18)	.895	.149	.155	.667	.466	(42)	.500	.507	.504	(33)
460617000	1,812	.326	(40)	.027	.020	.023	(42)	.871	.000	.000	.700	.393	(52)	.500	.946	.723	(2)
486013000	4,921	.322	(41)	.032	.037	.034	(34)	.792	.246	.257	.786	.520	(31)	.500	.259	.379	(45)
460520000	885	.318	(42)	.011	.021	.016	(50)	.931	.186	.141	.624	.471	(40)	.375	.618	.497	(36)
479917000	2,460	.318	(43)	.038	.042	.040	(33)	.784	.152	.162	.720	.455	(45)	.250	.387	.319	(50)
479914000	3,812	.312	(44)	.092	.004	.048	(24)	.807	.204	.227	.496	.434	(46)	.375	.400	.387	(44)
479916000	2,869	.311	(45)	.076	.011	.043	(28)	.944	.090	.100	.702	.459	(43)	.250	.627	.439	(41)
479909000	3,118	.305	(46)	.090	.008	.049	(23)	1.000	.039	.047	.808	.474	(39)	.625	.483	.554	(25)
460416000	921	.289	(47)	.057	.007	.032	(38)	.898	.178	.196	.761	.508	(34)	.375	.355	.365	(48)
461001000	688	.276	(48)	.000	.080	.040	(32)	.918	.066	.042	.801	.457	(44)	.375	.358	.366	(46)
485009000	1,268	.275	(49)	.000	.016	.008	(52)	.765	.260	.253	.623	.475	(38)	.500	.232	.366	(47)
487018000	821	.273	(50)	.050	.002	.026	(40)	.776	.306	.334	.307	.431	(49)	.375	.000	.188	(53)
486014000	904	.271	(51)	.004	.003	.004	(53)	.687	.276	.280	.483	.432	(47)	.500	.138	.319	(49)
487017000	2,758	.260	(52)	.030	.013	.021	(48)	.822	.176	.168	.000	.291	(53)	.125	.390	.257	(52)
461218000	1,534	.236	(53)	.029	.018	.024	(41)	.919	.040	.020	.715	.424	(50)	.000	.539	.269	(51)

4.2.1 Census Divisions exhibiting the highest adaptive capacity

There exists a corridor in each province where all the CDs rank consistently in the first quintile (i.e., top ten) of adaptive capacity in the Prairie region. The highest-ranking corridor extends from the Winnipeg/Portage la Prairie area south to the United States border along and to the east of the Red River. The second-highest-ranking corridor exists in the Calgary area and extends southeast through to the United States border between Lethbridge and Medicine Hat. In Saskatchewan, a corridor of high-ranking adaptive capacity extends through the central part of the province from the Saskatoon and Regina areas.

The highest-ranking CD in the whole Prairie region extends around the communities of Morden and Winkler in southern Manitoba. These are not large urban centres, yet this CD ranks the highest in terms of adaptive capacity based on census data. For this CD, the determinant values were as follows:

- economic resources (ranked 19th);
- technology (ranked 8th);
- information, skills and management (ranked 5th);
- infrastructure (ranked 2nd);
- institutions and networks (ranked 28th); and
- equity (ranked 10th).

The three highest ranking CDs in Alberta are found in the south-central part of the province owing to high and very high rankings for all determinants except the equity determinant. The technology determinant warrants some analysis given that three of the four Census Divisions in this cluster rank in the top ten. The water access indicator (as measured by the value of irrigation equipment relative to all other farm equipment) was not a major factor except for the fourth-ranked Census Division east of Lethbridge where it ranked first among all 53 Census Divisions. Computer technology (as measured by ratio of farms reporting the use of computer) and technological flexibility (as measured by ratio of the value of tractors under 100 hp to all other equipment) contributed significantly to the high ranking for this determinant.

The institutions and networks was another strong determinant of adaptive capacity for this cluster of CDs with all ranking in the top ten. Important indicators within this determinant were e-mail and Internet use and access to agricultural education institutions to facilitate exposure to new and emerging viewpoints and information sources. Curiously, only two of the four Census Divisions in this cluster ranked in the top ten in relation to economic resources, despite the province being one of the wealthiest in the country.

In Saskatchewan, the two highest-ranking CDs are in the central part of the province and include the cities of Saskatoon and Regina. They show very high to high rankings on all determinants with the exception of the information, skills and management determinant in which they ranked average. Average and high-ranking CDs exist to the west of Saskatchewan's higher-ranking corridor and extend to the Alberta border. Two CDs with high scores are located on the western boundary of this area and extend to the Alberta border. These areas show average to high scores on all determinants with the exception of very low rankings on the economic resources and infrastructure determinants, respectively.

The tenth overall ranking for the Saskatoon area is largely influenced by top ten rankings in the economic resources and institutions/networks determinants. In terms of economic resources, the diversity of employment opportunities was a large factor. In terms of institutions and networks, access to educational institutions was an important factor as was the extent of social capital as measured by the proportion of informal operating arrangements (e.g., partnerships without written agreement and sole proprietorships). The rationale for the latter being that informal business relationships require closer personal relationships as compared to more formal contractual arrangements. And given this, it can be potentially easier for these farms to rely on their network of relationships to help during times of need.

4.2.2 Census Divisions exhibiting the lowest adaptive capacity

Equally important to observations of Census Divisions exhibiting the highest adaptive capacity are observations on the other end of the spectrum. The first and most obvious observation is that CDs with the relatively lowest adaptive capacity all line the northern extremity of the Prairie eco-zone, with the exception of southwest and southeast Saskatchewan. Below we analyze cases in each province to better understand why these northern CDs rank lower in adaptive capacity to climate change.

In viewing Figure 4-7 for Manitoba we see the trend holding true for which all of the northernmost CDs in the Prairie eco-zone are ranked in the lowest ten overall. Manitoba's Interlake region is situated between Lake Winnipeg and Lake Manitoba. This Census Division exhibits the lowest ranking (53^{rd}) for adaptive capacity of all Prairie CDs, despite being located within a few hours drive of some of the highest-ranking Census Divisions in the Prairie agricultural region. Of the six determinants of adaptive capacity and their underlying indicators, which are contributing the most to this low ranking? There are approximately 1,500 farms reporting in this Census Division. The individual determinants rank as follows:

- economic resources (ranked 22^{nd});
- technology (ranked 53^{rd});
- information, skills and management (ranked 49^{th});
- infrastructure (ranked 41^{st});
- institutions and networks (ranked 50^{th}); and
- equity (ranked 51^{st}).

The results appear to show that while economic resources are not among the determinants contributing most to the low adaptive capacity ranking, the contributions from the other five determinants are approximately equal. The technology determinant however, did receive the lowest ranking overall in this respect. For this determinant, the indicator for computer technology was among the lowest of all CDs (as measured by the ratio of farms reporting computer use), as were technological flexibility (as measured by the ratio of tractors under 100 hp to all other equipment) and technological exposure (as measured by the ratio of technologically demanding to less-demanding farm types). The institutions and networks determinant of adaptive capacity was the next greatest contributor to the low overall adaptive capacity ranking for this CD. While this CD ranked relatively high in terms of the social capital proxy indicator (as measured by the ratio of informal partnerships) and the access to agricultural education indicator (as measured by proximity to regionally significant agricultural institution), it ranked among the lowest with respect to e-mail and Internet use.

In Saskatchewan only one CD is in the lowest quintile (i.e., lowest 10). However, the overall trend holds true—the northernmost CDs in Saskatchewan's Prairie eco-zone are all within the next lowest quintile. The breakdown of determinants for the lowest-ranked CD in Saskatchewan (45th of 53 CDs) is as follows:

- economic resources (ranked 36th);
- technology (ranked 41st);
- information, skills and management (ranked 42nd);
- infrastructure (ranked 28th);
- institutions and networks (ranked 43rd); and
- equity (ranked 41st).

Based on these determinant rankings, economic resources and infrastructure appear to contribute the least to the CD's relatively low overall ranking.

The overall trend holds true in Alberta with the lowest-ranked CDs lining the northern and western extremities of the Prairie eco-zone. But curiously, there is one CD that exhibits a relatively average ranking for adaptive capacity (21st overall) in this northern area and surrounded by some of the lowest-ranked CDs in the Prairies. A key fact for this CD is that it includes the urban centre of Grand Prairie. The CD to the immediate north is ranked second lowest overall in terms of adaptive capacity, owing largely to the same determinants as the lowest-ranked CD in Manitoba, namely infrastructure via relatively low soil resources and transportation networks, and institutions and networks via considerable distance to agricultural education institutions and limited e-mail and Internet use. The Grand Prairie-centred CD ranked around average for all determinants, but received a boost in ranking from the equity determinant (ranked sixth overall).

5.0 Discussion

The spatial analysis of the adaptive-capacity index and its determinants for the 53 Census Divisions within the Prairie eco-zone has given us a unique view of the ability of farm families and communities to potentially deal with climate shocks and stresses that will occur in the future due to climate change. To the best of our knowledge this is the first use of census data to gain an understanding of adaptive capacity across the Prairies. Combined with our ongoing field work to study on-the-ground adaptive behaviours of farm families, this analysis will provide an important foundation for policy development to help maintain and improve the capacity of farm families and communities to adapt to future climate shocks and stresses.

In this section we study the characteristics of the underlying indicator data to better understand what signifies high and low adaptive capacity in the context of the results presented in Section 4. We then view the adaptive capacity results within the context of the broader Prairie Climate Resilience Project and consider future climate projections for the Prairie region as a prelude to stating the policy implications of these results.

5.1 Characteristics of the underlying indicator data

The data analysis thus far has been relative. That is, we have been able to discuss CDs as exhibiting either higher or lower adaptive capacity, but have not been able to say if adaptive capacity is in fact high or low. Within the scope of this paper this question will remain unanswered. Addressing this question requires results of field-level studies to learn precisely if individual farms have adapted and if so, why—and if not, why. These field-level studies are underway at this time. A look at the actual data values for the normalized indicators presented previously in Tables 4-1 through 4-7 can help to at least establish—in an absolute sense—what is meant by the highest- and lowest-ranked indicators for each of the determinants.

Table 5-2 presents for each of the 22 indicators the actual data points for the highest and lowest values (e.g., 1 and 0 normalized indicator values). Table 4-3 establishes the spectrum for each indicator. The high and low data values for each indicator allow one to understand what is exactly meant by a CD having the highest or lowest ranking for Internet use among all CDs across the Prairies.

Consider a few indicators as an illustration. For the economic resources determinant, off-farm earnings as a percentage of total family income varied from a high of 75 per cent to a low of 37 per cent. Asserting that the low value of 37 per cent is not sufficient to allow a farm family to weather tough times and that the high value is sufficient is not so easy a task. Such an assertion would require closer analysis of farming households with these characteristics.

For the technology determinant, the ratio of farms reporting computer use to all other farms ranged from a high of 124 to a low of 33. This means that for the least technologically savvy Census Division, for every one farm not using a computer, there are 33 farms that are. While this gives us a feel for the likelihood of the use of computers in the Census Division, it does not tell us exactly how the computers were used and if they have actually helped farms adapt to climate variability and surprises. We can assert based on relatively sound rationale that computer use can potentially help these farms adapt—via access to weather forecasts, commodity prices, new and innovative farming practices, etc.—but verifying this would require field-level investigations in a number of Census Divisions.

More straightforward is the soil resources indicator for the infrastructure determinant. For this indicator the proportion of area in dependable agricultural land ranges from a high of 5081 to 24. This means that for the Census Divisions with the worst soil resources, for every one hectare of poor land there are 24 hectares of dependable agricultural land. While the signal for this indicator might be more clear than for say computers, understanding if this is not sufficient for the average farm in this Census Division to weather tough times would require further analysis.

These illustrations highlight that the strength of the indicators clearly comes from their aggregation and the overall signal they can provide as to whether a Census Division is tending toward lower or higher adaptive capacity. Field-level analysis of the most important factors that allow farm families and communities to adapt will provide the most useful information for how to direct future public policy efforts to facilitate adaptation efforts. Indicator mapping such as that reported in this paper can help to identify regions where the need for public policy interventions is most acute.

Table 5-2. High and low values for each indicator.

Determinant	Aspect	Indicator	Units	High Value	Low Value
Economic Resources	Income generation relative to capital investment	Ratio of gross farm receipts to total capital investment. Higher is better.	$/$	60	8
	Income generation relative to summary expenses	Ratio of income to expenses. Higher is better.	$/$	125	103
	Off-farm earnings	Off-farm earnings as a percent of total family income where families have at least one farm operator. Higher is better.	$/$ x 100	75	37
	Diversity of employment opportunities	Ratio of off-farm contribution of time to on-farm contribution of time. Not available with current dataset. Alternative was the ratio of employment in agriculture to employment in other industries within CD. Lower is better.	Persons/ Persons	1,920	6
Technology	Water access technology	Ratio of value of irrigation equipment to value of all other farm equipment. Higher is better.	$/$	25	0
	Computer technology	Ratio of farms reporting use of computer to all other farms. Higher is better.	No. Farms/No. Farms	124	33
	Technological flexibility	Ratio of value in tractors under 100 hp to total value of all other tractors. Lower is better.	$/$	104	16
	Technological exposure	Ratio of technologically-demanding to less demanding farm types. Higher is better.	No. Farms/No. Farms	70	1
Information, Skills and Management	Enterprise information management	Ratio of farms reporting computer livestock and crop record keeping to all other farms. Higher is better.	No. Farms/No. Farms	34	10
	Sustainable soil resource management practices	Ratio of area of no-till or zero till seeding to tilled area. Higher is better.	Area/Area	422	21
	Sustainable environmental management practices	Ratio of farms reporting windbreaks and shelter belts to all other farms. Higher is better.	No. Farms/No. Farms	43	11
	Human resources management	Ratio of total farms reporting paid ag labour to all other farms. Higher is better.	No. Farms/No. Farms	116	39
Infrastructure	Soil resources	Proportion of area in dependable agricultural land. Higher is better.	Area/Area	5,081	24
	Transportation network	Ratio of high capacity to low capacity roads. Higher is better.	km paved/km unpaved	375	10
Institutions and Networks	Informal operating arrangements	Ratio of total farms reporting formal agreements to total no. of farms reporting sole proprietorships and partnerships without written agreement minus miscellaneous category. Lower is better.	No. Farms/No. Farms	42	8
	E-mail use	Ratio of total farms reporting E-mail use to all other farms. Higher is better.	No. Farms/No. Farms	59	17
	Internet access	Ratio of farms reporting Internet use to all other farms. Higher is better.	No. Farms/No. Farms	63	20
	Opportunity to access agricultural education institutions	Distance between centroids of each Census Division and the nearest regionally significant Ag institution. Lower is better.	km	462	4
Equity	Employment opportunities	Unemployment rate from Statistic Canada's 2001 Census of Population 20% Sample Data for Population of 15 years and over. Lower is better.	%	10	2
	Opportunity to access health and social services	Ratio of labour force in health and social service occupations to all other occupations. Statistics Canada 2001 Census of Population 20% Sample data for Population. Higher is better.	Persons// Persons	31	11

5.2 Future vulnerability

Within the context of the Prairie Climate Resilience Project, this analysis of adaptive capacity will be coupled with a companion analysis of exposure to historic climate variability across the Prairies to understand areas most vulnerable to climate variability—remembering that vulnerability is a function of both exposure to climate stress and the capacity to adapt to the exposure. A particular area can be vulnerable to even modest exposure to climate stress if the area has little or no capacity to adapt. Conversely, it is also possible that an area, despite high exposure, is not particularly vulnerable given a high capacity to adapt to the stress.

As illustrated in the analytic framework for the Prairie Climate Resilience Project on Figure 5-1, this desk-level analysis of vulnerability will be used to help guide our ongoing farm- and community-level appraisals of existing adaptive capacity and its role in building resilience to climate change. This latter field-level effort will provide a synthesis of current and planned policies that can build resilience to climate change. A final stage of the project will include an adaptation priority analysis based on an analysis of future climate variability and change and the resilience analysis to identify regions where building resilience to climate change may be of highest priority and what types of policy interventions might be most helpful.

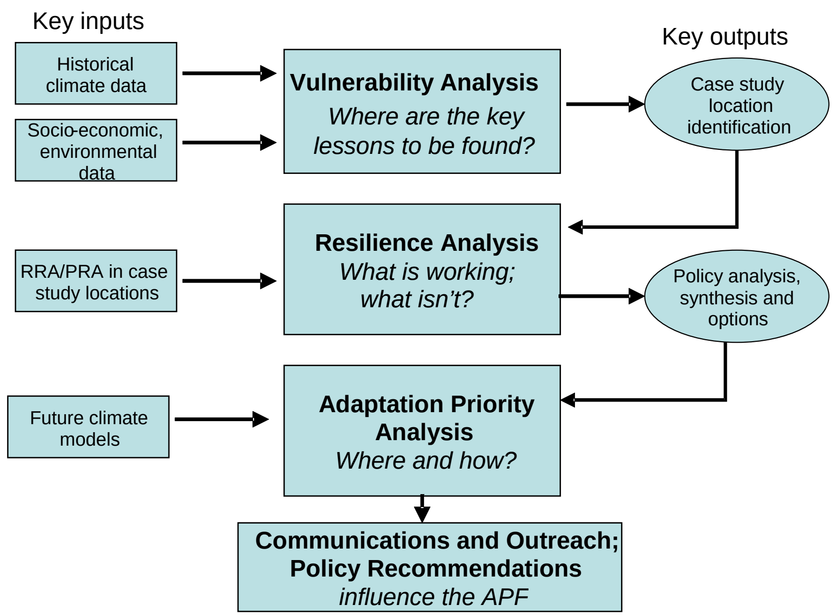


Figure 5-1. Analytical framework for the Prairie Climate Resilience Project.

The overlaying of the map for the adaptive-capacity index in the Prairies (refer to Figure 4-7) with a map of exposure to historic climate variability will be the focus of the next paper to emerge from this project. But we can take a glimpse toward what this "double-exposure" mapping might look like by overlaying Palliser's famous triangle on our map of adaptive capacity indices for each Census Division. Figure 5-2 illustrates that although most of the northern Census Divisions exhibiting the lowest adaptive capacity in the Prairie agricultural region lie outside this high drought-exposure triangle, a number of Census Divisions lining the southern extremities of the Alberta-Saskatchewan and Saskatchewan-Manitoba borders could be particularly vulnerable given the combination of average to low rankings of adaptive capacity and historical exposure to drought conditions.

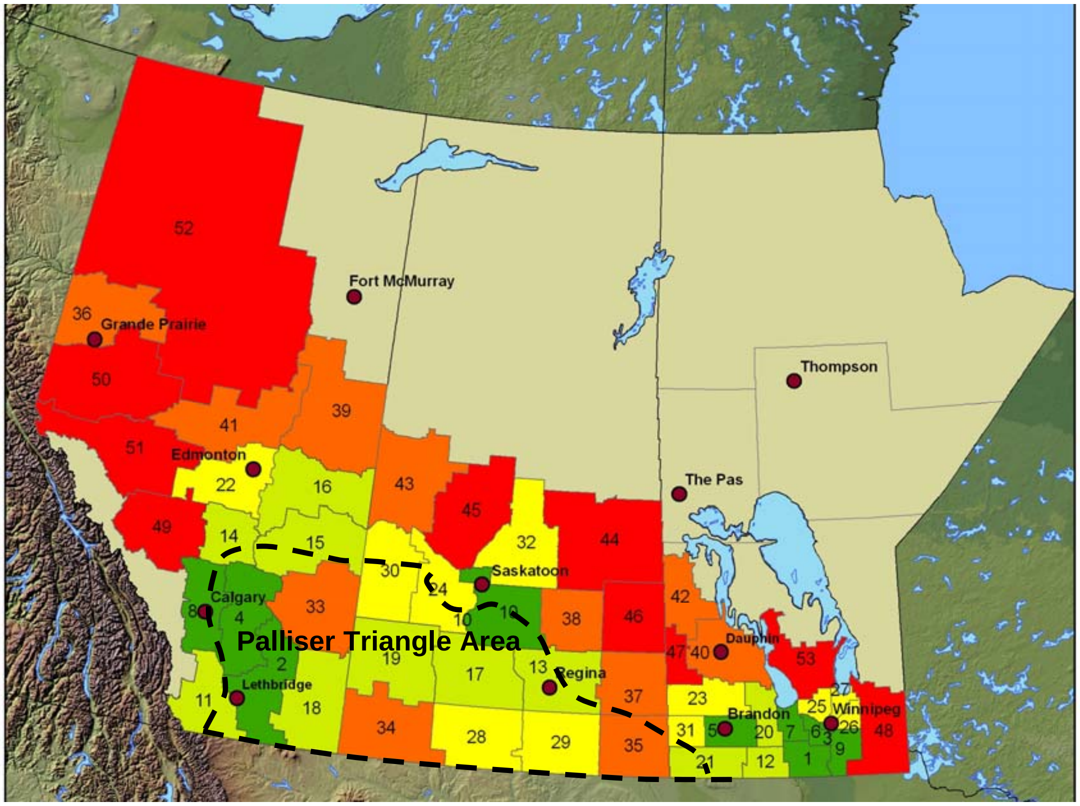
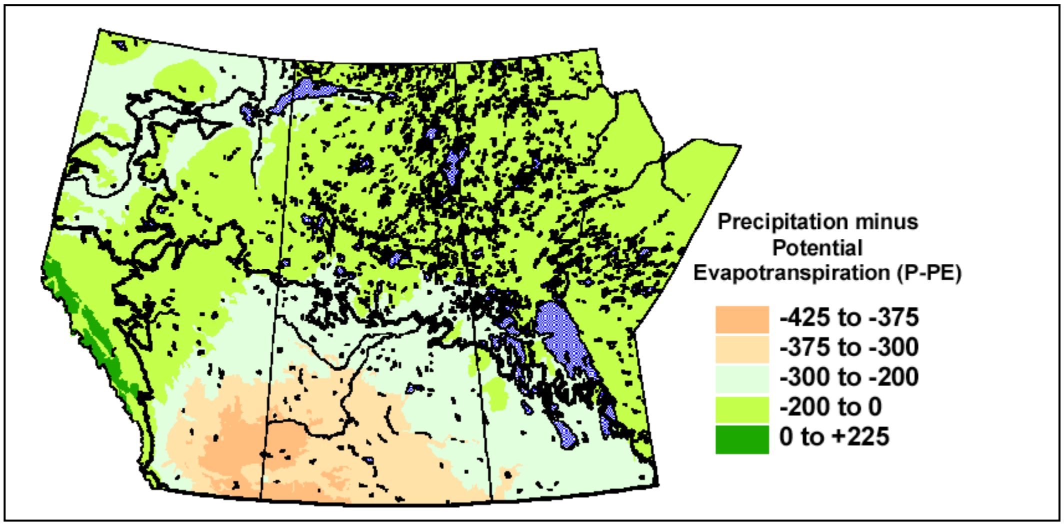


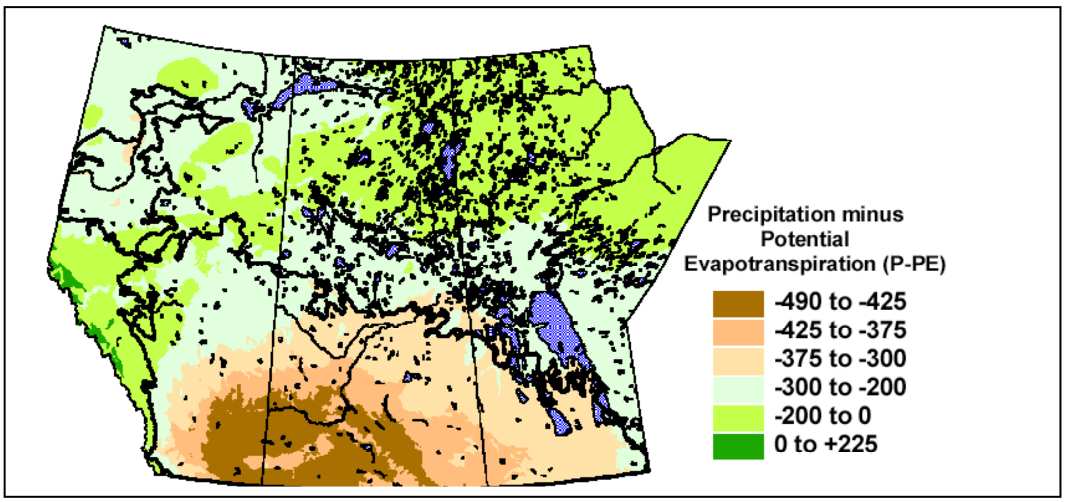
Figure 5-2. Map showing an overlay of the adaptive-capacity index across the Prairies with Palliser's famous triangle for severe drought exposure (Palliser Triangle area approximated from Spry, 1968).

We can also take a glimpse toward future vulnerability by overlaying the adaptive capacity map with projections from global climate models. Historically, the earth's climate has always been changing. But an interesting observation has been made based on an analysis of temperatures from the last 1,000 years—the last 100 years have seen a rapid increase in average Northern Hemisphere temperatures with the last 10 years likely to have been the warmest (IPCC, 2001). The collective voice from the global scientific community—represented through the Intergovernmental Panel on Climate Change (IPCC)—attributes the emission of greenhouse gases (GHGs) from our fossil-fuel-based economy as one of the primary causal factors for the global climatic changes that have been observed over the last half century.

The advent of computer technology has allowed scientists to take a uniquely close look at the effect GHG emissions have on climate and, most importantly, to make projections of future climate trends. Computer models have been developed to simulate the complex interaction among physical processes of atmospheric circulation, large-scale ocean circulation, thermodynamics of sea and ice interactions, and the hydrologic cycle of land surfaces. Figure 5-3 (b) presents the results of one potential future climate change scenario for the period 2050. This particular global climate model projection illustrates that for one possible future climate-change scenario, the moisture deficit (precipitation less potential evapo-transpiration) relative to baseline conditions (Figure 5-3 [a]) could be much greater in magnitude and extent (Nyirfa and Harron, 2001). The consequence of this projection in light of the adaptive-capacity results is that some of the more northern Census Divisions that exhibited relatively low adaptive capacity and were outside of Palliser's Triangle of drought-prone conditions could also be considered particularly vulnerable to variable dry conditions.



(a) Moisture deficit 1961–1990.



(b) Projected moisture deficit 2040–2069 (scenario CGCM1).

Figure 5-3. Projected moisture deficit for the Prairie agricultural region (source: Nyirfa and Harron, 2001).

6.0 Policy Implications and Next Steps

The results of this study are helpful to policy design for climate-change adaptation in a number of ways. First, the very exercise of researching current thinking on adaptive capacity and mining existing census data for relevant information has illuminated many aspects that can influence adaptive capacity on the Prairies (see Table 3-1). Of course, field-level analysis is necessary to assess how important these indicators are to the capacity of farm families and communities to adapt to climate shocks and stresses. Nonetheless, the aspects listed in Table 3-1 are a pragmatic guide for policy-makers at this early stage of policy analysis and development for climate-change adaptation on the Prairies.

Second, spatial analysis of the adaptive-capacity indices for Census Divisions across the Prairies revealed that adaptive capacity is likely to be positively correlated with proximity to urban centres. Proximity to urban centres brings with it positive benefits in the form of:

- off-farm earnings;
- diversity of employment opportunities;
- computer technology;
- use of computers in farm management;
- transportation networks;
- e-mail/Internet use to keep abreast of current climate trends and innovative farming practices; and
- opportunities to access agricultural education institutions.

The implications for policy are twofold. First, policy interventions that facilitate any of the above in the more remote rural areas would be beneficial. For example, programs to facilitate high-speed Internet access and education in the use of computers for communication, information gathering and farm management are likely to help build adaptive capacity. Second, it implies that aspects that are less correlated with locations near urban centres should receive special policy attention. Such aspects include:

- ensuring agricultural commodity prices are fair;
- access to irrigation equipment (debatable);
- promoting sustainable soil-management practices;
- discouraging farming on marginal land; and
- use of farm equipment versatile to variable climate and land conditions.

The most pragmatic insight that can be gleaned from these results requires additional knowledge of the degree of exposure to climate. The combined information of adaptive capacity and exposure to stress gives us an understanding of vulnerability. Areas which are most vulnerable require policy attention. The climate projections in Figure 5-3 (b) give us one possible scenario of future exposure and, when combined with the adaptive capacity maps, can give us a glimpse at which areas are most vulnerable and, therefore, might require more policy attention.

But the future is inherently unknowable, even with the advent of sophisticated computer modelling. So there is a need for continuous monitoring of underlying climate parameters that signal stress and shock and of aspects of adaptive capacity. In relation to monitoring of adaptive capacity, the determinants and indicators of adaptive capacity are a good start to the types of information that are important to track. However, our analysis revealed some significant data gaps. The two most critical were (1) readily available information on the extent of surface and groundwater resources to inform the infrastructure determinant and (2) data on the distribution of income within Census Divisions, such as the Gini coefficients, to inform the equity determinant.

The results presented in this paper are being used to help evaluate locations for detailed field surveys to better understand the aspects that have helped farm families adapt to historic climate shocks and stresses in Manitoba, Saskatchewan and Alberta. The farm-level surveys will illuminate actual actions that farm families have taken to adapt in the past and will help to determine which of the aspects and indicators presented in this paper are most important. Most importantly, this future research will provide useful guidance to policy-makers who are responsible for addressing the adaptation imperative across the Prairies as related to the agricultural sector and rural livelihoods.

There are several other future research arenas that would be beneficial to explore in relation to the adaptive-capacity index and methods presented in this paper. These include:

- replicating the analysis in other agricultural regions of Canada;
- conducting time-series analysis to assess the changes over time of the determinants and indicators contributing to adaptive capacity;
- applying more sophisticated mathematical techniques of analysis such as principal components analysis;
- undertaking analysis at the sub-census-division level to provide finer geographic resolution;
- analyzing adaptive capacity for different classifications of farms—for instance, investigating the farms that produce the majority of agricultural output; and
- refining and applying similar analysis methods to other important sustainability issues in agriculture, including BSE and globalization.

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