Dry times: hard lessons from the Canadian drought of 2001 and 2002

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Droughts are one of the world's most significant natural hazards. They have major impacts on the economy, environment, health and society. In 2001 and 2002, many regions within Canada experienced unprecedented drought conditions, or conditions unseen for at least 100 years in some regions. This article draws upon a national assessment of this drought with particular attention to its implications for the agriculture and water sectors, although some attention is also devoted to other sectors. The study's methodology involves a comprehensive inter-disciplinary, cause–effect integrated framework as a basis to explore the characteristics of drought and the associated biological and physical impacts and socio-economic consequences. Numerous primary and secondary sources of data were used, including public and semi-public sources such as Agriculture and Agri-Food Canada, Environment Canada, Statistics Canada, Crop Insurance Corporations and provincial governments, as well as phone interviews, focus groups, print media surveys

Temps arides : Les dures leçons des sécheresses canadiennes de 2001 et 2002

Les sécheresses représentent une des catastrophes naturelles les plus importantes au monde. Elles causent de graves dégâts sur l'économie, l'environnement, la santé et la société. En 2001 et 2002, plusieurs régions du Canada ont été touchées par des conditions de sécheresse sans précédent, ou pour certaines d'entre elles, qui n'avaient pas été observées depuis plus d'une centaine d'années. Cet article présente sommairement un bilan national de cette sécheresse en mettant davantage l'accent sur les incidences sur les secteurs de l'agriculture et de l'eau. D'autres secteurs sont également abordés. La démarche méthodologique de l'étude s'appuie sur un cadre intégré de cause à effet global et interdisciplinaire à partir duquel les particularités des sécheresses, les impacts d'ordre biologique et physique, ainsi que les répercussions socioéconomiques, sont explorés. Un grand nombre

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and economic modelling. Evidence indicates that the risk of drought is increasing as demands for food and water relentlessly climb and the manifestations of climate change become more apparent. The key to better dealing with drought lies in taking the steps necessary to enhance our adaptive capacity and decrease vulnerability.

Key words: Canadian droughts, vulnerability, economic impacts, biological impacts, physical impacts, adaptation

de sources primaires et secondaires de données ont été utilisées, dont des sources publiques et semi-publiques comme Agriculture et Agroalimentaire Canada, Environnement Canada, Statistique Canada, des sociétés d'assurance en production agricole et des gouvernements provinciaux, en plus d'entrevues téléphoniques, de groupes de discussion, de sondages publiés dans la presse et de modélisations économiques. Les données obtenues indiquent que les risques de sécheresse augmentent, que la demande alimentaire et en eau augmente aussi de manière continue et que les effets des changements climatiques se font de plus en plus perceptibles. La solution pour mieux faire face à la sécheresse se trouve dans les mesures prises pour améliorer notre capacité d'adaptation et réduire notre vulnérabilité.

Mots clés: sécheresses canadiennes, vulnérabilite, impacts économiques, biologique, impacts, physique, adaptations

Introduction

Droughts are natural hazards that can have devastating effects on the environment, society and the economy. However, as one of the most complex of weather hazards, droughts are very difficult to define. The comprehensive definition of drought is: 'a prolonged period of abnormally dry weather that depletes water resources for human and environmental needs' (Atmospheric Environment Service Drought Study Group 1986). Many definitions exist for each of the main types of drought, including meteorological, agricultural, hydrological and socio-economic. For example, a meteorological drought applies to a long-term lack of precipitation that is frequently intensified by anomalously high temperatures that increase evapotranspiration. This often leads to other types of droughts including agricultural (periods during which soil moisture is insufficient to support crops), hydrological (prolonged periods of unusually low surface run-off and shallow groundwater levels) and socio-economic droughts (an unusual shortage of water that produces an adverse effect on society and the economy) (Maybank *et al.* 1995).

This article draws upon a national drought assessment by Wheaton *et al*. (2005), the first national drought assessment in Canada, and one of the first in North America. Other assessments of droughts in Canada generally focus on only a part of Canada, such as the Prairie Provinces (e.g., Arthur and Freshwater 1986; Wheaton and Arthur 1989; Wheaton *et al.* 1992). A literature review by Kulshreshtha *et al.* (2005b) conducted for this national assessment discusses many more drought impact reports. The primary purpose of the national assessment was to document and evaluate the Canadian drought of 2001 and 2002, and to determine the bio-physical, socio-economic and other impacts, where such impacts were measurable. The major focus of the study was on the agriculture and water sectors, although some attention was devoted to non-agricultural sectors (e.g., forestry, water supplies, hydro-electricity, tourism, transportation). Droughts are serious threats as most human activities and ecosystems are dependent on reliable, adequate water supplies (Bonsal *et al.* 2004). The character of droughts depends on a wide range of factors, including the affected area, timing, duration and antecedent conditions; their impacts in turn depend on a region's vulnerability, its exposure to climate risk (e.g., drought), sensitivity and ability to adapt. However, droughts are generally more spatially fragmented, less intense and shorter than what was witnessed in Canada in 2001 and 2002. All the Canadian provinces experienced drought conditions in one or both years. This drought was exceptional by many measures: it was unusually large in area, severe and embedded in a long dry period.

The weather of 2001 and 2002 included the worst drought in at least 100 years in parts of Canada, taking a widespread and devastating toll. This record to near-record drought was preceded by dry-to-drought conditions, and followed in some areas by persisting dry-to-drought conditions in 2003. Multiyear droughts are much more severe and difficult to cope with than shorter droughts due to their compounding impacts and the additional drain on adaptive resources. This multiple exposure effect, when combined with the extent and severity of the 2001 and 2002 drought, produced significant challenges, especially for agriculture, water managers and rural communities.

People adapted to the drought to differing extents and generally adaptations were considerable, costly, disruptive, problematic and still left losses. Also, some of the impacts resisted adaptation methods. We modified the terms 'adaptation, adaptive capacity and vulnerability' from the climate change literature to suit drought assessment. 'Adaptation' is defined as adjustment in natural or human systems in response to actual or expected droughts or their effects (after Watson and the Core Writing Team 2001). The goal of adaptation is to moderate harm or to exploit beneficial opportunities. Adaptive capacity is the ability of a system to adjust to droughts (or to any other physical or socio-economic stressors) to moderate potential damages, and to take advantage of opportunities or cope with the consequences (after Watson *et al.* 2001). Some of the main questions to ask about the adaptation process include: who or what adapts, how do they adapt, what is the trigger for adaptation and when do they adapt (Smit *et al.* 1999; Wheaton and MacIver 1999)? Drought adaptation decisions are made at various levels: individuals, groups, institutions and local to national governments. Drought adaptation processes or strategies include sharing and/or bearing the loss, modifying drought effects, research, education, behavioural changes and avoidance (Burton *et al.* 1993). The adaptive responses to drought occur on two main time scales: as a short-term tactical response early in the drought or as a longer-term strategic response planned before or after the drought to deal with future droughts (Watson *et al.* 2001). Vulnerability is the degree to which a system is susceptible to, or unable to cope with, the adverse effects of drought. It is a function of exposure to the drought and capacity to adapt (after Watson *et al.* 2001). In this regard, the disastrous drought of 2001 to 2002 provided a foundation of lessons for reducing Canada's vulnerability to future droughts and likely enhanced the level of adaptive capacity.

The article is organized in four main parts, beginning with an outline of data and methods. The results are presented next with a description of the drought climatology, followed by physical impacts and adaptations, biological and economic impacts and adaptations, non-farm impacts and an overview of economic impacts and government programs. The article ends with a view of possible future droughts, proposed action planning and a conclusion.

Data and Methods

This study draws upon various types of data, climatic, hydrologic and economic, including agricultural production (e.g., grass growth, crop yields, livestock). Only a sample of the data developed is summarized (Table 1) because of the large size of the inventory. For example, several climate variables were used to describe the droughts, including temperature, precipitation, wind and the Palmer Drought Severity Index (PDSI). The time series of the PDSI was one of the tools used to examine drought extremes, trends and spatial extent. Economic impact variables examined included net income, bankruptcies, trade and value of production. Unfortunately, some data were not available for 2002 before the completion of the project. Comparable PDSI values were not available at the time of writing. Other data limitations are described for each method in the national assessment.

Secondary sources of data were numerous and include public and semi-public sources such as Agriculture and Agri-Food Canada, Environment Canada, Statistics Canada, Crop Insurance Corporations and provincial governments. Primary data sources included phone interviews, focus groups, print media surveys and economic modelling.

Table 1
Data inventory—bio-physical examples

Data set	Variable	Type of data	Description	Source	Period
Climate	Temperature, precipitation, wind	Tables	Monthly, means, totals, extremes	Environment Canada (EC), agriculture and agri-food Canada (AAFC)	Period of record
	Temperature and precipitation	Maps	Cumulative and seasonal departure from normal	EC	2000–2002
	Precipitation	Maps	Percent of average precipitation	AAFC	2001–2002
	Palmer Drought Severity Index	Tables	Seasonal and monthly	Skinner pers. comm. 2003 EC	Various start dates to 2001
	Palmer Drought Severity Index	Maps	Monthly	Ryback pers. comm. 2001, 2002, 2003 EC	September 2000 to December 2002
	Palmer Drought Severity Index	Maps	Seasonal	Skinner pers. comm. 2003 EC	
	Evapo-transpiration	Tables	Monthly and annual	Chipanshi, pers. comm. 2003 AAFC	2000–2002
	Snow cover	Tables	Seasonal	Brown pers. comm. 2002 EC	1955–2001
	Upper atmospheric circulation data	Tables	500 mb geopotential heights and anomalies	Climate Diagnostic Centre	2000–2002
	Visibility and blowing dust	Field reports print media traffic accident reports		AAFC various newspapers various provincial departments	2000–2002
Water	Stream flow	Tables	Water discharge rates	EC	Period of record
	Groundwater	Graph	Water levels	Provincial agencies	Period of record
	Reservoir levels	Tables	Water levels	EC, provincial agencies	Period of record
	Ponds	Tables	Pond counts (twice per year, May and July)	EC	Period of record
	Dugouts	Map	Water levels	AAFC	1999–2002
	Irrigation	Tables and maps	Irrigated acres	Provincial departments of agriculture	Various
Agricultural production	Grass growth	Maps, print media survey, provincial crop reports, producer interviews		AAFC	2000–2002
	Livestock (cattle)	Tables inventories, producer interviews		Statistics Canada 2002, provincial agriculture departments, Kulshreshtha and Marleau 2005b	Various start dates–2003
	Crop production	Tables		Statistics Canada	1976–2002
	Grasshopper risks	Maps		Provincial agriculture departments, AAFC	2000–2003

Because drought impacts most of society, the methodology of the study required a comprehensive interdisciplinary and integrated research framework (Figure 1). This cause–effect integrated framework was used to explore several linkages: factors causing drought lead to droughts of various characteristics; droughts result in biological and physical impacts of various types; then these impacts lead to socio-economic consequences. The locations, severity, duration and

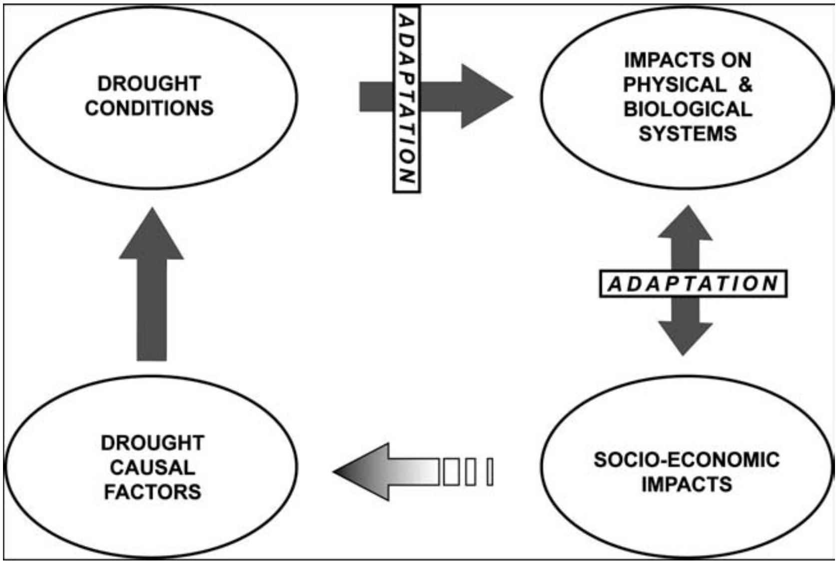

Figure 1
A cause–effect research framework showing drought causes, drought characteristics, impacts and adaptations (Wheaton *et al.* 2005, adapted from Watson 2001)

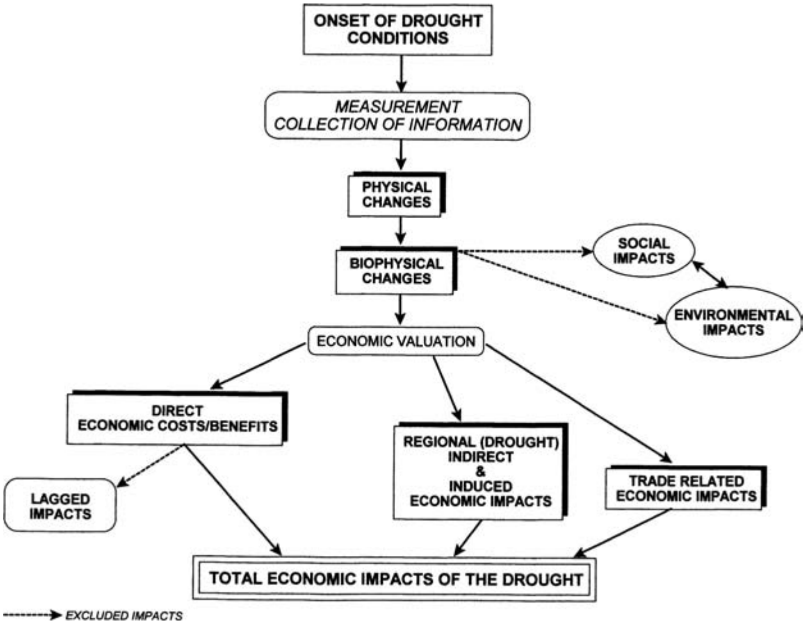

Figure 2
Overview of the methodology, with further economic details (Kulshreshtha *et al.* 2003)

frequency of the droughts were determined. Physical and biological impacts we explored included wind erosion, crop growth and yield, pasture and hay production, livestock, surface water (stream flows, dugouts, reservoirs and wetlands), groundwater and forest fires.

More details on the economic subcomponents of the methodology are supplied in Figure 2. Biophysical impacts of drought cause a wide range of social, environmental and economic impacts. Evaluating economic effects involves assessing direct costs and benefits, regional level indirect and induced economic impacts and trade-related economic impacts. These components combine to produce the total economic impacts of drought.

All components of the project were integrated through the adoption of common objectives and methods. Methods included a literature review, time series analyses, an extensive set of phone interviews with agricultural producers and communities (140 producers, 19 extension workers, 97 community contacts) using prepared instruments, print media surveys, focus groups, expert opinions and Statistics Canada's inter-provincial economic input-output model. This wide variety of methods enabled comparisons and ensured robustness of results. When two different types of methods provide similar findings, the confidence in the results is increased. The following results are summarized from the national assessment (Wheaton *et al.* 2005).

Drought climatology

The 2001–2002 drought was unique and ranks amongst the most severe droughts of North America for the period of record (approximately one century in most areas). Also, this multiyear drought occurred as part of a much longer series of dry-to-drought conditions. This drought followed a relatively wet period in much of the 1990s. Then from fall 1999 to November 2003, well below-normal precipitation was reported in parts of Alberta and Saskatchewan for consecutive seasons for more than four years. For example, Saskatoon's annual precipitation in 2001 was not only the lowest on record but also was a full 30 percent lower than the previous driest year in the 110-year record. Saskatoon was by no means unique, with many stations reporting record or near-record dry years in 2001 or 2002 (Wheaton 2005a; Wheaton and Wittrock 2005). Even parts of Atlantic Canada experienced dry summers for four to five consecutive years (Koshida 2005a). Sauchyn *et al.* (2003) also found that most climate stations in southeastern Alberta and southwestern Saskatchewan had record low precipitation in 1999–2001.

Record to near-record drought in 2001 is indicated by the PDSI (Figure 3). The time series of the PDSI was used to examine drought extremes, trends, variations and spatial extent. Negative PDSI values represent dry-to-drought conditions and positive PDSI values indicate wetter conditions. Substantial variation is evident in these time series. Several climate stations exhibit slight long-term trends towards drier conditions (Wheaton 2005a).

The summer (June–August) average PDSI was used to compare the spatial extent of the drought years of 2001 and 2002, as compared to other selected major North American drought years of 1931, 1961 and 1988 (Figure 4). This comparison was limited by the small number of climate stations and comparable drought years. This composite map illustrates the very extensive drought years of 2001 and 2002 comprising a larger area across Canada than the other selected major drought years. Furthermore, summer drought in 2001 and 2002 extended much farther northward, and spread farther eastward and westward than the earlier major droughts depicted. This recent drought appears to be one of the first coast-to-coast droughts in Canada since the inception of instrumental weather records. The most intense drought was concentrated in the agricultural areas of Saskatchewan and Alberta (Wheaton *et al.* 2005).

We also examined the evolution of the 2001 and 2002 drought. Preceding dry conditions clearly set the stage for the drought of 2001. The winter of 2000 to 2001 brought extremely low precipitation, with the largest deficits in Alberta and western Saskatchewan, and near-normal temperatures to most of southern Canada. An extremely important source of moisture, prairie snow cover, for the winter of 2000 to 2001 was low (Wheaton and Wittrock 2005). Spring 2001 continued the dry trend over large parts of Canada, including interior British Columbia, southern Alberta, much of agricultural areas of Saskatchewan, the Great Lakes area and most

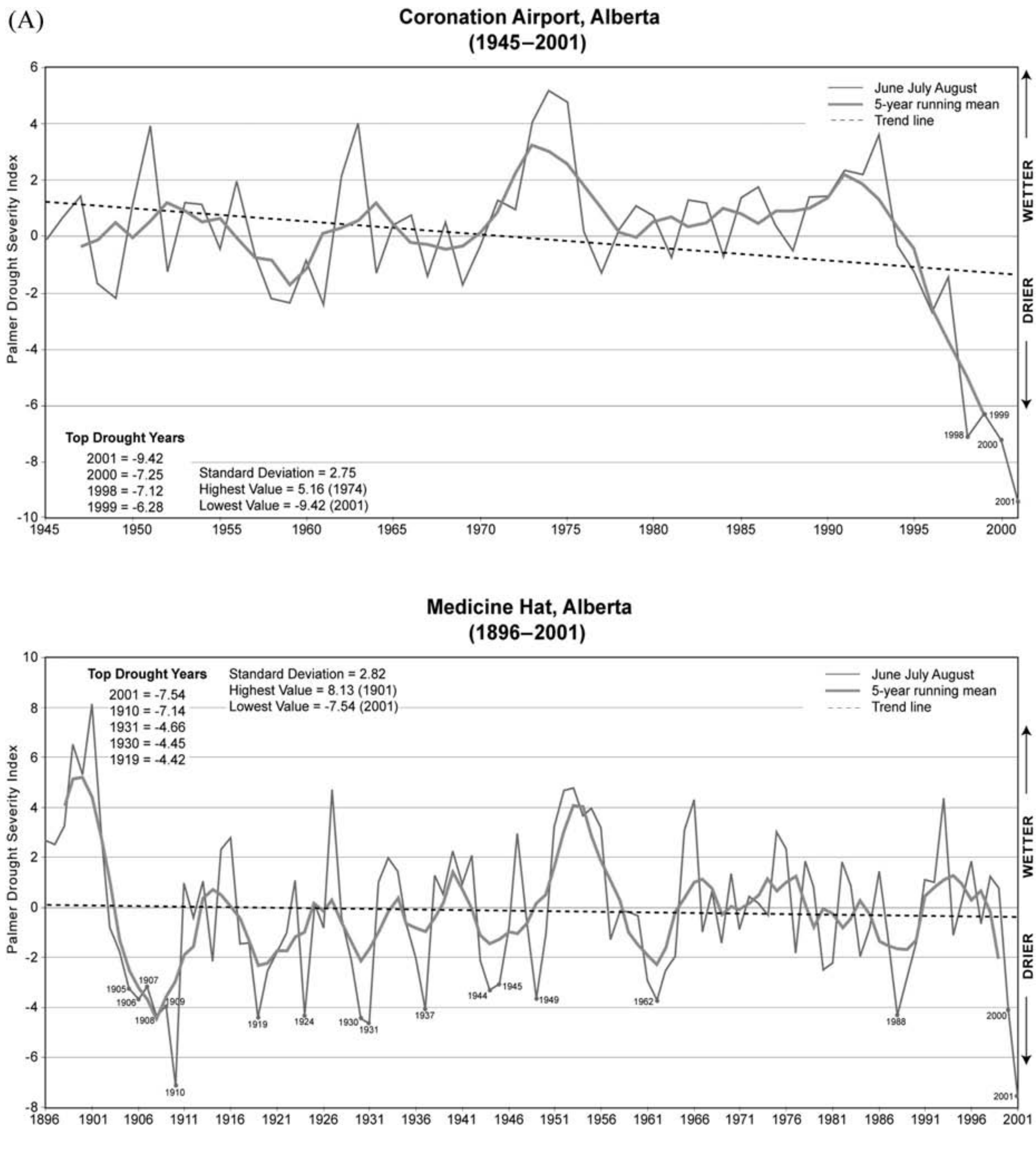

Figure 3

A. Time series of summer (June, July, August) Palmer Drought Severity Index (PDSI) for Coronation and Medicine Hat, Alberta (dates are labelled for PDSI less than or equal to −;3) (Wheaton 2005a; Data: Skinner, W. 2003; *Personal e-mail Communication*. Mr. Walter Skinner, Climate Research Branch, Environment Canada, Downsview, ON). B. Time series of summer (June, July, August) Palmer Drought Severity Index (PDSI) for Prince Albert and Saskatoon, Saskatchewan (dates are labelled for PDSI less than or equal to −;3) (Wheaton 2005a; Data: Skinner, W. 2003; *Personal e-mail Communication*. Mr. Walter Skinner, Climate Research Branch, Environment Canada, Downsview, ON)

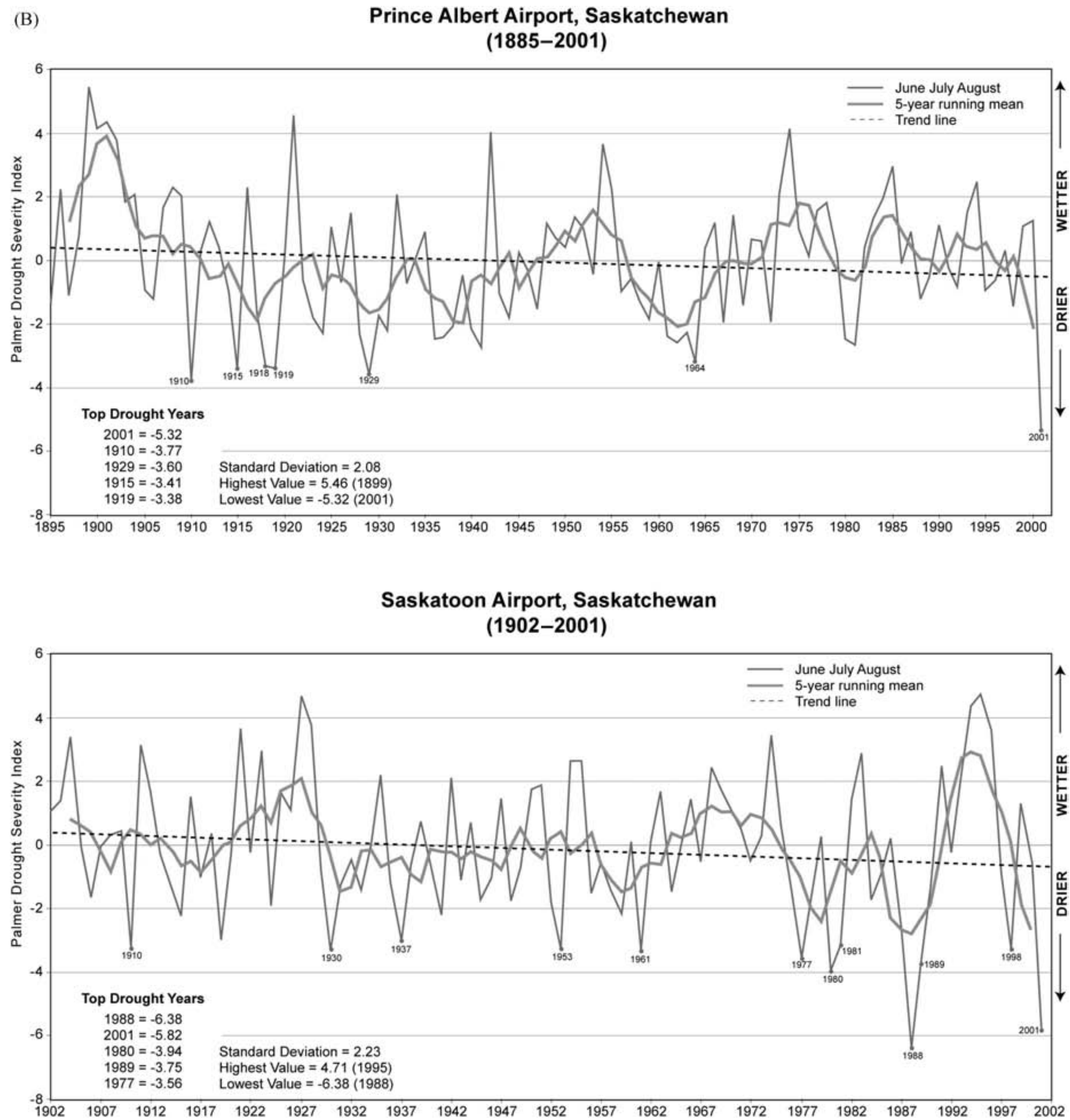

Figure 3
Continued

of the Atlantic Provinces. In contrast, well-above-normal precipitation occurred in Manitoba and northwestern Ontario (Koshida 2005a; Wheaton and Wittrock 2005).

The summer season brought increased demands for water as severely dry conditions persisted through the summer and autumn of 2001 over most of the already dry areas of

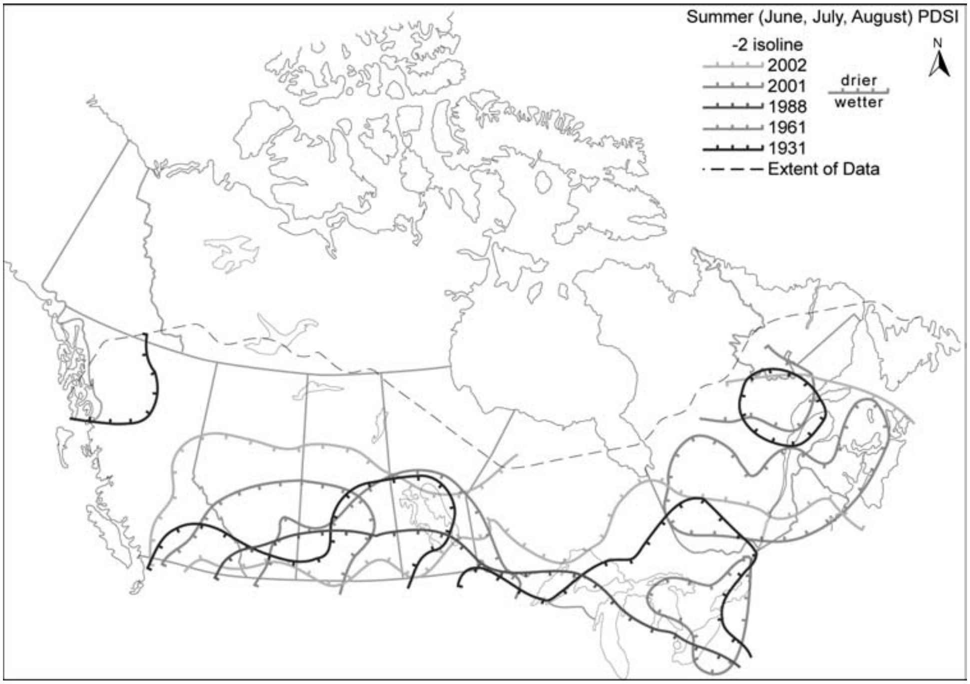

Figure 4
Spatial comparison of major droughts of 2002, 2001, 1988, 1961 and 1931 using the summer (June, July, August) Palmer Drought Severity Index Isoline of −2 (Wheaton *et al.* 2005; Data: Skinner, W. 2003; *Personal e-mail Communication*. Mr. Walter Skinner, Climate Research Branch, Environment Canada, Downsview, ON)

the country. In the summer of 2001, very dry conditions encompassed most of southern Canada from central British Columbia to the Atlantic Provinces. Associated temperatures were above normal (Figure 5). The winter of 2001–2002 not only continued the dry trend over much of southern Canada but also brought above-normal temperatures. Again, Alberta and western Saskatchewan were the focus of drought conditions (Wheaton *et al.* 2005).

The spring of 2002 saw extreme conditions in most of the country, characterized by unusually low temperatures and the still persistent well-below-normal precipitation. The very cold spring was fortunate, as warmer temperatures would have increased demands on already limited water supplies. The dry trend eased in central British Columbia, southern Ontario and Québec, with the receipt of above-normal precipitation (Wheaton *et al.* 2005).

In summer 2002, most of southern Canada again experienced well-below-normal precipitation and above-normal temperatures (Figure 5). An exception for summer 2002 was southern Alberta and southwestern Saskatchewan where precipitation was over 50 percent above average. Other areas in Saskatchewan and Alberta received above-normal summer rainfall, but some of this rainfall was too late to help agricultural production for that year. Wet conditions in the spring and fall of 2002 alleviated the drought in most of Atlantic Canada. In contrast, fall and winter of 2002–2003 brought lingering dry-to-drought conditions to areas of the central to northern agricultural region of the Prairie Provinces. These results support the conclusion that the 2001–2002 drought was indeed significant on a continental and century-length scales (Wheaton *et al.* 2005).

Physical impacts of the droughts and adaptations

Good-quality and reliable water supplies are crucial to plants, animals, people and economic activities. The 2001–2002 drought was a strong reminder of the importance of water, and the

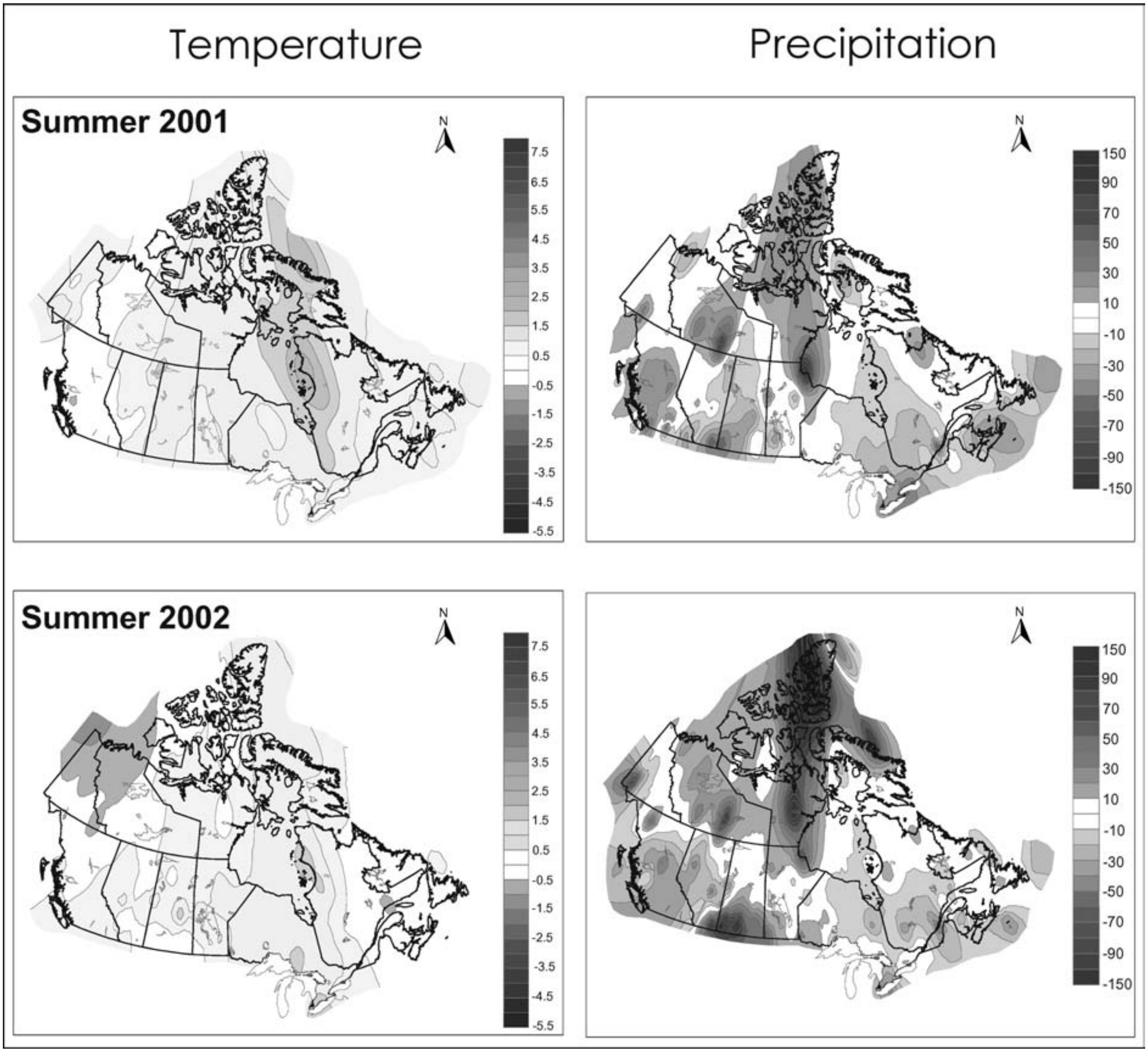

Figure 5
Precipitation and temperature departures from normal (percent) across Canada for summer (June, July, August) 2001 and 2002 (after Environment Canada 2002)

challenges brought people together in many ways to deal with water scarcity issues. We documented drought impacts on water supplies, including stream flows, wetlands, dugouts, reservoirs and groundwater. Secondary impacts of water scarcity affected irrigation and municipal water supplies, as well as recreational and tourism activities (Koshida 2005b; Wittrock 2005a).

In British Columbia, stream flows were below average in 2001, but near normal in 2002. The worst situation appeared to be in Alberta and Saskatchewan, as many rivers and streams had well-below-average flows (or no flows) between 2000 and 2002 (Wittrock 2005a). Mean annual flows of several rivers in Nova Scotia, New Brunswick and Prince Edward Island were also at a 20-year low, and farmers in Nova Scotia reported that irrigation needs exceeded supplies. Adaptation was constrained by lack of knowledge concerning water needs, supplies and water management. These water shortages were significant as they restricted livestock and crop production. (Koshida 2005b; Wittrock 2005a).

Dry conditions in southern Ontario resulted in requests by Water Response Teams, as required under the Ontario Low Water Response Plan, to reduce water consumption in some watersheds. The Great Lakes–St. Lawrence River system experienced record low levels in 2001, part of a downward trend that began in the late 1990s. Navigation in the Great Lakes area slowed in 2001, causing an $11.25 million decrease in business volume due partly to low water levels (Koshida 2005c).

Trend analyses were limited by the sparse groundwater level observation network, particularly in eastern Canada. Preliminary trend analysis indicates decreasing groundwater levels in several areas of western Canada. Adaptive responses included improving well efficiency and increasing the numbers of new wells. For example, in Prince Edward Island, the 2001 drought contributed to an increase in demand for new high-capacity wells. This situation underscored the need to vastly improve groundwater monitoring, research and assessment of long-term supply and demand (Koshida 2005b; Wittrock 2005a).

In British Columbia, reservoir levels were generally lower than normal in 2001, but returned to near normal in 2002. Many major reservoirs in Alberta and Saskatchewan had well-below-normal levels in 2001 and during the first five months of 2002. Some recovery occurred in southern locations in 2002. Manitoba's reservoir levels generally did not suffer in 2001 or 2002 (Wittrock 2005a). Interviews with rural community leaders indicated water supply and/or quality problems in areas including the Okanagan region of British Columbia, central Alberta in 2002, and southwest Saskatchewan in 2001 (Kulshreshtha *et al.* 2005).

Dugouts, or constructed ponds, are often essential adaptations to water scarcity on Prairie farms, particularly for livestock and household use. By the fall of 2000, Prairie dugouts were drying out, and this trend became worse in 2001. Dugout water supplies rebounded somewhat in southern Alberta and Saskatchewan in 2002, as the dry pattern shifted northward. At the farm level, dugouts were the most negatively affected water supply source (Wittrock 2005a). Wetlands in Prairie agricultural regions are particularly sensitive to drought, especially during multiple dry years. The number of natural Prairie ponds in May 2002 was the lowest on record, reflecting this sensitivity (Wittrock 2005a).

Although irrigation was considered an important adaptation option across Canada during the drought, it incurred higher-than-average labour and energy costs, as well as management problems. For example, low water supply available for irrigation in the southeast Kelowna Irrigation District of British Columbia led to water use restrictions imposed in April 2001. The unprecedented combination of high irrigation demand and low water supplies in Alberta resulted in unique voluntary approaches to irrigation water management (Wittrock 2005a). Trading of water rights amongst irrigators and processors was also reported by Nicole and Klein (2006). Irrigation needs also exceeded supplies in Nova Scotia and Ontario in 2001. In Prince Edward Island, growers without irrigation experienced a 50–100 percent crop loss in 2001 (Koshida 2005b, 2005c).

Individuals, municipalities, provincial and federal governments and associations suggested and applied adaptation measures to deal with limited water supplies and water quality problems. These measures included water conservation and rationing, water sharing, water transfers, hauling water, drilling new wells and using several other new sources of water, such as pipelines from more remote, secure sources. Restrictions were placed on watering of lawns, golf courses, and other nonessential water uses across Canada. In addition, water conservation measures were promoted through the distribution of public awareness materials and public service announcements (Koshida 2005b, 2005c; Kulshreshtha *et al.* 2005a; Wittrock 2005a).

Wind erosion of soil is a very serious hazard and results in environmental, health (including mortalities) and socio-economic costs (Wheaton 1992). Soil lost by wind erosion is a long-term cost, and often takes decades or longer to restore (Anderson 1977). Wind erosion tends to be more serious in Saskatchewan and Alberta than other provinces (Wheaton and Chakravarti 1990). The most frequent wind erosion events on the Canadian Prairies in 2001 and 2002 occurred in

Photo 1
Wind erosion and dust storms caused considerable soil and much other damage in a large area south of Saskatoon, Saskatchewan, in the summer of 2003 (photo by E. Wheaton, SRC)

Alberta and Saskatchewan (Photo 1). May of both 2001 and 2002 was the month with the greatest number of wind erosion events, including massive dust storms. No agency routinely monitors wind erosion or blowing dust events any longer, so only a few *ad hoc* observations compiled from field and media reports were available for assessment. This serious lack of monitoring makes it almost impossible to determine the nature of wind erosion events, confirm whether they are increasing or decreasing as a result of land management practices or gauge the effectiveness of control measures (Wheaton 2005b).

A first attempt at using a proxy method of traffic accident data for evaluating wind erosion events was tested. At least 32 incidents of blowing dust with associated traffic accidents were reported in Saskatchewan between April and September 2001 (Wheaton 2005b). This total is large as it was only exceeded once during the 1977–1988 period of dust storms documented by Wheaton (1990). Blowing dust may have been a contributing factor in two fatalities associated with these accidents (Wheaton 2005b).

The drought of 2001–2002 was a stern test of farm management practices that reduce wind erosion. Although wind erosion was severe, it would probably have been much worse without the increase in soil conservation practices in the past several decades. However, these drought-related wind erosion events make it clear that the adaptation work is far from complete.

Agricultural impacts of drought and adaptations

The 1990s saw many years of sufficient precipitation in western Canada and increased production trends. This trend dramatically reversed in 2001, particularly in Alberta and Saskatchewan, where some regions reported record low crop production in 2001 and 2002 for a 25-year period. In contrast, crop production in British Columbia and Manitoba was near normal (Wittrock 2005b).

Alberta and Saskatchewan crop yields and harvested areas were below average in both 2001 and 2002 resulting in a reduction in the value of farm-level crop production. The situation was worse in 2002 for both provinces, with almost all agricultural areas in Alberta suffering production losses. Alberta crop producers lost \$413 million in 2001 and \$1.33 billion in 2002. In Saskatchewan, estimated value of reduced crop production accounted for losses of \$925 million in 2001 and \$1.49 billion in 2002. The farm cash receipts (a proxy for economic state of the farm economy) did not suffer by the same magnitude since withdrawals were made from farm inventories as an adaptation measure under drought conditions. Reduction in farm cash receipts in 2001 and 2002 were $267 and $920 million, respectively for Alberta, and $652 and $953 million, respectively for Saskatchewan (Kulshreshtha and Marleau 2005a).

Drought brought a host of other problems. Pests, such as grasshoppers, thrive in drought conditions, and massive outbreaks combined with drought to further cut crop production, especially in Alberta and Saskatchewan. Weeds can tolerate drought well and were a problem, even in grasslands. Shelterbelts designed to protect cropland and farmsteads were also severely affected by drought, to the point of dying out in some areas (Wittrock 2005b).

In southern Ontario and Québec, crop production impacts were widely dispersed and highly variable across locations and crop types. Production of two main field crops grown in Québec (soybeans and hay) ranged from slightly below to slightly above average. Québec recorded crop losses, mostly in soybean and hay crops, estimated at $34 million in 2001 and $21 million in 2002. Drought damage to Québec's apple crop was evident with scald, calcium deficiency and early drop, as well as a 2001 production decline of 27 percent from the previous year (Grant 2005; Koshida 2005f).

In Ontario, 2001 field crop yields dropped significantly for grain corn, soybeans and hay. Losses in production were estimated at $295 million in 2001 and $140 million in 2002. Grain corn and soybean yields recovered to near normal in 2002, but hay yields remained low in many areas. The hot, dry weather of 2001 led to improved grape quality and production, although the warm, dry winter reduced the ice-wine grape harvest. Ontario apple yields dropped by eight percent in 2001, and plummeted further the following year when yields of popular varieties dropped 30–50 percent from 2001 (Grant 2005; Koshida 2005f).

Ontario is Canada's largest vegetable-growing region. From drought stress in 2001–2002 yields dropped significantly for many vegetable crops, including carrots, white onions, cabbages and potatoes, especially where irrigation was not available. While irrigation was the main option used to deal with rainfall deficits, it was costly in terms of energy and labour. Wet conditions in the spring and early summer of 2002 ended the drought. However, a record-dry spell occurred in August 2002 with parts of southwestern Ontario receiving less than 20 percent of normal precipitation. As a result, the effects of drought were not recognized until late summer 2002, taking many producers by surprise and allowing fewer adaptation measures. Earlier recognition may have enhanced adaptation capacities (Koshida 2005f).

In Atlantic Canada, many crops were hit by the 2001 drought in particular, but again, drought impacts varied considerably from region to region and crop to crop. Nova Scotia was severely affected with 2001 crops such as wild blueberries suffering 50–75 percent production losses. Crop production losses in spring wheat, hay, potatoes, beans, apples and blueberries totalled an estimated $27.5 million in 2001 and $16.5 million in 2002. There were severe irrigation water shortages and water quality issues. Even producers with access to irrigation suffered 20–25 percent yield losses—another example of the limits of current adaptation measures (Grant 2005; Koshida 2005d; Kulshreshtha and Marleau 2005a).

The southeastern and eastern portions of New Brunswick were most affected, reporting yield losses of horticultural crops of 30–60 percent in 2001. In Prince Edward Island potato production dropped 36 percent from 2000 to 2001. Soybean producers also incurred losses. Growers without irrigation lost 50–100 percent of their crops. The value of potato crop production was reduced by $52.7 million. Newfoundland reported decreased cole crop production (e.g., cabbage, broccoli, cauliflower and brussel sprouts) and decreased horticultural crop yields in 2001 (Grant 2005; Koshida 2005d).

Where possible, an increased reliance on irrigation was the primary adaptation to drought, particularly for fruit and vegetable crops in eastern Canada. However, increased irrigation resulted in higher energy and labour costs. Other adaptations included small reductions in fertilizer and herbicide applications, fuel and labour. Adaptations appeared to be minor in eastern Canada in 2001 and 2002 because drought conditions were not recognized until well into the growing season, when most management decisions had been made and operating costs had already been incurred (Grant 2005; Koshida 2005d, 2005f; Kulshreshtha and Marleau 2005a). Areas not commonly affected by drought were hit (e.g., northern agricultural Prairies and eastern Canada), contributing to the vulnerability of producers and communities less experienced in dealing with drought.

Grass growth was poor over a large area of the Prairies in the spring to fall of 2001 and 2002. May 2002 was the worst month for grass growth and June was almost as bad. Most of Alberta was severely affected. A wide swath across Saskatchewan was a close second in terms of both area and duration. Poor pasture growth stretched into southwestern Manitoba. Only a narrow slice of southeastern Saskatchewan escaped the 'poor growth' classification (Wheaton 2005c).

Several adaptation strategies were documented, including transporting hay, utilizing feed types not normally used, and using available public and private lands as well as cropland, also not normally used. Where adaptation was not successful, livestock lost weight, became sick from drinking poor quality water, eating poor quality food or from overcrowding, or developed problems associated with eating unusual feed. When so much grazing and hay land is affected so severely for so long, limits to adaptation are reached. Adaptation action and planning are also extremely limited by sparse and ad hoc information and applied research, including grass growth forecasting (Koshida 2005e; Wheaton 2005c).

The scarcity and high cost of feed and water supplies left drought-impacted livestock producers with many difficult decisions (Photo 2). Feed shortages were widespread, affecting pasture land, hay land and feed grains. The timing and spatial extent of most droughts rarely affects so many sources of livestock feed (Wheaton 2005c).

Alberta's herd reduction in 2001 and 2002 resulted in two consecutive years of below-normal cattle numbers. The 2002 decrease of more than ten percent (600,000 head) saw record low cattle numbers since 1997. This drop is another example of an impact requiring a long-term recovery period. Saskatchewan's total livestock numbers did not appear to be affected. In British Columbia, livestock sale receipts increased from 2000 to 2001, only to fall in 2002. Poor prices and herd inventory liquidations resulted in reduced income in 2002 (Kulshreshtha and Marleau 2005b; Wittrock 2005c).

Some producers sold cattle early in anticipation of the continuation of the 2001 drought, leading to negligible economic impacts on producers in 2001. This depressed the cattle prices during the last quarter of 2001 and that trend continued well into 2002. As a result, the 2002 drought

Photo 2
Dry dugout near Paradise Hill, Saskatchewan, August 2002 (photo by AAFC)

had a significant impact, with an estimated loss to producers of $143.4 million, almost half in the province of Alberta (Kulshreshtha and Marleau 2005b).

A variety of industries with ties to agriculture suffered across Canada. Farm input suppliers were hit by lower demand for their products, while food processors experienced local shortages of raw material. For example, in both 2001 and 2002, Ontario soybean crushers were forced to draw down carry-over stocks and increase imports at higher costs to maintain their crush levels. Vegetable processors saw their throughput reduced due to a lack of product in close proximity. Value-added processors in Prince Edward Island (e.g., French fry producers) reported a downturn in business from a lack of raw material. Access to long-term markets in the eastern United States for Prince Edward Island coal products was threatened by the product shortfall (Kulshreshtha and Guenther 2005).

In British Columbia, hydro-electric power generation was curtailed, necessitating more purchases of power from neighbouring jurisdictions. While forest fires were not as prevalent in British Columbia, the incidence of fires in Alberta in 2002 increased to five times the previous 10-year average (Kulshreshtha and Guenther 2005).

Some recreational areas in Alberta were also adversely affected due to low lake levels and intense fire risks (Photo 3). Impacts in Saskatchewan were similar, including reduced hydroelectric power generation. Production shortfalls in 2001 were compensated for by purchases of power from other sources (Kulshreshtha and Guenther 2005).

Summary of economic impacts

Drought impacts were more serious and widespread in western than eastern Canada, where impacts were more localized and variable (Table 2). In western Canada, the total value of production dropped by about $930 million in 2001, doubled to $2.067 billion in 2002 and totalled some $3 billion for the two drought years. The hardest hit province in 2001 was Saskatchewan (48 percent of the Canadian drought-induced

Photo 3
Several years of drought have resulted in the lowest water levels in the Georgian Bay Region, Ontario, since the 1960s (photo by W. Leger, Environment Canada, Ontario Region)

Table 2
Summary of agricultural losses due to the 2001 and 2002 drought in Canada, by province (Kulshrestha 2005)

Province	Reduction* in value of production in 2001 (000$)	Reduction* in value of production in 2002 (000$)
British Columbia	$0	$30,001
Alberta	$271,060	$1,008,500
Saskatchewan	$654,940	$1,000,980
Manitoba	$6,980	$27,770
Western Canada	$932,980	$2,067,251
Ontario	$294,730	$139,690
Québec	$34,080	$20,550
Nova Scotia	$27,510	$16,510
Prince Edward Island	$50,230	$0
Eastern Canada	$406,550	$176,750
Total Canada	$1,339,530	$2,244,001

*Reduction in value of production was estimated as a sum of change (increase or decrease) in value of sales of crop and livestock products and in expenditures on farm inputs. If the change in the value of sales was positive, agricultural losses were equated to be nil. For crop production, analysis was done on a census agriculture region level while for livestock it was on a provincial level. Benchmark for crop products was previous six- to 10- year level, while for livestock it was previous two years (on account of livestock cycles).

agricultural production losses), with Ontario and Alberta second and third (Figure 6) (Kulshreshtha and Grant 2005). Drought contributed to a negative or zero net farm income for several provinces for the first time in 25 years. A negative net farm income occurred in Prince Edward Island for 2001, in Saskatchewan for 2002, and a zero net farm income was reported for Alberta in 2002 (Statistics Canada 2003).

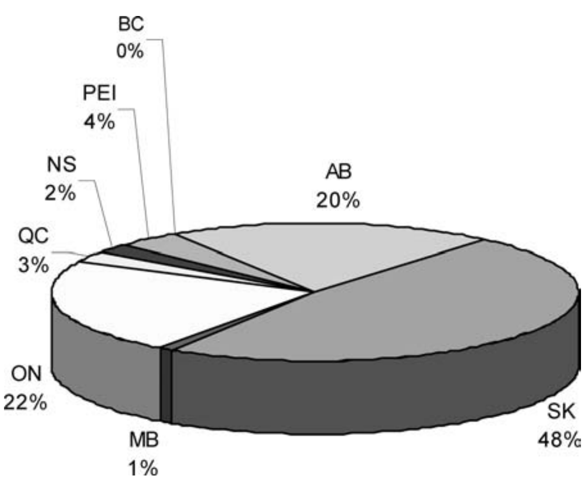

Figure 6
Provincial distribution of 2001 drought-induced agricultural production losses (Kulshreshtha 2005)

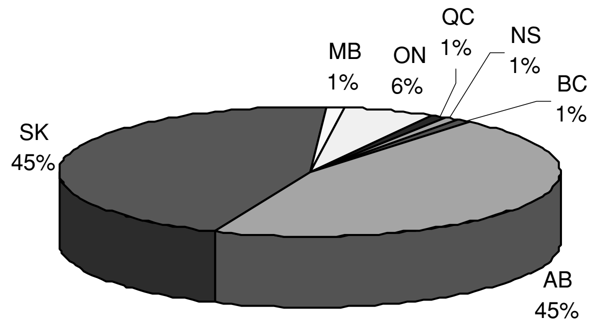

Figure 7
Provincial distribution of 2002 drought-induced agricultural production losses (Kulshreshtha 2005)

Saskatchewan and Alberta shared the bulk of 2002 agricultural production losses, with each accounting for 45 percent of the Canadian total (Figure 7). In eastern Canada, the total value of production dropped by approximately $406 million in 2001 and $176 million in 2002. The total loss estimate was $583 million over the two-year period. The total Canadian loss in value of agricultural production for both years is estimated at $3.6 billion (Kulshreshtha 2005).

In an economic system, actions taken by a group of individuals affect other individuals in the same region, as well as in other parts of the country. Actions of farmers as a result of drought are no exception. As farmers' incomes are reduced, so are their expenditures on farm and household needs. These changes then affect other industries and lead to a greater change in the economy. To measure the total change in the Canadian economy resulting from the 2001 to 2002 drought, Statistics Canada's interprovincial input-output model of Canada was used (Kulshreshtha 2005).

The economic impact of the 2001–2002 drought rippled throughout the Canadian economy, as consumers spent less and demand for goods and services declined. Using the above input-output model, it was estimated that the 2001 drought resulted in a $2.1 billion drop

Table 3
Reduction in gross domestic product and loss** in employment resulting from the 2001 and 2002 drought in Canada, by region (Kulshrestha 2005)

	Loss** of GDP (000$)		Loss** in employment (no. of workers)	
Region	2001	2002	2001	2002
British Columbia	$0	$42,955	0	224
Prairies	$1,434,619	$3,108,331	10,083	17,803
Central Canada	$412,886	$228,132	4,038	1,949
Maritimes	$115,122	$21,750	1,042	223
Trade-related impacts*	$164,031	$251,840	2,474	3,578
Total Canada	$2,126,658	$3,653,008	17,637	23,777

*Refers to those changes in non-drought regions created by interprovincial trade.
**Loss was based on estimated absolute change in the GDP or employment during the drought period.

in Canada's gross domestic product (GDP) and a loss of 17,637 jobs in various parts of the country (Table 3). The 2002 drought was more intense on the Prairies compared with the rest of Canada. The GDP loss in that year was approximately $3.6 billion, with the total loss estimate over the two drought years pegged at some $5.8 billion (Kulshreshtha 2005).

Overview of government response programs

Negative economic and social impacts stemming from the 2001 to 2002 drought years were partially offset by government response and safety net programs. These include crop insurance, the Rural Water Development Program, the Net Income Stabilization Account (NISA), the Canadian Farm Income Program (CFIP) and the Livestock Tax Deferral Program. The challenges posed by the 2001–2002 drought were unusually severe, particularly for some sectors and regions. In such a severe multiyear drought, the wide range of adaptation measures, including government programs, could not cope with the immensity of the losses (Wittrock and Koshida 2005).

Under the crop insurance program, a federal/provincial/producer-funded program, more than 102,000 Canadian farmers insured almost 56 million acres (22.7 million hectares) in the 2001–2002 crop year. The Canada wide payout for this crop year was over $1 billion. Saskatchewan, Alberta and Ontario received the highest payments (Wittrock and Koshida 2005). In the 2002–2003 crop year, more than 100,000 farmers insured 68 million acres (27.5 million hectares). Payments exceeded $2 billion, or more than 500 percent above the 10-year average in Canada. Again, the highest payments were made in Saskatchewan (over $1 billion), Alberta (almost $800 million) and Ontario (over $100 million). Unfortunately, the reasons for payments are not specified and these numbers reflect problems other than drought. However, in the most severely affected areas, drought would clearly be a primary factor for these payments (Wittrock and Koshida 2005).

Causes and future occurrences of drought

Previous major western Canadian droughts have been associated with distinctive atmospheric circulation patterns over North America and persistent temperature patterns in the Pacific Ocean (Bonsal and Wheaton 2005). This tendency was tested for the drought years of 2001 and 2002. Surprisingly, analyses of the associated atmospheric and oceanic patterns revealed no consistent or easily identifiable features. In fact, analysis of the mid-tropospheric circulation during these droughts indicates that the patterns were distinctly different than those of the major prairie droughts of 1961 and 1988 (Bonsal and Wheaton 2005). This suggests that the scientific understanding of the driving forces behind sustained droughts may be less solid than expected. Additional research is needed to address the complexities of several other factors influencing drought, including large-area soil moisture patterns, vegetation, surface reflectance and atmospheric dust interactions. This research is required to improve seasonal forecasting capabilities for major droughts (Bonsal 2005).

The risk of droughts will continue in the future. Drought is one of the major hazards affecting Canada and drought is a normal part of the climate, especially for the Canadian Prairies. At least three main factors must be considered in determining the probability of future severe drought events: paleo-climatic evidence, increasing societal water requirements and climate change. The drought pattern over the past hundreds of years (as determined by paleo-climatological analysis of indicators such as tree rings) shows that major droughts were relatively rare in the twentieth century (Sauchyn *et al.* 2003). More severe, decade-long droughts occurred in the previous centuries and could recur. Secondly, society's increasing demand for good-quality water will increase the stress on the water system in times of severe shortages that occur during a drought period. These recent droughts clearly demonstrated that water needs can exceed supplies and that we must learn how to better manage water. A third consideration is the enhanced probability of drought caused by climate change. Most global climate models project increased summer continental interior drying and, as a result, a greater risk of droughts is projected for the twenty-first century. The increased drought risk is described as likely and is a result of a combination of increased temperature and evaporation not being balanced by precipitation (Watson *et al.* 2001; Williams *et al.* 1988).

These three factors clearly point to the threat of increasing severity and frequency of future droughts. This trend means that further investments in activities such as monitoring, assessment and adaptation are required. The increasing threat of drought risk to water availability in Canada is clearly critical to planning and policy at all levels and must be carefully considered.

Recommendations

Limitations on the national assessment were severe, including insufficient quality-controlled data for 2002 at the time of the project, analyses of cause–effect relations, implications and interpretations of findings, lag effects and adaptation measures and processes. These research gaps lead to the following recommendations:

- Sensitivity analyses of the cause–effect relationships that underlie the research framework. These relationships include the drivers of drought, drought to biophysical impacts and biophysical impacts to economic impacts. Another approach is to test and decide upon an appropriate, flexible and standardized suite of methodologies for assessing the impacts and adaptations to droughts. This will help ensure that lessons learned are properly documented and considered in policy development.
- A comprehensive drought assessment for each major future drought. These assessments must be comparable to allow sensitivity, adaptive capacity and vulnerability to be determined.
- Expansion and enhancement of Canada's current drought and drought impact monitoring. Monitoring is at a preliminary stage and requires considerable improvement to become effective at a national level. Agriculture and Agri-Food Canada's drought monitoring is a major step forward. To move toward improved monitoring and early warning systems, more drought indices are needed, as well as a much-improved network of monitoring stations and more communication vehicles for drought warning systems (Wilhite *et al.* 2005).
- Assessments of lag effects to determine the nature of recovery from drought and the resilience of each sector. Several drought impacts have time lags from the drought onset (as identified by drought indices such as PDSI) and can persist for years. These include soil degradation by wind erosion, grassland degradation and numerous economic effects, especially on livestock producers.
- Research on the temporal and spatial patterns of past and future droughts. The 2001–2002 drought could be the first time in observational history that a major drought has been as extensive across Canada and as far north in the Prairie Provinces. The new Canada DRI (Drought Research Initiative) aims to better understand the physical characteristics of, and processes influencing Canadian Prairie droughts, and to contribute to their better prediction, through a focus on the recent severe drought that affected the Prairies from 1999 to 2005 (Canada DRI 2007).
- Research to separate drought impacts from other impacts. For example, crop insects and diseases, frost and excess moisture may have also contributed to decreased crop yields. A comparison of 'before' and 'after' situations does not always lead to an estimate of the marginal effect of the droughts. Combinations of monitoring and modelling would assist this objective.
- Comprehensive research on the climatological causes and prediction of large-area droughts in

consideration of climate change effects (Bonsal and Regier 2007). A better understanding would permit seasonal forecasting of drought conditions and improve risk management before the event (Canada DRI 2007).
- Research to examine the process of adaptation and the effectiveness of adaptation in reducing vulnerability (Wheaton *et al.* 2007). These form the basics for drought plans and their implementation that are needed for successful adaptation (Wilhite 2005). Adaptation measures implemented by producers, communities, organizations and government responses helped reduce the negative biophysical and socio-economic impacts of the 2001–2002 drought in Canada. However, this drought was of such magnitude, persistence and intensity that severe hardship and residual impacts still occurred.
- Adaptation and vulnerability assessments are needed to determine who is at risk of impacts of future droughts, when, where and why.

The adaptive capacity required to better prepare for, and deal with such droughts requires strengthening, and new capacity needs to be developed. For example, a National Drought Adaptation Network should be considered. Such institutions have critical roles in decreasing vulnerability to drought damages (Riebsame *et al.* 1991; Wilhite 1993). A critical mass of experts across many disciplines is required for drought monitoring, research, coordination, planning and communication. National to local drought planning must be enhanced and accelerated and supported by a strong foundation of monitoring and research.

Conclusion

This study is the first national assessment of drought and its impacts in Canada. It addressed several impacts of the 2001–2002 drought. In addition, some critical knowledge gaps were identified. The study was conducted on a national scale and covered drought climatology, impacts and adaptation. This undertaking was pioneering in many respects, including time lines, research framework, application of existing and new research tools, nation-wide scale and integration of multiple disciplines. As a result of this work, a comprehensive description of the nature of these extensive and severe droughts and their bio-physical and economic impacts was achieved.

The Canadian drought of 2001–2002 will long be remembered for its widespread and devastating toll—a toll that can be measured in increments of economic loss and environmental deterioration. While no region of the country escaped unscathed, western Canada was hardest hit. Billions of dollars were lost, along with tens of thousands of jobs. The impact on livestock production and the landscape will, in some cases, require years to decades before a full recovery can be contemplated. Drought continued taking its toll in 2003 in several parts of Canada. This drought may be one of Canada's worst natural disasters since the 1930s.

A wide range of adaptation measures developed over the years did not fully deal with the impacts, thus underlining Canada's vulnerability to this natural hazard. It is also evident that much more needs to be learned about the phenomenon of drought and its impacts before decision makers will be in a position to reduce the vulnerability of their activities and sectors.

Evidence indicates that the risk of drought is increasing as demands for food and water relentlessly climb and the manifestations of climate change become ever more apparent. Canadian scientists must develop the capacity to predict droughts as part of seasonal forecasting efforts, and more detailed studies must be undertaken to better understand all aspects of Canadian droughts. The key to better dealing with drought lies in taking the steps necessary to enhance our adaptive capacity and decrease vulnerability.

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