Climate Change and Water

SSRB Final Technical Report
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Table of Contents

Page Number

Section 3 Appendices:

Page Number

Page Number

Appendices

List of Figures

List of Figures, Cont:

List of Tables

List of Tables, Cont:

List of Tables, Cont:

1 Executive Summary

This report summarizes the work and results of a study entitled "*Assessment of the Vulnerability of Key Water Use Sectors in the South Saskatchewan River Basin (Alberta and Saskatchewan) to Changes in Water Supply Resulting from Climate Change*". That study constitutes the socioeconomic research team component of a unique, two-team project that examined the impact of predicted climate change on the surface water supply of the South Saskatchewan River Basin (SSRB). A major contribution of the overall project was to link the physical hydrological and socioeconomic aspects of those changes in an innovative, "end-to-end" analytical framework. This report lays a foundation for future analyses and recognizes that the net impacts of climate change on the physical and social dimensions of the basin will continue to be influenced by shifting social, economic and environmental priorities and activities. The results presented here can inform site-specific decisions (as demonstrated for three cities) as well as guide infrastructure and policy debates. The value of applying these results in an integrated, yet practical, water management approach to assist in sub-basin, sectoral decision-making was a strong consensus of the expert and stakeholder consultations held across the basin as part of this study.

1.1 Background

This study looks at potential climate change impacts in one of Canada's largest and most vulnerable inter-provincial watersheds. Under climate change, the impact of changes in water availability on the socioeconomic system will depend on the type of water use, the quantity and quality of water required for a given use, and the institutions in place governing water use for a specific activity. For instance, the agriculture sector is highly dependent on irrigation for crop production. Major reductions in precipitation and streamflow could place stress on the entire river system and reservoirs from which water for irrigation water is or might be supplied. Should global warming or extreme events such as drought occur over an extended period, difficult allocation decisions may be required.

An understanding of various aspects of water use for the baseline period allows an initial assessment of the potential, future vulnerability of economic and social systems within the SSRB to changes in water availability. It also allows for the evaluation of current and future estimates of water use values and economic sensitivity under potential changes in climate, as well as for various scenarios considered as *competing* demands (such as changing demographics, increased production, or consumptive activity versus ecological water use). Given that the overwhelming proportion of surface water is used for irrigation and there is potential for expansion in Saskatchewan, continuing research is needed related to agricultural trade, crop choices, land use practices and associated irrigation demand.

1.2 Approach and Methodology

An integrated physical and social science analysis of climate-induced water supply impacts on the SSRB key water use sectors was achieved by having the two teams work forward in tandem with considerable internal and external consultation. The physical team used down-scaled climate scenarios from selected general circulation models (GCMs) to project surface water supplies in the SSRB under climate change. Using hydrologic models calibrated to the SSRB and forced by these down-scaled GCM scenarios, the physical science team was able to predict future water availability in terms of "naturalized" streamflows, that is, without the impacts of flow regulation and withdrawals. These streamflow scenarios were coupled with a selection of socioeconomic scenarios. The choice and range of the socioeconomic scenarios were informed by the concurrent analysis of water use patterns, both within the watershed boundaries and for external stakeholders reliant upon diverted surface water supplies.

The work of the socioeconomic team built upon its own application of geographical information systems (GIS) and a summary of physical geography to analyze the impacts of the physical team's modeling results. The SSRB overall has regional Prairie limitations, making the regional assessment of economic activity a worthwhile endeavor. However, it also has distinct sub-basin physical and climatic circumstances, with three eco-regional divisions (the Cordillera, foothills and Great Plains) and associated differences in baseline resources and precipitation. This sub-regional character and the vulnerabilities of stakeholders are likely to be further emphasized by each sub-basin's prospects under the physical team's down-scaled GCM forecasts, with sub-basin sets of forecast streamflows determined, as *envelopes*, through hydrological modeling. Central in the interpretation of the physical results was the recognition that climate change will drive a more active precipitation cycle, building upon existing regional patterns. These patterns include: spring snowmelt in the Rockies which provides the majority of surface water supply; heavy spring and early summer rains which recharge soil moisture and groundwater reserves; and glacier melt which contributes to instream flows, but to a decreasing extent downstream. These combined observations suggest that streamflows across the full basin will not be uniformly impacted, even though the glacier mass is evidently in decline.

The socioeconomic team's methodology pursued foundation physical and conceptual work, water management expert and stakeholder consultation, and applied regional economic (input-output) assessment and economic efficiency valuation. The watershed was first defined and the surface water use was documented in socioeconomic terms, with water use definitions applied in a standardized manner. The concepts of climate impacts and vulnerabilities and stakeholders were then explored, with the realities of water management, commitments and allocations informed through expert and stakeholder consultation. The regional economic benefits associated with water use, by sector and sub-region, were assessed, with the prospects for key stakeholders then refined through economic efficiency valuation on a sub-basin basis. As the emerging results suggested these sub-basin circumstances would be quite distinct, considerable effort was made to explain the economic efficiency concepts, methodology and assumptions, devise a suitable scenario-based approach, and use this approach to couple with the physical team's streamflow envelopes, to demonstrate the end-to-end physical to socioeconomic exercise on both local (city) and wider (sub-basin) bases.

1.3 Key Findings

This study built upon prior research on the potential impacts of climate change in the Canadian Prairies (Natural Resources Canada, 2002). Regionally, the potential changes anticipated include: changes in annual streamflow, possibly with large declines in summer streamflow; increased likelihood of severe drought, and increasing aridity in semiarid zones; and increases or decreases in irrigation demand and water availability (ibid).

The key findings of the SSRB study were:

- The South Saskatchewan River Basin (SSRB) will continue as a pivotal agricultural region, with irrigation capacity and efficiency already achieved in Alberta, but additional capacity existing and currently underutilized in Saskatchewan.
- Although the share of surface water used for agriculture across Canada is only 9%, it is almost 50% in the Prairie Provinces and particularly high in the SSRB, at 86.5%.
- Growth in irrigation is likely to put the most pressure on the SSRB surface water supplies due to its high water consumption intensity and scale of water use.
- Non-agricultural water use in the SSRB includes municipal (8.7%), thermal (3.0%) and industrial (1.8%) uses. Municipal water services for residential, commercial and urban industrial use typically have high return flows and are not likely to add significant pressure to water supply despite their larger combined proportion. However, the thermal and industrial sectors have the potential to impact significantly on water quality (including temperature) as well as increase water use, retention and demand in response to an expanding economy.
- Actual water consumption (withdrawals minus return flow) was close to 70% in 1996 but this varies across water use sectors. Changes in the timing of return flows may prove critical.
- The SSRB is highly vulnerable under climate change as stakeholders face increasing temperatures, accelerated evaporation and a more active precipitation cycle. Agricultural users are particularly vulnerable to abrupt changes; adaptive challenges due to the gradually shifting conditions will likely be exacerbated by more frequent extreme events (flooding, drought, hail and windstorms).
- The downscaled global climate models (GCMs) as selected projected a range of impacts. They indicate a possible change in annual precipitation of between a reduction of precipitation (-3.8%) estimated by the Echam model to an increase in precipitation (11.5%) by the Ncar model. The third model also estimates an increase in precipitation and the overall average of all models indicates a modest increase in precipitation of 3.6%. Temperature increases could range from 1.5°C to 2.8°C for the same projection period centred on 2050.
- The downscaled instream flow impacts suggest a risk of significant decrease in surface water availability, with an average decrease in water supply of 8.4% across all basins.
- These projected impacts have considerable variation across the SSRB sub-basins. The instream flow decrease could be highest in the Red Deer River basin at -13% on average (ranging from -32% to +13%), followed by the Bow River basin at -10% (from -19% to +1%), the shared (Alberta/Saskatchewan) South Saskatchewan River basin at -8.5% (from -22% to 8%), and the Oldman River basin at -4% (from -13% to 8%).
- The SSRB population could easily double from 1.5 to 3.1 million under a medium growth scenario with the strongest growth in the Bow River basin.
- By 2046, irrigation consumption (withdrawals minus return flow) could increase by 23% with non-irrigation consumption rising 103%.
- The high proportion of irrigation use (at 31% of water availability based on the 1961 to 1990 regime) suggests that non-irrigation demand will not be a significant risk to surface water resources in the SSRB.
- The 154 million cubic meters of non-irrigation water consumed in 1996 only amounts to 1.9% of available surface water which, under a medium growth scenario, could increase to 3.8% by 2046. Increased efficiency of water consumed in the municipal sector is likely.

- Climate change is likely to reduce water availability by approximately 546 million cubic meters between 1996 and 2046 while the rise in consumption from irrigation could be 440 million cubic meters under a medium growth scenario.
- Instream flow needs which could draw from the 4,182 million cubic meters (67%) of remaining unallocated water available in 1996 may only be able to draw from 53% of remaining water in 2046, after climate change and medium growth demands in irrigation and non-irrigation use are factored in.
- Viewed in another way, critical ecological (instream flow) needs plus baseline human consumptive need operate within overall water availability, leaving the unallocated portion of water available (essentially, a "buffer") to absorb all additional demands, including consumptive growth and climate change as well as the uncertainty and variability associated with both.

1.4 Project Sponsorship, Collaboration and Target Audience

The work was performed by a core team of researchers, but influenced by many experts and practitioners working across the breadth of southern Saskatchewan and Alberta. The co-team collaborative exercise, involving socioeconomic and physical science research teams, was funded by Natural Resources Canada under its Climate Change Impacts and Adaptation Program (CCIAP). For the socioeconomic component, a significant portion of this funding was used for expert and stakeholder workshops, consultation and outreach, as well as local, regional and national dissemination of results. It was the socioeconomic team's role to document key water use sector activity, apply a layered socioeconomic methodology, work with the physical team to develop an end-to-end analytical exercise, and determine, through this collaboration, the potential impacts of climate-induced water supply change.

Since its inception in May 2003, the socioeconomic study has been administered by the University of Saskatchewan, with Environment Canada involved in both co-team collaboration and the coordination of management and technical advisory committees. The core socioeconomic research team is led by Project Leader, Lawrence Martz, with University of Saskatchewan researchers, Joel Bruneau and Suren Kulshreshtha, and supported by post-graduate and graduate student researchers, Terry Rolfe and Robert Armstrong. The Environment Canada co-team project collaborators include Project Leader, Alain Pietroniro (National Water Research Institute (NWRI)) with NWRI researcher, Brenda Toth, who worked in close consultation with Joel Bruneau on the dove-tailed physical-to-social science exercise.

The target audience for the social science component evolved since the project's inception. There was a shift towards the practical application of results by key stakeholders. This was prompted by observed, sub-regional variations of economic activity and climate change impacts in the basin, increasing awareness of uncertainty under climate change assessment, and the government's shift towards more *transdisciplinary* dialogue on resource decision-making. The primary project task was to develop an intuitive end-to-end framework capable of meshing the more predictable dynamics with the uncertainties associated with climate change and human response. The limiting reality of *cascading uncertainties* became clear and the initial goal of pursuing greater precision in forecasting anticipated impacts was accordingly down-played. The methodology laid out here subscribes to academic rigor nonetheless and lays out a foundation for extensions by clearly setting out the models, conditions and assumptions used.

1.5 Structure of the Final Technical Report

This technical report summarizes the completion and adjustment of the project deliverables contracted. It begins with an Introduction (Chapter 2) which lays out the project scope and objectives, as well as the research questions and associated steps for knowledge acquisition, methodology and information dissemination. These steps were influenced by the evolving interpretation of core concepts linking climate change impacts to stakeholder vulnerability, as explained in Chapter 3. Chapter 4 describes the methodology used, including watershed and water use definitions, how economic analysis is used to consider both regional and marginal market impacts, and how a scenario-based approach can be applied. The specified deliverables are listed in the Introduction, with the linked methodology and results are set out in Chapters 4 through 11. The additional work performed as required to keep pace with the changing circumstances and awareness is also highlighted. Chapter 3 provides a sequence of conceptual interpretation, reflecting on the nature of surface water, human impacts and vulnerability, and stakeholder definition and engagement; many of these concepts are reiterated or refined, as applied, in methodologies described in Chapters 5 through 9. Chapter 4 reflects on the development of an overall methodology *per se*, suitable for both the intuitive end-to-end exercise and presentation of results to stakeholders.

Chapters 5 through 10 present the core of the methodological work and analysis. Chapter 5 begins with a physical geography description of the South Saskatchewan River Basin (SSRB), followed by Chapter 6 which lays out water use review in historical context, a taxonomy for differentiating water use, and a socio-economic database with measurement aggregated by key stakeholder sectors by sub-basin. Chapter 6 also focuses upon the importance of identifying net water *withdrawals* and prospects for further analyses refined on an infrastructure nodal basis. Chapter 7 reviews the use and limitations of economic impact analysis for capturing a region-wide or provincial snapshot of water use, focusing on both the basic and a customized application of the input-output (IO) model for the SSRB. Chapter 8 documents key water use sector aggregate results with the data assimilation, calculations and assumptions used to customize the socioeconomic database documented in Appendix C. Chapter 9 provides an introduction to the economic valuation of water, outlining the key economic concepts, premises, calculations and the sources of values used. This chapter then systematically determines, for each key sector, the water use, sector and where possible sub-sector values of water, and the total value of water. The economic value of water in each sector, as well as the average and short- and long-run marginal costs of water, can be used to interpret vulnerabilities within specific timeframes as well as within the larger regional (IO) snapshot, where duly noted. Chapter 10 describes the rationale for the scenario-driven approach assumed to meet the needs of stakeholder and policy decision-makers.

Chapters 11 and 12 document the application of an end-to-end exercise at two levels. Chapter 11 describes in detail how the physical science establishment of a net annual basin water supply can be determined on a sub-basin basis; these sub-basin forecast flows are then linked to the socioeconomic counterpart of sub-basin sectoral emphases and impacts, with coupling of the selected downscaled climate change and consumption scenarios. The “envelope of scenarios” approach is commonly used for business decisions; this approach, as mirrored here, projects a baseline of business-as-usual and considers the extreme worst and best case scenarios to define the outer regions for potential response or vulnerability. Chapter 12 provides an illustrative site-specific, tri-city comparison of potential outcomes meshing climate change and related hydrology with economic growth and population scenarios.

Chapter 13 reiterates the interim results and conclusions and sets the methodological base work and outcomes of this study's initial end-to-end exercise within a longer-term research frame. This section also summarizes several avenues for policy work already identified for immediate extension. This report includes one such example as Appendix P, demonstrating not only an institutional policy linkage but collaborative potential with other concurrent studies (in this case, the SSHRC-MCRI Chile-Canada comparative study undertaken by the University of Regina).

References:

Natural Resources Canada (2002). Climate Change Impacts and Adaptation: A Canadian Perspective – Water Resources. Climate Change Impacts and Adaptation Directorate, Natural Resources Canada, Ottawa

2 Introduction

2.1 Project Scope and Objective

This report summarizes the outcomes from a regional climate change and water supply impacts study performed on one of Canada's largest and most vulnerable agricultural watersheds. This two-team research effort on "*Climate Change and Water Supply in the South Saskatchewan River Basin (SSRB)"* was funded by the Climate Change Impacts and Adaptation Program (CCIAP) of Natural Resources Canada. The objective of the study is to document key water use sector activity and perform an end-to-end physical and social science analysis of potential impacts associated with climate-induced effects. This two-team approach looks at two aspects of climate change. The first is a physical science component that uses down-scaled climate scenarios from selected general circulation models (GCM) to predict future water availability in the SSRB under the potential impact of climate change. The goal was to first quantify the hydrological implications of climate change not only for a large watershed, but also for its major sub-basins. The socioeconomic component, in turn, inventoried water use, considered the regional economic structure, and assessed the vulnerability of key water sectors to prospective changes in the water supply. This technical report details the socioeconomic project outcomes and documents how the dove-tailed linkage was achieved. The physical science team is issuing a separate technical report to detail their methodology and findings.

2.2 Project Components

The South Saskatchewan River Basin (SSRB) Climate and Water Study consists of two linked projects funded independently by the Climate Change Impacts and Adaptation Program (CCIAP), coordinated through one advisory committee. The projects are:

- *Water Availability in the SSRB under Climate Change*. This is a physical science study designed to predict future water availability in the SSRB under the potential impact of climate change using hydrologic models forced by downscaled climate scenarios from selected general circulation models (GCM).
- *An Assessment of the Vulnerability of Key Water Use Sectors in the SSRB (Alberta and Saskatchewan) to Changes in Water Supply Resulting from Climate Change*. This is a social science study designed to assess the socio-economic impacts of climate-change-induced water resource availability on the key water use sectors in the SSRB.

2.3 Project Goals

The goals of the study were to:

1) provide a framework to guide decision-makers in water use policy and planning;
2) demonstrate the feasibility of an SSRB-wide *end-to-end* analysis;
3) identify interconnections between human activity, climate and water resources;
4) lay out possible future scenarios to guide decision-makers; and
5) identify major issues to refine analysis

2.3 Setting

The South Saskatchewan River Basin (SSRB) crosses provincial and international boundaries, as shown in Figure 2.1. The surface water flows are subject to two formal apportionment agreements as it moves from the Continental Divide through southern Alberta into south-central

Saskatchewan. The SSRB is comprised of four major sub-basins: the Red Deer, Bow, Oldman and South Saskatchewan. A sophisticated system of major reservoirs and diversions regulate river flows and divert water to areas of high demand, including the city of Regina which lies well outside of the physical watershed.

Runoff generation and hydrologic regimes vary tremendously across the SSRB. Most of the streamflow carried by the major tributaries of the SSRB is not generated on the Prairies, but is derived from snow and glacier melt in the Rocky Mountains. Roughly 90% of the total South Saskatchewan River flow is derived from the Rocky Mountains while the Saskatchewan portion of the basin contributes only about 2% of the flow. Soil moisture conditions and local runoff in the Prairie portion of the basin, however, are largely dependent on local snowfall and rainfall (Atlas of Saskatchewan 2001).

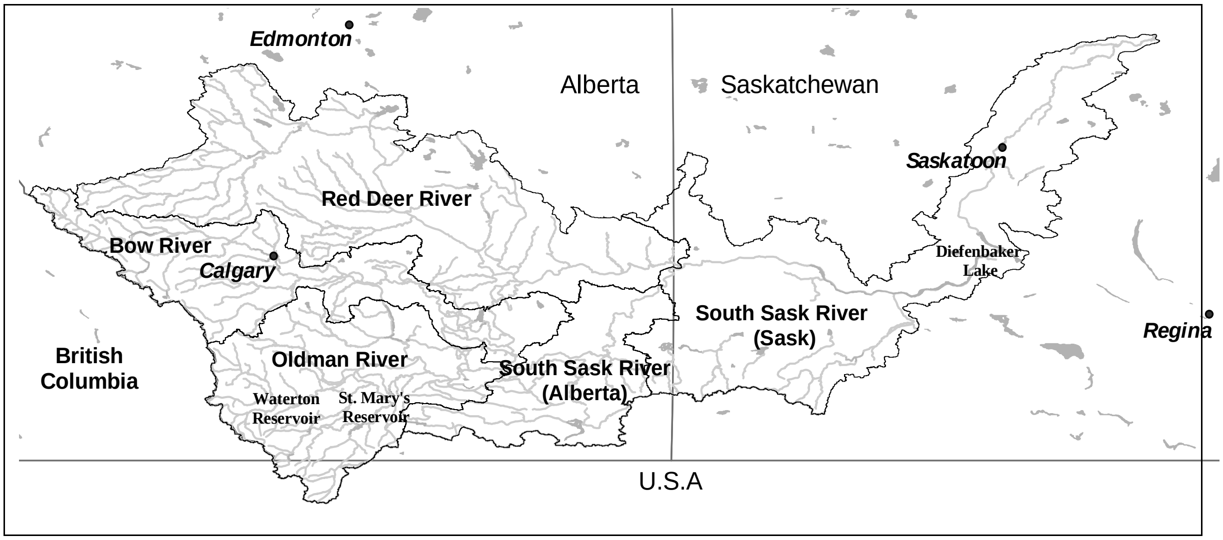


Figure 2.1 *South Saskatchewan River Basin (Armstrong, in Martz et al., 2004, 2).*

It is a challenge to predict regional weather and climate change patterns on a regional and sub-regional basis due to scale discordance and the diversity of SSRB geography. As reported in Martz et al. (2004), the General Circulation Models (GCM) predict climate change will produce generally warmer temperatures across the Canadian Prairies, although uncertainty remains on GCM predictions of precipitation. Changes in regional temperature and precipitation are expected to vary geographically and by season. The impact of these changes on water resources will be further complicated by the interaction of temperature and precipitation (e.g. warmer temperatures can increase evapotranspiration enough to reduce soil moisture and runoff even despite increases in precipitation). Changes in the climate system could also result in a greater frequency of extreme events such as droughts and floods. In 2002, Natural Resources Canada reviewed the current state of knowledge and assessed the most likely impacts of climate change on water resources of the Canadian Prairies. These are summarized in Table 2.1.

Potential Changes	Associated Concerns
• Changes in annual streamflow, possible large declines in summer streamflow • Increased likelihood of severe drought, increasing aridity in semiarid zones • Increases or decreases in irrigation demand and water availability	• Implications for agriculture, hydroelectric generation, ecosystems and water apportionment • Losses in agricultural production, changes in land use • Uncertain impacts on farm sector incomes, groundwater, streamflow and water quality

Table 2.1 *Potential impacts of climate change on water resources in the Canadian Prairies* (Natural Resources Canada, 2002)

Historical data show trends consistent with Table 2.1. This region has become warmer and somewhat drier in the last five decades (Gan, 1998), and a greater number of rivers in west central Canada are exhibiting earlier spring runoff. Recent years have also brought severe and prolonged hydrological and agricultural drought to the Prairies.

Human activity evolving under these varied sub-basin conditions has taken on distinctive patterns given resource availability, proximity to markets, production prospects, and infrastructure development. Other dimensions of economic geography, such as settlement, agriculture, industry and recreational activity, reflect the SSRB's internal eco-regional distinctions: the Cordillera, foothills and Great Plains. Across the SSRB, three main agricultural land uses persist, for cropland, grassland and forage. Water control, capture, storage and diversion within the SSRB is well-engineered and closely monitored; water allocation and recycling must not only serve municipal, irrigation, commercial and industrial needs, but also preserve both recreational and critical instream and riparian ecological contributions. Two features of this managed system are of particular note. First, the largest water body within the SSRB is a constructed reservoir, Lake Diefenbaker, covering about 430 km^2, whereas most of the SSRB rivers flow in deeply defined channels, fed by alpine sources and a relatively narrow contributing area along the valleys. Secondly, the Qu'Appelle Valley Dam and diversion supply water to the cities of Moose Jaw and Regina and mining operations east of the watershed. Within the SSRB boundaries, a considerable portion of the land has internal drainage and does not contribute overland runoff to the main rivers. Only about 85,000 separate wetlands remain, covering about 500,000 hectares in total. Most of these are in Saskatchewan, within the shared South Saskatchewan sub-basin, and less than one acre in size. However, about 60% of the SSRB wetlands' gross area overall is in the Red Deer sub-basin, where wetlands are three acres on average.

2.4 Research Questions Addressed

Four of the five research questions raised in the original study agreement were funded and addressed. Questions 1) to 4) listed below were funded. Question 5 was not.

1. *What is the current water use by sector and by SSRB sub-basin?*
2. *What would the economic cost of water availability changes be due to climate change?*

3. *What is user vulnerability to changes in water availability under climate change?*
4. *What might water use look like in 2040?*
5. *What government policies and programs might help us adapt to this change?*

2.5 Deliverables

SSRB Socio-Economic Project Base Requirements for Period One:

1. (Sub-Objective 1)
A bound Interim Technical Report entitled "*Water Use in the South Saskatchewan River Basin*" was released to the Advisory Committee December 9, 2004. This report was also posted electronically on the website and made accessible to both Advisory and Technical committee members. This report met the requirement of identifying "key current water use in the SSRB by type of users and location". The report did not fully document *in situ* water use as few data on the recreational and non-market use values were found across the breadth of the SSRB.

2. Sub-Objective 2 (Part A) An Interim Technical Report on the value of water for regional economic development was also released December 9, 2004, documenting the development of a "*South Saskatchewan River Basin Input-Output, Employment and Water Use Model*".

2. Sub-Objective 2 (Part B) An Interim Technical Report on the value of water for economic efficiency was also released December 9, 2004, as entitled "*Economic Value of Water in the SSRB*".

Together, these three outputs met the requirement of "documenting water values...for economic efficiency, for regional development, and water allocation (marginal measures) for the various sub-basins of the SSRB".

Sub-Objective 2 Enhancements.
Two additional tasks were undertaken to document existing research for this analysis. A literature search was first performed with the support by Environment Canada. Then, a collaborative, limited research report was commissioned to help identify the knowledge and literature gaps. The Saskatchewan Research Council (SRC) released this latter study of "*An Assessment of Recent Past and Current Projects Relevant to the (SSRB) Study*" to the Advisory Committee on December 9, 2004.

3. Sub-Objective 3 The task of "forecasting future water use for various users in the SSRB for the period to 2040" was achieved through the dove-tailing of selective climate and socioeconomic scenarios. The limitations of forecasting, under *cascading uncertainties*, were acknowledged, and an alternative, pragmatic scenario approach was developed as a management and planning tool.

The factors affecting current and prospective key sector water use were identified in the Interim Technical Report on "*Water Use in the South Saskatchewan River Basin".* This report was submitted to the Advisory Committee December 9, 2004.

The modeling of forecasted water availability and use under climate change using the Water Use Analysis Model (WUAM) is an effort which continues at this time, under the auspices of the National Water Research Institute (NWRI). The SSRB socioeconomic database was customized to support the WUAM's modeling capabilities.

Sub-Objective 3

The dove-tailed exercise documented in this final report outlines the prospective future demands for surface water to 2050. Under the approach taken here, climate change is considered as another competing "demand", which may compromise water use for commercial or ecological purposes.

This study focused upon interpretations of vulnerability in light of the UNFCC guidelines for regional assessment. A standard schematic for assessing the impacts to environmental exposures was applied. The determination of threshold levels was performed for the key water sectors through calculation of water values and economic sensitivities (shadow prices); the limitations on each sectors' options reflects their water use and distinct planning horizons.

References:

Atlas of Saskatchewan, 2001. CD-ROM Edition, University of Saskatchewan.

Martz, L., S. Kulshreshtha, R. Armstrong, A. Pietroniro, T. Horbulyk and J. Bruneau, 2004. Climate Change and Water Resources in the South Saskatchewan River Basin, paper presented at the 57th Canadian Water Resources Association Annual Congress, June 16-18, Montreal.

Natural Resources Canada, 2002. Climate Change Impacts and Adaptation: A Canadian Perspective – Water Resources. Climate Change Impacts and Adaptation Directorate, Natural Resources Canada, Ottawa.

3 Water Supply Impact Valuation under Climate Change: Concepts

3.1 Project Orientation as Evolving

With its initial consultations in May 2003, the SSRB socioeconomic study has been a long-term effort. It involved an extensive network of direct and collaborative researchers whose research and discussions with stakeholders helped chart a revised study course to serve these stakeholders in the most practical but rigorous terms possible. Since 2003, the orientation of the international research community on the subjects of adaptation and vulnerability also evolved significantly, influenced by emerging research on climate change. Governments, scientists and professionals, along with communities and the public at large, have become increasingly aware of the need to work across all disciplines and engage stakeholders as much as possible in the monitoring of conditions and impacts, as well as the planning and assessment of adaptive strategies. Since 2003, the socioeconomic team's core study objective did not change: it remains that of "*assessing the vulnerability of key water use sectors in the South Saskatchewan River Basin to changes in water supply resulting from climate change"*. However, the approach and presentation of results were revised given these contextual developments and the recognition of an expanded audience.

This project is seminal in its end-to-end effort linking physical and socioeconomic impacts due to climate change. Not only did this effort result in considerable learning during the study period, but it will continue to provide a foundation for learning for future end-to-end analyses. One of the most important outcomes, from a social science perspective, was the realization that physical science applications, assumed to be more so standardized, may be subject to significant variation where applied in different jurisdictions with varying priorities and conditions. Before physical science data can be aggregated and results modeled, there is likewise the need for reconciliation of concepts and methodological assumptions, a step assumed *de rigor* in the social sciences. Furthermore, there remains the challenge that the concepts used by scientists and professionals do not always match those held by stakeholders and the public.

This study looks at potential climate change impacts in one of Canada's largest and most vulnerable inter-provincial watersheds. The work was performed by a core team of researchers, but influenced by many experts and practitioners working across the breadth of southern Saskatchewan and Alberta. For the socioeconomic component, a significant portion of the project funding was used for expert and stakeholder workshops, consultation and outreach, as well as local, regional and national dissemination of results. Stakeholders and water managers indicated that they were most receptive to a practical planning approach which can be intuitively used in sub-basin, sector-specific and collective decision-making. The study results presented here are linked through a layered methodology capable of informing municipal decisions (i.e. for cities) or guiding broader economic and resource policy. This foundation exercise can now be efficiently repeated and enhanced every five years, coinciding with *Census of Canada* releases, to provide a recurrent planning snapshot of baseline and evolving economic and environmental circumstances and associated impacts cast within an envelope of possible scenarios under climate change.

The target audience for the socioeconomic component broadened since the project's inception. The shift towards the practical application of results by stakeholders was driven by the growing recognition that many climate change impacts are quite site-specific, as are options for adaptation. Along with these sub-regional variations of climate and economic impacts, there is increasing recognition of the complexity of climate change and the uncertainty associated with its prediction. More front-line awareness and involvement is being encouraged by government in particular, to help foster a *transdisciplinary* dialogue on resource decision-making. The primary task of this study was to develop a framework capable of meshing the more predictable scientific dynamics with the uncertainties associated with climate change and human response. The limiting reality of these combined, *cascading uncertainties* were clear and the initial goal of pursuing greater precision in forecasting anticipated impacts was accordingly down-played. Stakeholders clearly indicated that they were not looking for one “best guess”, having developed skepticism about the reliability of such predictions in the past, but welcomed instead a range of possibilities to consider while planning alternative strategies capable of dealing with shifting international trade and other economic circumstances.

3.2 Unique Characteristics of Water

Before any economic valuation is applied, it is useful to review the characteristics which set water aside as a unique resource. These characteristics also contribute to the challenge of managing its use. In particular, freshwater has become an increasingly scarce resource influenced by its physical and hydrologic attributes, varying supply and demand, inter-temporal legal and political decisions, and associated social attitudes.

Water is by nature mobile and its quality varies as it flows, evaporates and permeates through the full water cycle. Given this mobility, it is difficult to establish and maintain clear ownership. This mobility creates high-exclusion costs and makes conventional valuation through markets difficult (Young, 2005). Despite this mobility, water supplies are considered “bulky” by economists insofar as they are relatively inexpensive but difficult to transport.

Surface water supplies have nevertheless been subject to a wide variety of precedents where downstream rights are concerned. A key challenge in terms of this apportionment has been the variable nature of its supply: this supply varies not only seasonally and year-to-year, but in longer-term cycles which also link local supplies to global climate phenomena.

Water is a substance required universally to support life. No other chemical compound can satisfy the essential liquid needs of flora and fauna, by facilitating nourishment and cleansing. Water acts as a solvent, not only absorbing and distributing nourishment but also diluting and relocating wastes. Although these functions might appear clearly separable, they are more evidently cyclical, with users drawing upon the water supply, and either reserving it temporarily or returning it to municipal systems, watercourses or groundwater. These users are highly interdependent insofar as the cycles of use and return contribute to downstream access and quality.

The downstream impacts of water use are seldom fully accounted for in economic decisions. Any unintentional impacts have traditionally been viewed in economic terms as “externalities”. This is an incentive to have government regulation not only on usage but the quality of return flows. Public investments are also justified due to the economies of scale associated with water storage and treatment. Surface water supplies can be managed as such by consolidated efforts which reduce costs on a per unit basis. Such management is more difficult for groundwater supplies, where information on the quantity and quality is difficult to assess. Subterranean conditions typically create slower flows, impacting significantly on the quality of the water.

3.3 The Full Water Cycle and Human Response Under An Ecosystems Approach

Under an ecosystems approach, the influence of climate change must be cast over multi-dimensional realms, including both terrestrial and aquatic physical and biotic systems, including human social systems. The human parameters of evolution and adaptation are part of this holistic puzzle. It is therefore imperative to understand both interests and motivations on the part of all resource stakeholders, and specifically, water interests both near and afar. The notion of property rights has been evolving under the umbrella of global common property regimes (Ostrom, 1990). Accordingly, people both near and afar have mobilized environmental response to local activities, in particular those with serious environmental implications. Consumers now often demonstrate their preferences by purchasing or boycotting goods with pro-active or compromising attributes, respectively. This growing activism and the scope of international response make it more difficult to define those who hold interests in collective water resources and are considered stakeholders.

For these reasons, it has become increasingly important that local economic stakeholders and community members be more fully engaged in water resource planning. Local residents are likely to be more immediately aware of climate and water impacts; their livelihoods may be severely impacted by water shortfalls or excess, as well as changes in water quality. However, it is naïve to assume that local interests in any basin can be isolated from interests and policies elsewhere. A well-organized, inclusive process of local involvement is often needed to respond to and balance interests from external parties whose actions may at times be at odds with local interests and values. It is also unwise to assume local interests are uniform, both collectively and individually. There is always a multi-dimensionality of response as all people assume different roles which may simultaneously apply to water use: as owners of businesses and homes, as employees, as recreational participants and those with scenic or environmental interests.

The mix of sector-specific interests with the multiplicity of stakeholder roles is one reason why a multi-dimensional, mixed method approach is useful for examining resource use, change and vulnerability. A formal business sector may have a customary timeline for planning, may face set operational and institutional constraints, and have a limited range of input and output options with associated costs, risks and limitations. These circumstances can be quantified on a sub-regional sector basis as demonstrated here in Section 9. The combined impact of the constraints, resource use, costs and benefits can also be reflected regionally and economy-wide as shown in Section 7.

Stakeholders simultaneously have affiliations which connect them to local, regional, national and international networks which either formally or informally expose them to, or buffer them from, impacts in any one area or dimension. For example, farmers who are heavily reliant upon energy sources in their operations may also benefit from holding investments or having family employed in the energy sector. The recognition of role multiplicity and reciprocal benefits or obligations, as known to influence community “resilience” is a driving force behind the continuing debate of the concept of “vulnerability”.

3.4 Limitations on Resources: The Shifting Focus of Impacts under the UNFCCC

Canada is a signatory under the United Nations Framework Convention on Climate Change (UNFCCC) which requires its parties explore programs to facilitate adaptation to climate change. Until recently, there was an overwhelming emphasis on knowledge and technical solutions geared towards the mitigation of direct climate change impacts. This focus led to the development of methods and tools to systematically evaluate different adaptation strategies and resulted in the release of many useful outputs, including the 1999 Compendium of Decision Tools to Evaluate Strategies for Adaptation to Climate Change. Work is underway to extend the range of tools to assess human adaptation and expand the repertoire of decision-making under an umbrella which considers the “entire process of vulnerability and adaptation assessment” (UN, 1999, 2).

The UNFCCC focused first on the magnitude and urgency of climate change as driven by global general circulation models (GCMs). This focus linked global climate scenarios and their physical exposures to regional biogeophysical sub-systems (such as the carbon and hydrological cycles) and resource sectors such as agriculture and forestry. However, there has been growing interest in how these climate change impacts might be mitigated or exacerbated by socioeconomic systems and challenges associated with human security. There has thus been a shift in focus from a more limited, market-based economic view of resource management to a broad socioeconomic framework which casts human vulnerabilities in socio-political context. This increased emphasis on human geography (linking human situation to time and place) provides an improved link between climate change and institutional evolution, although as Folke *et al*. (1998) argue, formal human institutions and ecosystem responses may be inherently incongruent.

3.5 The Concept of Vulnerability: Evolving Interpretations

Recently, there have been important developments in the literature on vulnerability as it pertains to socioeconomic systems and the management of water resources. As a concept, vulnerability continues to be of focus because of the word's inclusion in critical documents including the United Nations Framework Convention on Climate Change (Smit, 2005). The Intergovernmental Panel on Climate Change (IPCC) defines vulnerability as: "the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity" (McCarthy et al., 2001, Box SPM-1). This definition specifically links climate change exposures to resulting environmental and socioeconomic impacts.

Figure 3.1 shows how exposures and associated sensitivities across human and ecological systems translate into a sector or community's resilience or susceptibility to harm. This net vulnerability is a function of the characteristics of the exposures themselves (frequency, extent, magnitude and duration). Human and environmental components exhibit sensitivities to these exposures in turn, in light of their endowments and system networks. The *net* vulnerability depends in turn on the resourcefulness of both sectors and communities; these human domains share physical and social capital, access to and liquidity of resources, and combine coping responses within socio-political context. The extent to which sectors or communities cope with or may even benefit from direct or indirect exposures in turn influence collective resilience.

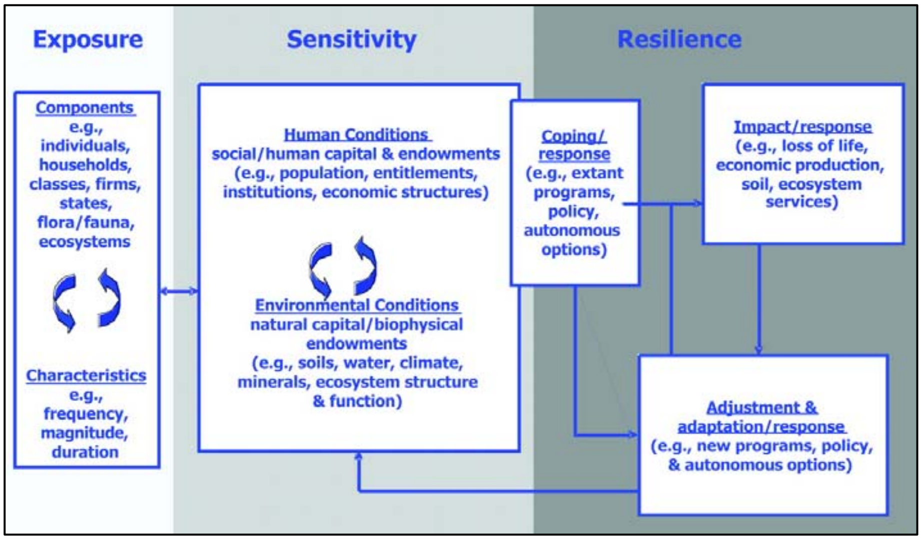


Figure 3.1 *Reproduced with permission (Turner et al., GWSP, 2003, 8077)*

However, there are many facets to sector and community vulnerability which make it difficult to separate physical environment from human civilization exposures. Berkes and Folke (1988) highlighted the inseparability of human and environmental systems, reaffirming linkages between ecological and social system resilience. (Folke *et al.*, 2002, 36) explain how combined "ecological resilience" should be viewed as both integrated and dynamic:

> The amount of change a system can undergo and still remain within the same state or domain of attraction, is capable of self-organization, and can adapt to changing conditions (after Carpenter *et al* 2001). Holling (e.g. 1986a) defined ecological resilience as the magnitude of disturbance that a system can experience before it moves into a different state (stability domain) with different controls on structure and function…" (Folke *et al.*, 2002, 36)

3.6 Defining Key Stakeholders

The task of defining stakeholders for natural resources has become more challenging as explained above in Section 3.3. Individuals with local economic interests typically occupy simultaneous roles as stakeholders, as business owners, home owners, or participants otherwise in recreational or environmental activity. Individuals resident in more distant communities may also have interests, exerting direct influence seldom (i.e. during travel) or indirectly through investment, product support, personal contributions, or activism.

The task of defining key stakeholders who will be significantly impacted, in socioeconomic terms, from marginal changes in water supply under climate change is fortunately quite clear. Here, the identification of stakeholders is achieved by determining the type and extent of water usage as well as the marginal pricing or access effects which climate change may have on the contributions marginal changes in surface water make towards productivity or enjoyment. The type and extent of water use must be carefully considered so that the term "water use" is not applied too broadly, that is, without considering the dynamics of the full water cycle. This necessitates the use of a taxonomy of water use which not only differentiates between surface water withdrawals and instream (or *in situ*) use, but also between water intake, demand, requirements and actual consumption. This taxonomy is applied in Sections 6, 7, 8 and 9, where the water use by key sectors is analyzed (Section 6.4), water withdrawal use is determined by key water use sector across provincial and sub-basin divisions (Section 8), the economic contribution of marginal changes in water is computed for each sector (Section 9), and the overall impact of surface water use by sector to the regional and sub-regional economies is documented (Section 7).

As detailed in Section 8, the key SSRB stakeholders in terms of surface water withdrawal are agriculture (irrigation and stock-watering), residential (urban domestic and rural demand), municipal demand (for urban residential, commercial and industrial services), industrial (for mining, oil, and gas), and energy (for thermal or hydroelectric production). Many stakeholders engaged in recreational, scenic and ecological activities are simultaneously participants in the goods and services economy, both as workers and consumers. The impact of changes in surface water supply due to climate change, as may affect instream enjoyment of surface water supply is both highly contextual and complex. Small changes in the surface quantity may be less influential on recreational and scenic enjoyment than changes in water quality (including turbidity and chemical composition), but this depends upon geography. For example, upstream, abrupt spring flows may contribute to higher returns for recreations such as rafting, whereas lessened downstream mid-season flows may lead to compromised channels due to silt concentrations. The relationship between surface water supply and water quality is, again, a critical interaction, but unfortunately not within the scope of project funding at this time.

3.7 Project Outreach to Advisory Members and Stakeholders

Much effort was made to communicate the research planning and results to advisory committees and stakeholders as summarized in the following appendices. *Section 2 Appendix 1* details how the SSRB team convened regular management and technical advisory sessions, presented at conferences, conducted stakeholder workshops, and surveyed stakeholders informally at related events. The SSRB team used this stakeholder and expert input to design a regional conference to address "*Climate Change and Water in the Prairies*" issues while disseminating the SSRB team results publicly on June 21-23, 2006 in Saskatoon. This two-day conference event hosted four keynote speakers and over thirty presenters in total. The session themes were transdisciplinary, reflecting concerns highlighted earlier by SSRB stakeholders. Intergenerational, community-oriented content was also featured, as the conference event was co-hosted by the Prairie-wide stakeholder organization, Partners FOR the Saskatchewan River Basin (PFSRB). Other than this conference event and its Proceedings outputs, the socioeconomic study team disseminated over 15 formal publications, including 3 interim advisory reports, 3 working documents, and 10 publicly available conference papers as detailed in *Section 2 Appendix 2* below. The SSRB social and physical science teams also held two public Water Forums at the University of Saskatchewan, drawing local public attendance and media attention. *Section 2 Appendix 3* details the media coverage achieved by the SSRB team efforts, estimating that an audience of 386,825 was reached through a series of interviews and articles.

References:

Berkes, F. and C. Folke (2002). Back to the Future: Ecosystem Dynamics and Local Knowledge, in *Panarchy* by Lance H. Gunderson and C.S. Holling (eds.). Washington, DC: Island Press, 121-146.

Berkes, F. and C. Folke (eds.), (1998). *Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience*. Cambridge, UK: Cambridge University Press.

Folke, C. et al., (2002) *Resilience and Sustainable Development*: Science Background Paper commissioned by the Environmental Advisory Council of the Swedish Government in Preparation for the WSSD. International Council for Science (ICSU) Series on Science for Sustainable Development No. 3, Paris.

Folke, C., I. Pritchard, F. Berkes, J. Colding and U. Svendin, (1998). *The Problem of Fit Between Ecosystems and Institutions*. International Human Dimensions Programme (IHDP). IHDP Working Paper No 2. At: www.uni-bonn.de/IHDP/public.htm.

Holling, C. S., (1986a). The resilience of terrestrial ecosystems: local surprise and global change, in *Sustainable Development of the Biosphere*, W. C. Clark and R. E. Munn (eds.), Cambridge: Cambridge University Press, 292-317.

McCarthy, J., O. Canziani, N. Leary, D. Dokken and K. White, (2001). *Climate Change 2001: Impacts, Adaptation and Vulnerability*. New York: Cambridge University Press.

Ostrom, E., (1990). *Governing the Commons: the evolution of institutions for collective action*. Cambridge and New York: Cambridge University Press.

Smit, B., (2005). Comments made in his plenary session, Canadian Climate Change Impacts and Adaptation Annual Conference, Montreal, PQ, May 3-7.

Turner, B., R. Kasperson, P. Matson, J. McCarthy, R. Corell, L. Christensen, N. Eckley, J. Kasperson, M. Martello, C. Polsky, A. Pulsipher and A. Schiller, (2003). *A framework for vulnerability analysis in sustainability science*. At: www.pnas.org/cgi/10.1073/pnas.1231335100.

United Nations (UNFCCC), (1999). Compendium on methods and tools to evaluate impacts of, vulnerability and adaptation to climate change. On-line since 2003 at: http://unfccc.int/adaptation/methodologies_for/vulnerability_and_adaptation/items/2674.php

Young, Robert A., (2005). *Determining the Economic Value of Water: Concepts and Methods*. Washington, DC: Resources for the Future.

Section 3 Appendix 1
Summary of SSRB Team Stakeholder Outreach, Conference and Workshop Work

Summary of SSRB Team Travel for SSRB-related Work:

1. January 16, 2004. Calgary, Stakeholders' Meeting.
2. December 9, 2004. Calgary, SSRB Management Advisory Committee Meeting.
3. June 17, 2005. Calgary, SSRB Management Advisory Committee Meeting.
4. Fall 2005. Bruneau travel to Ottawa to meet with Environment Canada and Statistics Canada.
5. Spring 2006. Ottawa Bruneau participation in Freshwater for the Future Policy Workshop.

Stakeholder Outreach and Conference Work:

1. May 31-June 3, 2004. Edmonton. Human Dimensions of Weather and Climate, 38th Annual CMOS Congress, SSRB team presentation on "A Study of Climate Change, Water Availability, and Regional Socioeconomic Impacts in the South Saskatchewan River Basin".
2. June 16-18, 2004. Montreal, CWRA 57th Annual Conference. SSRB team presentation.
3. July 13-16, 2004. Lethbridge, Confronting Water Scarcity Conference. Bruneau presentation.
4. October 6-8, 2004. Saskatoon, CWRA/PFSRB Conference. SSRB team presentation.
5. November 2-3, 2004. Regina. CWRA Watershed Stewardship Workshop. Rolfe attended, observing IWRM approach and soliciting stakeholder input.
6. February 16-18, 2005. Edmonton, CCIARN Workshop. Rolfe attended and assisted (scribed Panel Comments). Sponsor: CCIARN Agriculture.
7. May 4-7, 2005. Montreal, QC. CCIARN Annual Conference "Adapting to Climate Change in Canada, 2005: Understanding Risks and Building Capacity". Rolfe presented.
8. May 10-11, 2005. Saskatoon, Wetland Policy and Mitigation Workshop. Rolfe attended, considering wetland water use issues and soliciting stakeholder input.
9. June 2, 2005. London Ontario. Annual Congress: Climate Change Symposium. Rolfe Presented. Sponsor: SSHRC/CCIARN Agriculture.
10. June 14-17, 2005. Banff CWRA 58th Annual Conference "Reflections on our Future". Five presented: SSRB Co-Team: Martz, Rolfe, Bruneau, Kassem, Toth, and Pietroniro.
11. June 30 - July 2, 2005. Budapest. Annual Conference of Society for the Advancement of Socio-Economics. Rolfe presented. Sponsor: University of Saskatchewan.
12. August, 2005. Bruneau Presentation to Water Managers from Hebei Province, "Water Resources and Climate Change in the SSRB", Department of Agriculture, University of Saskatchewan.
13. September 22-23, 2005. Winnipeg (IISD) Prairie Water Policy Symposium. Bruneau Attended to consider policy concerns related to water use.
14. October, 2005. CREE Conference. Bruneau session chair and discussant.
15. October 27-29, 2005, Toronto, York University. CANSEE Bi-Annual Conference. Canadian Society for Ecological Economics, Rolfe presented.
16. November 16-19, 2005. Climate Change Workshop, University of Halle-Wittenberg, Germany. Rolfe workshop contribution. Sponsors: University of Halle-Wittenberg, and University of Saskatchewan.
17. November 22-25, 2005. New Delhi India, International Water Resource Association. Rolfe presented. Sponsor: University of Saskatchewan.
18. January 24-26, 2006, Regina. IWRM, SSRB affiliate/CWRA-SYP attendee Matt Regier.
19. March 2-3, 2006, Winnipeg. CCIARN/IISD Climate Change, Water and Hydro Workshop.
20. April 2-5, 2006, Edmonton. CWRA/Alberta ENV Conference on Climate Change and Water. Bruneau and Toth presented.
21. June 4-7, 2006. CWRA 59th Annual Conference. Toronto. SSRB team, SSRB co-team, and CSALE affiliates presented: Bruneau, Hauschild, Toth, Farnese and Rempel, respectively.
22. June 21-23, 2006. "Climate Change and Water in the Prairies", Conference co-hosted by the SSRB team and Prairie-wide stakeholder association, Partners FOR the Saskatchewan River Basin. Six presentations directly by SSRB team and affiliates. All presentations on program selected according to interests derived from SSRB stakeholder survey and views solicited at other events above.
23. June, 2006. "With Smart Water Management, Climate Change Need Not Impede Economic and Population Growth", Martz and Bruneau, Star Phoenix article.
24. September, 2006. CREE Conference. Bruneau session chair and discussant.
25. September, 2006, Collaboration Between Bruneau, Michel Villeneuve (Environment Canada), and Steven Renzetti (Brock University) on "Report on Industrial Water Recycling in Canada", (ongoing).

Section 3 – Appendix 2
South Saskatchewan River Basin (SSRB) Project Team Publications

Armstrong, Robert, Elise Pietroniro and J. Terry Rolfe, (2004). Water Use in the South Saskatchewan River Basin. SSRB Interim Technical Report, University of Saskatchewan, Saskatoon, SK.

Armstrong, Robert, (2005). Re-Assessment of 1996 Census Population, Livestock and Water Use Information. SSRB Technical Report on the SSRB Socio-economic Database Methodology, Observations and Assumptions, University of Saskatchewan, Saskatoon, SK.

Bruneau, Joel F., (2006). South Saskatchewan River Basin Water Withdrawal Forecasts and Scenarios, Department of Economics, University of Saskatchewan, Saskatoon, SK.

Bruneau, Joel F., (2004). Economic Value of Water in the SSRB. SSRB Interim Technical Report, University of Saskatchewan, Saskatoon, SK.

Bruneau, Joel F. (2006). South Saskatchewan River Basin Water Withdrawal Forecasts and Scenarios, Department of Economics, University of Saskatchewan, Saskatoon, SK.

Bruneau, Joel F. and J. Terry Rolfe, (2005). The Economic Impact of Climate Change in the South Saskatchewan River Basin (SSRB). 58th CWRA Conference, June 14-17, Banff, Alberta.

Bruneau, Joel. and Brenda Toth, (2005). Impact of Economic Development on Water Resources in the SSRB under Climate Change. Position Paper for SSRB Management Advisory Committee, December 2005 and submission to “Climate Change and Water in the Prairies” Conference.

Kulshreshtha, S. and W. Thompson, (2004). South Saskatchewan River Basin Input-Output, Employment and Water Use Model. Interim Technical Report, University of Saskatchewan, Saskatoon.

Martz, Lawrence W., J. Terry Rolfe and Robert Armstrong, (2005). Climate Change and Water Resources in the South Saskatchewan River Basin: An Overview. 58th CWRA Conference, June 14-17, Banff, Alberta.

Rempel, Toni, (2005). An Assessment of Current Water Management: A Comparative Analysis of How Saskatchewan Can Approach Future Water Management. BIOCAP-CSALE contribution to SSRB Project, Saskatoon, Saskatchewan.

Rolfe, J. Terry, J. FitzGibbon, R. Plummer and L.W. Martz, (2005). Assessing Vulnerabilities Associated with Reduced Water Supply Due to Climate Change. International Water Resource Association (IWRA), November 22-25, 2005, New Delhi.

Rolfe, J. Terry, (2005). The Future of Socio-Economics and Public Involvement for Addressing Vulnerabilities in the South Saskatchewan River Basin. 58th CWRA Conference, June 14-17, Banff, Alberta.

Rolfe, J. Terry and Josi Hauschild, (2006). “Climate Change and Water in the Prairies” Conference Proceedings on-line and hard copy Proceedings (pending).

Rolfe, J. Terry, Michael Trant and Lawrence W. Martz, (2004). How Agricultural Policy Choices Related to Climate Change Adaptation May Affect Community Health, Working Paper presented at the 2005 Congress of the Humanities and Social Sciences, June 2, London, , in press with University of Toronto Press.

Wittrock, V., (2004). An Assessment of the Vulnerability of Key Water Use Sectors in the South Saskatchewan River Basin (Alberta and Saskatchewan) to Changes in Water Supply Resulting from Climate Change: a Limited Report for the South Saskatchewan River Basin (SSRB) Project by Saskatchewan Research Council, SRC Publication No. 11759-2E04, Saskatoon, SK.

Section 2 Appendix 3
University of Saskatchewan Research Communications Media Tracking: Coverage

Author: *Period:* January 2005 -

Date	Byline: Author/ Reporter	Publication/ Outlet	University of Saskatchewan Contact	Story Subject	Comments	Reach	Ref #
16-Jun-06	LAWRENCE MARTZ, JOEL BRUNEAU	STAR PHOENIX SASKATOON	LAWRENCE MARTZ	WATER MANAGEMENT GROWTH CAN CO-EXIST	GEOGRAPHY	61,000	29B65D
23-Jun-06	BRENT BOSKER	CKBI-AM PRINCE ALBERT (8:04 AM)	LAWRENCE MARTZ	LESS WATER WILL BE AVAILABLE FROM THE SOUTH SASKATCHEWAN RIVER DUE TO CLIMATE CHANGE	GEOGRAPHY	1,300	69F1DF-7
23-Jun-06	KELLY PROVOST	CJLR-FM LA RONGE	LAWRENCE MARTZ	CLIMATE CHANGE WILL REDUCE THE AMOUNT OF WATER AVAILABLE FROM THE SOUTH SASK RIVER IN COMING DECADES ACCORDING TO A STUDY DONE BY THE U OF S AND ENVIRONMENT CANADA	GEOGRAPHY	14,300	69F1F9-11
23-Jun-06	RAE GROENEVELD	ON AGRICULTURE (CJGX-AM YORKTON) 12:38 PM	LAWRENCE MARTZ	STUDY CONDUCTED BY U OF S SAYS AVAILABILITY OF WATER ON SOUTH SASK RIVER WILL DROP BY 10% BY 2050	GEOGRAPHY	12,700	69F292-10
23-Jun-06	TIM CALDER, RAE GROENVELD	CJGX-AM YORKTON (5:33 PM)	LAWRENCE MARTZ	STUDY CONDUCTED BY U OF S SAYS AVAILABILITY OF WATER ON SOUTH SASK RIVER WILL DROP BY 10% BY 2050	GEOGRAPHY	12,700	69F32A-8
23-Jun-06	TED DELLER	CBK-AM 6:30 AM	LAWRENCE MARTZ	STUDY SHOWS THAT CLIMATE CHANGE WILL REDUCE THE AMOUNT OF WATER AVAILABLE FROM THE SOUTH SASK RIVER	GEOGRAPHY	31,000	69E76B-1
23-Jun-06	TED DELLER	CBK-AM 8:30 AM	LAWRENCE MARTZ	STUDY SHOWS THAT CLIMATE CHANGE WILL REDUCE THE AMOUNT OF WATER AVAILABLE FROM THE SOUTH SASK RIVER	GEOGRAPHY	36,000	69ECA9-2

Section 2 Appendix 3, Continued

Date	Byline: Author/ Reporter	Publication/ Outlet	University of Saskatchewan Contact	Story Subject	Comments	Reach	Ref #
23-Jun-06	SARAH MACDONALD	STAR PHOENIX SASKATOON	LAWRENCE MARTZ	WATER AVAILABILITY ON RIVER TO DROP, STUDY SUGGESTS	GEOGRAPHY	61,000	2A32DF
24-Jun-06		EDMONTON SUN (EDMONTON)	LAWRENCE MARTZ	CLIMATE CHANGE THREATENS RIVER	GEOGRAPHY	75,775	2A4657
26-Jun-06	TED DELLER	CBK-AM (6:30 AM)	LAWRENCE MARTZ	A NEW STUDY SAYS CLIMATE CHANGE IS GOING TO REDUCE THE AMOUNT OF WATER THAT IS AVAILABLE FROM THE SOUTH SASK RIVER IN THE COMING DECADES	GEOGRAPHY	31,000	6A1482-1
23-Jun-06		MOOSE JAW TIMES-HERALD (MOOSE JAW, SASK)	LAWRENCE MARTZ	AVAILABILITY OF WATER FROM SOUTH SASK RIVER WILL DROP BY 2050, STUDY SAYS	GEOGRAPHY	10,250	2A61DA
24-Jun-06		THE LETHBRIDGE HERALD (LETHBRIDGE, AB)	LAWRENCE MARTZ	S. SASKATCHEWAN RIVER FLOWS LIKELY TO DROP, STUDY SAYS	GEOGRAPHY	20,700	2A8562
24-Jun-06		THE PRINCE GEORGE CITIZEN (PRINCE GEORGE, BC)	LAWRENCE MARTZ	CLIMATE CHANGE DRYING UP RIVER	GEOGRAPHY	19,100	2A7724
TOTAL AUDIENCE REACH						**386,825**	

4 Methodology

The research objective has been to study the marginal impacts of climate change on the surface water resources of the South Saskatchewan River Basin (SSRB). This involves understanding how the impacts of potential climate change can affect the availability of water, as well as water use and requirements. Interaction of the two, first from a hydrological point of view, and then from a social and economic point of view can impact the society in terms of vulnerability and the need for adaptation. This study is comprised of two main modeling components: (1) a physical component simulating future availability of water in the SSRB under a range of possible climate change scenarios, and (2) a socioeconomic component assessing the impacts of water resource availability on major water users and their vulnerabilities to changes in water supply under climate change. Methodologically, the study employs a disaggregated and distributed approach to estimating water resource demands and uses. Existing climate, hydrological and socioeconomic models are calibrated and updated for the SSRB to address several key issues, namely: to document current water use patterns and estimate the value of water use by type of use (for a base year); forecast the availability of water and water use for a time period in the foreseeable future; assess the vulnerability of regional withdrawal and in-stream water users to changes in water supply under climate change; and, establish a framework for addressing policies and programs that govern water use and adaptation to potential change.

4.1 Linking the SSRB Basin, Climate Change and Socioeconomic Impacts

The study began by defining the South Saskatchewan River Basin (SSRB) which crosses both provincial and national boundaries, as shown in Figure 4.1. The surface water flows are subject to two formal apportionment agreements as it moves from the Continental Divide through southern Alberta into south-central Saskatchewan. The SSRB is comprised of four major sub-basins: the Red Deer, Bow, Oldman and South Saskatchewan (shared Alberta-Saskatchewan) sub-basin. A sophisticated system of major reservoirs and diversions regulate river flows and divert water to areas of high demand, including Regina which lies well outside of the watershed proper.

Figure 4.1 *South Saskatchewan River Basin (Armstrong, in Martz et al., 2004, 2).*

The study then conceptualized the larger physical context of regional and global climate change, which impacts both river basin hydrology and water use by society and its economic sectors. Figure 4.2 shows the focus of this study as represented by solid lines. The influence of regional and global dynamics is captured in down-scaled general circulation models (GCMs), calibrated to actual 1961-1990 hydrological data for the river basin. Using these hydrologic models calibrated to the SSRB and forced by selected down-scaled GCM scenarios, the physical science team was able to predict future water availability in terms of "naturalized" streamflows, that is, without the impacts of flow regulation and withdrawals. These streamflow scenarios were coupled with a selection of socioeconomic scenarios. The choice and range of the socioeconomic scenarios were informed by the concurrent analysis of water use patterns, both within the watershed boundaries and for external stakeholders reliant upon diverted surface water supplies. The socioeconomic component draws upon market data from the economic system to develop and integrate water use cost estimates and sensitivities. This end-to-end framework simulates possible futures to help water managers and policy analysts examine the benefits of new water use strategies, infrastructure and other resource development, investments in technical change, and both economic and equity issues related to institutional structure and policies.

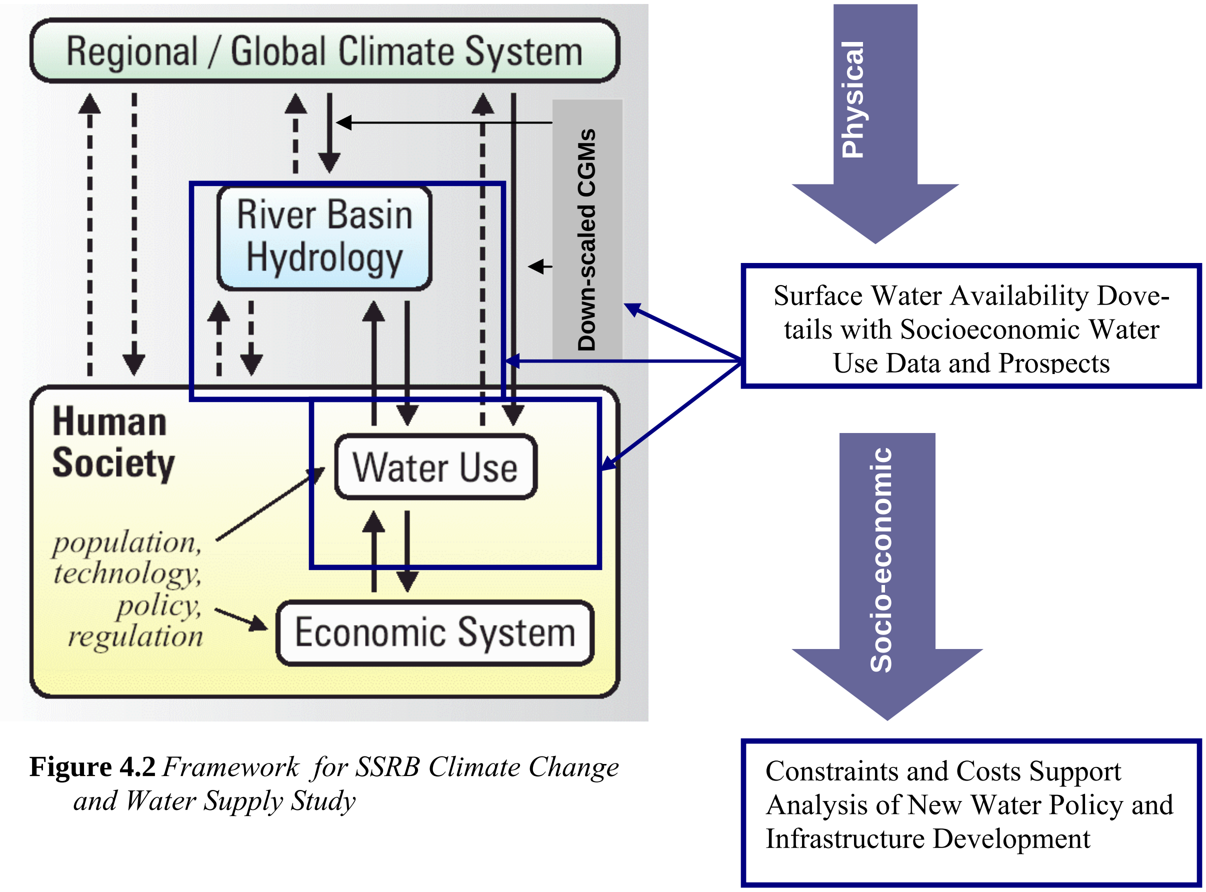


Figure 4.2 *Framework for SSRB Climate Change and Water Supply Study*

As shown in Figure 4.2 above, there are many potential links between the regional and global climate system and the human social system. The links not currently being addressed by this study are represented by dashed arrows. However, the regional and global climate system both impact and are impacted upon by many biological systems other than human society. All of these sub-systems contribute to water cycling within a much larger global water system (Figure 4.3); this full water cycle embraces "all of the physical, chemical, biological, and anthropogenic manifestations of water in the Earth System". It is intent of this study to develop a framework which has the potential to capture all elements of this cycle, bringing the analysis full cycle.

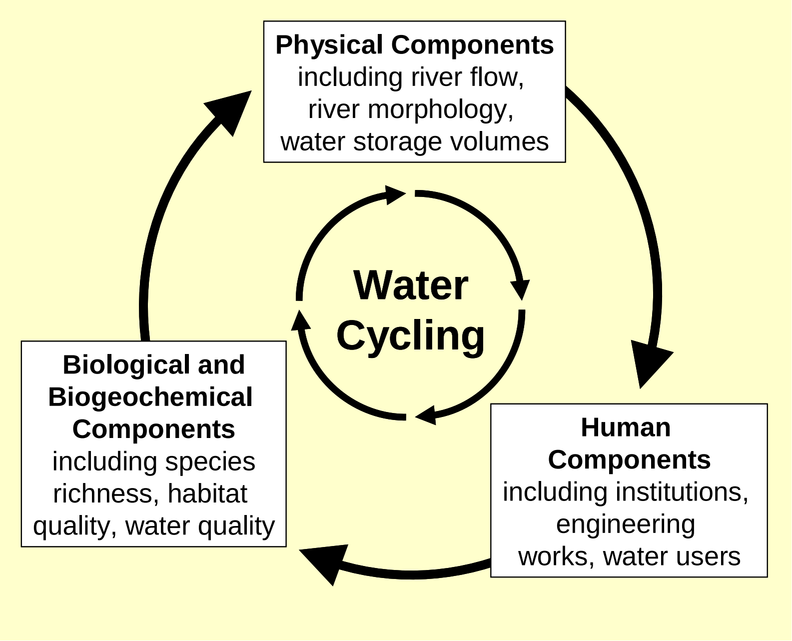


Figure 4.3 *Components in the Global Water System (GWSP, 2004, 18).*

Within these models above, the socioeconomic concepts outlined in the preceding chapter focus upon the human components and water use, considering sector contributions and vulnerabilities both in terms of regional economic impacts and economic efficiency. Water is a mobile resource and it is difficult to assign clear ownership: it moves through the full water cycle with varying quality and potential, while retaining its unique and essential ability to provide nourishment, cleanse and dilute pollutants. All of these physical attributes contribute to its socioeconomic value. Human economic responses are not, however, separated from the full water cycle under an ecosystems approach.

The ecosystem approach can be used to highlight the inseparability of complex environmental and social systems. This framework embraces the role of local communities and stakeholders as well as the influence of consumers and advocates from abroad. It also allows for the multi-dimensionality of human response: human agents and their networks play both direct and indirect complementary and competing roles in water use, through economic investment, development and support of technology and industry, participation in goods production and labour markets, and community advocacy and recreation. Impact assessment of marginal resource change and its associated economic costs and benefits focuses upon risk exposure and resulting vulnerabilities within the context of adaptive capacity and social resilience (Figure 3.1).

The analysis to date has been limited by the prescribed focus on socioeconomic impacts on key water use sectors and the marginal change of surface water supply driven by potential climate change. This initial mandate has been limiting in terms of impact assessment through the full water cycle; however, it has forced the refinement of water use terminology (see Section 4.2.1). The application of economic methods selected here were less limited by the comprehensive body of primary research on resource use and more so by gaps in indirect (near stream) use for recreation and aesthetic enjoyment, or further intrinsic use for delayed use or continuing non-use (conservation and endowment), as schematically shown in Figure 9.1. The Province of Alberta has been recognized for its advanced research contributions on both consumptive and non-consumptive recreational activities, with several studies applicable to instream enjoyment within the SSRB. Unfortunately, this research activity has lagged elsewhere in Canada, possibly due to less concentration and continuity of the national and provincial park systems as well as more scattered distribution of wetlands and recreational corridors. For measuring the vulnerability of recreational or non-use stakeholders across the SSRB, this gap creates a significant barrier to basin-wide analysis. Nevertheless, it remains unclear that a marginal change in enjoyment due to a small marginal change in water supply (say, up to 10%) would create a vulnerability alone, as water quality and other factors associated with the combination of water supply and quality (i.e. turbidity, temperature, etc.) are also critical factors impacting recreational enjoyment and endowment values. This is an area needing further study.

4.2 Water Impact Valuation

The methodology, foundation physical and conceptual work, water management expert and stakeholder consultation, and applied regional economic (input-output) assessment and economic efficiency valuation. The watershed was first defined and the surface water use was documented in socioeconomic terms, with water use definitions applied in a standardized manner. The concepts of climate impacts and vulnerabilities and stakeholders were then explored, with the realities of water management, commitments and allocations informed through expert and stakeholder consultation. The regional economic benefits associated with water use, by sector and sub-region, were assessed, with the prospects for key stakeholders then refined through economic efficiency valuation on a sub-basin basis. As the emerging results suggested these sub-basin circumstances would be quite distinct, considerable effort was made to explain the economic efficiency concepts, methodology and assumptions, devise a suitable scenario-based approach, and use this approach to couple with the physical team's streamflow envelopes, to demonstrate the end-to-end physical to socioeconomic exercise on both local (city) and wider (sub-basin) bases.

4.2.1 Methodological Features

1. Taxonomy of Water Use

For consistency and clarity, a taxonomy of water use was applied. This taxonomy establishes distinctions between water use, intake, demand, requirements and consumption. This taxonomy is set out generally in Section 6.3 for application in the SSRB and its sub-basins. It is reiterated in Section 7.3.5 with reference to single region, multi-regional and inter-regional models and in 7.5.2.1 for the development of water use coefficients for input-output (IO) analysis.

2. Key Water Use Sectors

The taxonomy of water use above is extended through analysis of water use for the key water use sectors identified in Chapter 8. In terms of water supply usage, the SSRB has the following key sectors: agriculture (for irrigation and stock-watering), municipal services (including urban residential, commercial and industrial use), residential (for urban domestic and rural populations), industrial (primarily mining, oil and gas), and energy (thermal and hydro-electric). It is often a challenge to calculate water usage and sensitivities to supply change within these categories: not all of the SSRB communities separate water use clearly within the sub-categories. Another challenge is that other frameworks such as regional IO analysis apply other categorical schemes. For example, Chapter 7 highlights how important the service sector is within the Prairie economy, recognizing the economic contribution of this sector, which includes many urban and peripheral public and private facilities including those for health, education, recreation and hospitality. The SSRB analysis has not yet focused on this category which could reveal significant cost and conservation implications.

Despite these challenges, the project was able to inventory water use across the key water use sectors. A socioeconomic database was first developed by Sobool and Kulshreshtha (2003), drawing from the Prairie Provinces Water Board (PPWB) database. It was then updated with supplementary sources and a customized data refinement strategy (see *Appendix C*). The supplementary survey information included: Environment Canada's *Municipal Water Use Survey* and *Industrial Water Use Survey*, Statistics Canada's *Census of Canada* and *Census of Agriculture.* Further data supplementation was made through direct inquiries to the Saskatchewan Watershed Authority; Agriculture and Agri-Food Canada (AAFC) and AAFC-PFRA (Prairie Farm Rehabilitation Administration); Alberta Agriculture, Food and Rural Development; the Province of Alberta; Canadian Wildlife Service; and Saskatchewan Regional Parks. The tailored database for SSRB water use remains an important legacy of this project. Ongoing effort to provide constructive input into survey refinement continues, as does data and methodological reconciliation, and the SSRB database precision is likely to improve further over the next decade.

3. The Physical Geography of the SSRB

The socioeconomic team first focused on the physical geography of the basin, expecting that any significantly varied circumstances will impact upon adaptation to changing surface water supply. Climatic conditions across the basin were studied using climographs of selected cities, each showing monthly mean temperatures and precipitation. The patterns of temperature were anticipated to reflect the mid-continental position of the basin, with cold winters and hot summers, although precipitation patterns were also studied across the SSRB sub-basins to determine differences in terms of both volume and timing. The Water Survey of Canada hydrometric station data was used to determine drainage areas of the sub-basins. Various sources were used to document the topography, land cover, ecoregional categories, major rivers and lakes, and any areas remaining in wetlands. Given the project's focus upon surface water supply, the watershed was also studied in terms of surface area contributing versus non-contributing to the major river systems, as well as the history of water developments and diversions.

4. Socioeconomic Database Development

The patterns of water use across the SSRB were studied. A spatially reconciled and customized socioeconomic database was developed for the base year 1996, tabulating water use by the major sectors identified for each sub-basin. This database captures all water withdrawals for the basin-interior GIS-configured human and livestock populations as well as any peripheral populations and operations further reliant upon SSRB surface water sources. The reconciliation of census divisions with SSRB sub-basins was performed for both the Census of Canada and Census of Agriculture, with any assumptions for data manipulation clearly set out in the *Re-Assessment of 1996 Census Population, Livestock and Water Use Information* (Appendix C).

The volumes and proportions of water use by key sector were determined basin-wide, provincially and by sub-basin, as set out in Chapter 8 for agricultural, residential, municipal, industrial and hydroelectric or thermal energy use. To provide a socioeconomic growth trajectory, the population growth between 1991 and 1996 was documented for SSRB urban centres as well as SSRB rural populations in Alberta and Saskatchewan. The investigation of industry water use was reliant upon, and limited by, the prior *Industrial Water Use Survey*; refinement of the SSRB socioeconomic database will continue as Environment Canada pursues an updated survey.

4.2.2 Socioeconomics of Surface Water Use in the SSRB

Under climate change, the impact of changes in water availability on the socioeconomic system depends on the type of water use, the quantity and quality of water required, and the institutions in place governing water use for a specific activity. The current study was to focus upon the quantity of surface water use rather than integrated quantity-quality issues. The impact of changing surface water supply under climate change was considered for both the regional economy and the key sectors' marginal efficiencies associated with water use.

The documentation of water use for the 1996 baseline period allows an initial assessment of the potential, future vulnerability of economic and social systems within the SSRB to changes in surface water availability. A regional and SSRB-specific input-output approach was developed for coupling with the marginal economic efficiency approach. The initial exercise documented here provides the foundation for further application of the input-output approach to determine the wider benefits and costs of various water policy options. As the policy component of the study was not funded, efforts became more so focused upon the dove-tailing of the marginal impacts of changing water supply under climate change in order to determine water use values, economic sensitivities, and hence, key sector vulnerabilities.

The project was to focus initially upon the vulnerability of key stakeholders under the prolonged and gradual exposure of climate change, rather than climate variability. This incremental impact exposure over the prescribed 50 year period (1996 to 2046) mirrors the temporal characteristics of impacts projected under the coupled global climate (GCM) models. This approach favours the identification and measurement of adaptation options and sensitivities through economic and institutional means. Our CCIAP-funded SSRB study was to focus upon economic aspects of adaptation, with the University of Regina's SSHRC-MCRI comparison of Canada versus Chile water management providing insights into institutional dynamics. Our study team was obliged nevertheless to understand some institutional aspects relating to water access and allocation. In preparation for future policy extension of the results reported here, a report was commissioned to identify study gaps through an *Assessment of Recent Past and Current Projects Relevant to the Study* (SRC, 2004) as well as subsequent *Assessment of Current Water Management* (Rempel; Appendix P).

The vulnerability model applied here, as set out in Chapter 3, considers how key water use sectors are subject to direct environmental exposures, which result in sensitivities due to the sectors' history of water use as well as current pricing structures, water supply and usage limitations, and the sectors' distinct planning horizons (Bruneau, 2004, CWRA Saskatoon presentation). The resilience of groups or communities in terms of their collective ability to cope and possibly benefit from exposures reflects a multi-layered dynamic. The project focused here on basin-wide as well as inter-provincial and sub-basin economic impacts and sensitivities. The results are relevant for Prairie-wide and continental Great Plains vulnerability analyses, as well as provincial and sub-basin comparisons of population concentrations, resource inventories, associated scale advantages, the impact of accumulated investment, and other political and social variations. At the institutional and agent-based (individual operator) levels, complementary analyses will help glean insights into the perceived options, learning capacities, incentives and disincentives of support programs, and the suitability of broader policies and institutional arrangements.

4.2.3 Demonstrating the Dove-tailed Scenarios Approach

The central thrust of the co-team exercise was to develop and complete an integrated physical and socioeconomic analysis of climate-induced water supply impacts on key water use sectors in the SSRB. The physical team used down-scaled climate scenarios from selected general circulation models (GCMs) to project surface water supply in the SSRB under climate change (Pietroniro, Toth, 2007). The hydrological implications under climate change were then determined for the SSRB sub-basins and coupled with selected socioeconomic scenarios. As set out in Chapter 10, a scenario-driven approach was determined as appropriate given the study scope and the orientation of consulted SSRB stakeholders.

The scenario-driven approach used here considers as its baseline the 1996 socioeconomic profile of the SSRB and its sub-basins. Scenarios are then applied to this baseline, informed by potential trajectories for growth and an understanding of the factors affecting water use for: 1) population and power needs, 2) primary production economic activity and 3) manufacturing and other services economic activity. Distinctions are made in Chapter 10 between the use of forecasts, scenarios and optimization models, as well as the distinction between risk and uncertainty. The scenarios framework applied here considers three dimensions: 1) business-as-usual, 2) economic dynamism, and 3) ecological sensitivity.

The full dove-tailed exercise is documented in Chapter 11. The process for establishing a net annual basin water supply is initially set out. Given the significant proportion of irrigation water use in the SSRB, the irrigation versus non-irrigation withdrawals and consumption are also set out. The linkage between water use vulnerability and varied scenarios for consumption is established; the approach taken here considers climate change as an additional demand upon supply. Sensitivity analysis is then carried out for both the worst case and best case scenarios, to provide an envelope for planning.

The study is as yet limited by its scope and funding. The water use patterns documented here assume a *status quo* baseline if projected forward because any significant adjustments made to the physical infrastructure, allocation rules, or other policies and practice have the potential to create both immediate and ripple effects upon sector activity and could significantly shift water use attitudes. The customized input-output model developed here could incorporate outcomes from the dove-tailed exercise in concert with assumptions about these infrastructure and policy parameters.

References:

Martz, L., S. Kulshreshtha, R. Armstrong, A. Pietroniro, T. Horbulyk and J. Bruneau, (2004). Climate Change and Water Resources in the South Saskatchewan River Basin, paper presented at the 57th Canadian Water Resources Association Annual Congress, June 16-18, Montreal.

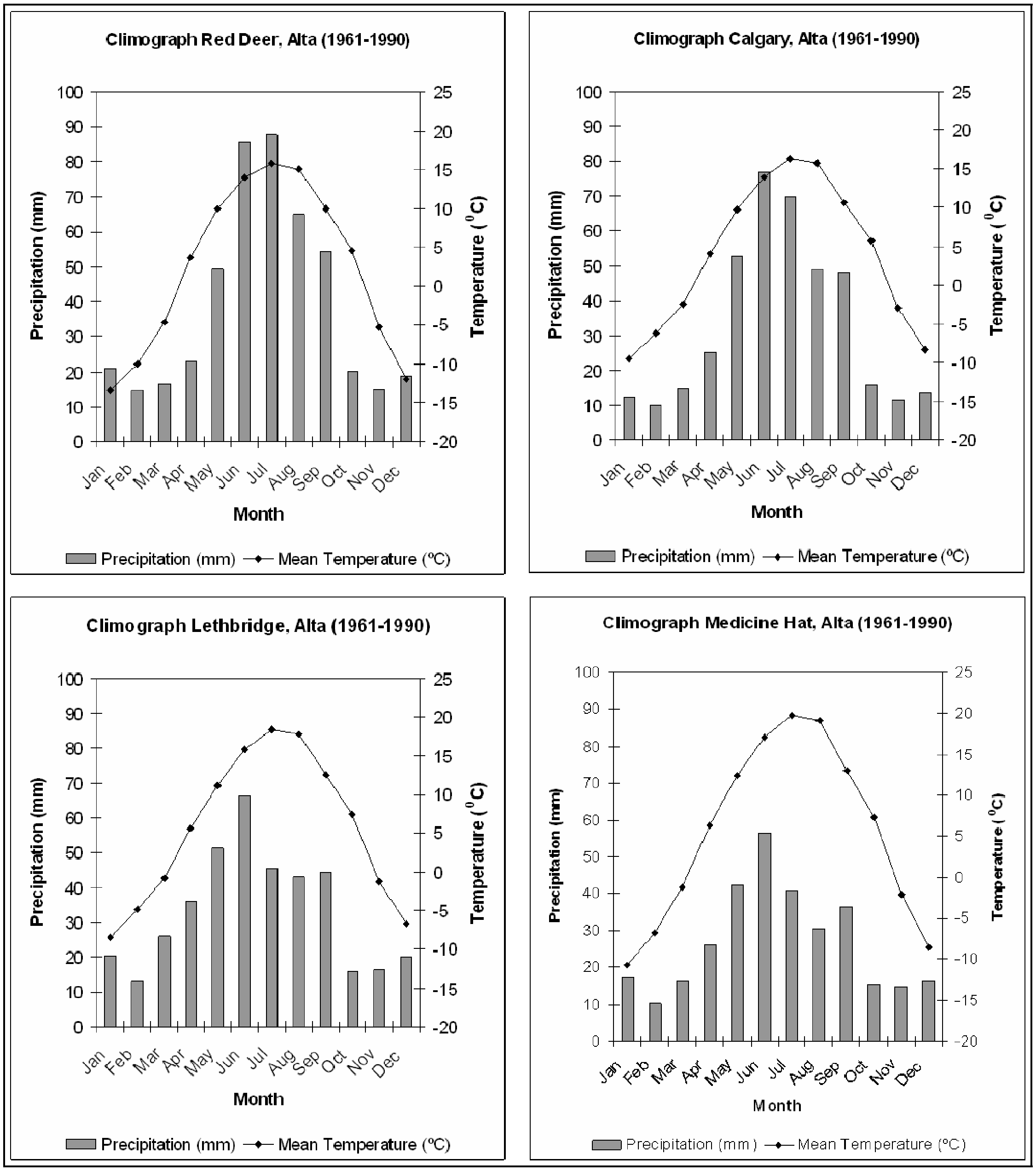
GWSP Framing Committee, (2004). The Global Water System Project: Science Framework and Implementation Activities. Earth System Science Partnership.

5 The South Saskatchewan River Basin: Physical Geography

The physical geography of the South Saskatchewan River Basin offers varied circumstances which impact on adaptive response to changing water supply under climate change. The following information about the physical character of the SSRB, such as climate and landscape, were taken from two reports written by the Lane and Sykes (1982) and the Saskatchewan-Nelson Basin Board (1972).

5.1 Climate and Water Supply

Figures 5.1 and 5.2 show the climate normals (1951-1990) for selected cities within the SSRB.



Climograph Red Deer, Alta (1961-1990)

Climograph Calgary, Alta (1961-1990)

Climograph Lethbridge, Alta (1961-1990)

Climograph Medicine Hat, Alta (1961-1990)

Figure 5.1 *Climographs for selected cities in SSRB, Alberta portion.*
Source: Environment Canada

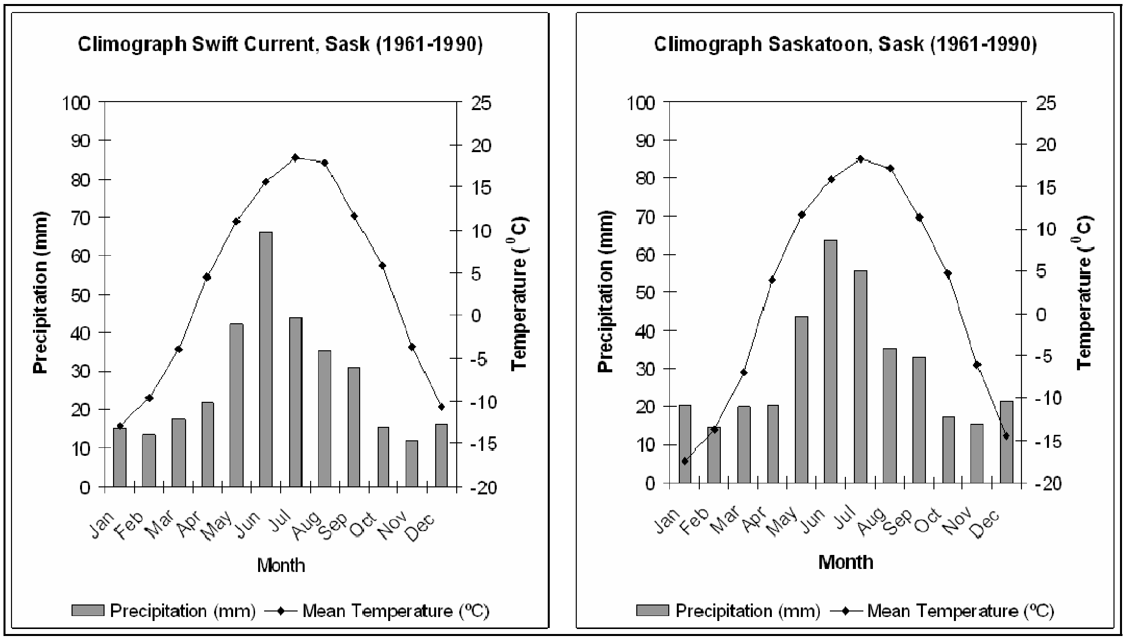


Figure 5.2 *Climographs for selected cities in SSRB, Saskatchewan portion.*
Source: Environment Canada.

The SSRB is located in a semi-arid cold continental region where temperatures can vary from 40°C in summer months to -40°C in winter months, with the hottest and coldest months being July and January respectively. In the winter months, a high pressure ridge develops over the region producing cooler temperatures with an abundance of sunshine. Warmer temperatures are often experienced in the southern region of Alberta, during the winter months in particular, due to dry, westerly winds that descend from the Rockies and sweep across the Foothills and Plains, producing the Chinook weather phenomena.

The SSRB is relatively dry due to its location in Western Canada. Annual precipitation across the basin varies spatially, from between 200 mm to 500 mm, with the Cordillera region receiving the largest amounts of precipitation. East of the foothills, conditions become drier due to the rain-shadow effect of the Rocky Mountains. While most of the annual precipitation is in the form of rain during the spring and summer months, the majority of the surface water supply comes from spring snowmelt. The majority of rainfall in spring and summer recharges soil moisture and groundwater reserves, but does not generally enter local streams as runoff. Some of the spring and summer runoff is also supplied by the Columbia Ice Field, the largest glacier in Canada, which gives rise to the headwaters of the SSRB.

5.2 Basin and Sub-Basins Locations

The SSRB is part of a major river system within the Nelson River basin that begins in the Rocky Mountains, extending across the Prairie Provinces and emptying into Hudson Bay as shown in Figure 5.3. The SSRB extends from the Continental Divide, through southern Alberta and into south-central Saskatchewan. The small portion of the basin that extends into Montana is not directly considered in this study; inter-jurisdictional issues do occasionally arise and relations between Canada and the United States on water supply and quality are dealt with elsewhere. As shown in Figure 5.4, the SSRB is comprised of four major sub-basins: the Red Deer, Oldman, Bow and South Saskatchewan (SSR), the last including both Alberta and Saskatchewan portions of the South Saskatchewan River.

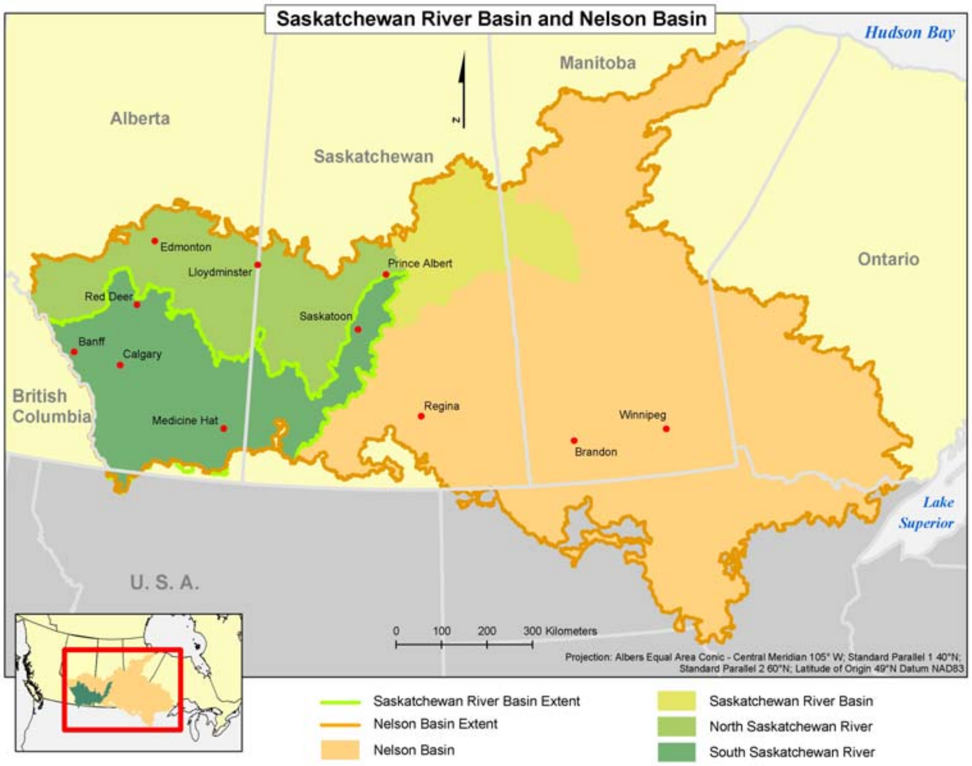


Figure 5.3 *Location of the SSRB.*
Map produced by GIServices, University of Saskatchewan.

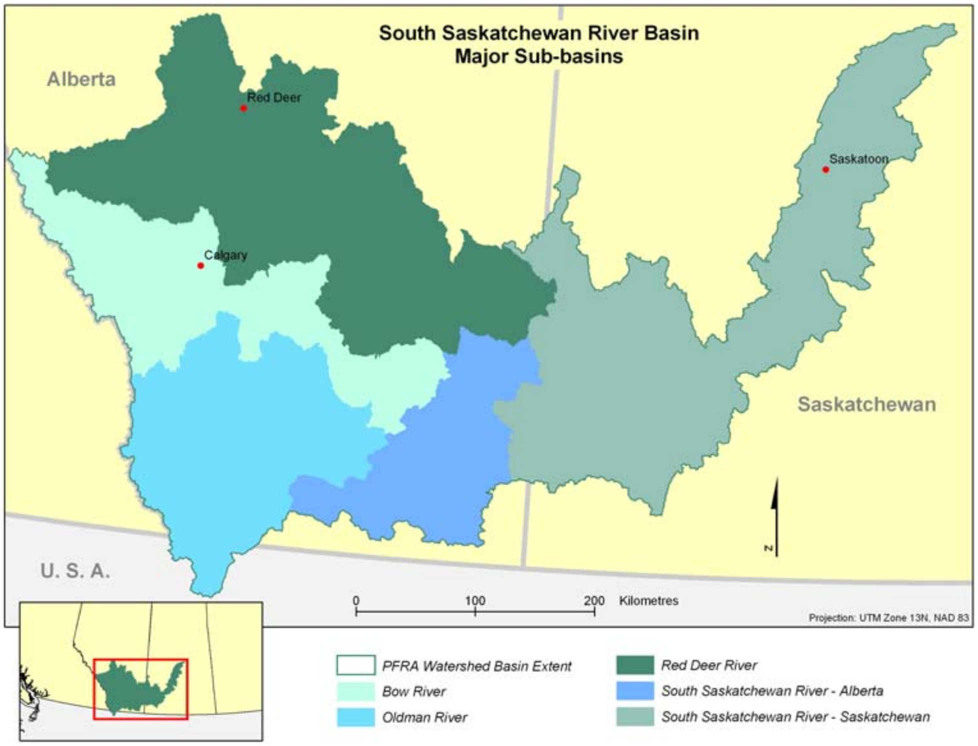


Figure 5.4 *Major sub-basins within the SSRB.*
Map produced by GIServices, University of Saskatchewan.

The *Water Survey of Canada* provides information about hydrometric stations (station ID, current status, location and drainage area, etc.) as well as hydrometric data to the public online. The reported drainage areas of several stations near the outlets of major rivers of the SSRB are shown in Table 5.1. The entire SSRB extends over an area of about 150,000 km^2 (through to St. Louis, Saskatchewan). The largest sub-basin in the SSRB is the South Saskatchewan (SSR) at about 48,000 km^2, and the smallest is the Bow River at just over 25,000 km^2. Figure 5.5 shows a more detailed map of the sub-basins or Gross Drainage Areas within the SSRB (provided by Agriculture and Agri-food Canada Prairie Farm Rehabilitation Administration (AAFC-PFRA)).

River	**Drainage Area (km^2)**
Entire South Saskatchewan River to St. Louis	148,000
Red Deer River near Empress	45,800
Bow River near mouth	25,300
Oldman River near mouth	27,500
South Saskatchewan River*	48,400

*Estimated based on drainage areas of entire SSRB, Red Deer, Bow and Oldman basins.

Table 5.1 *Gross drainage areas of major rivers in the SSRB.*
Source: Water Survey of Canada

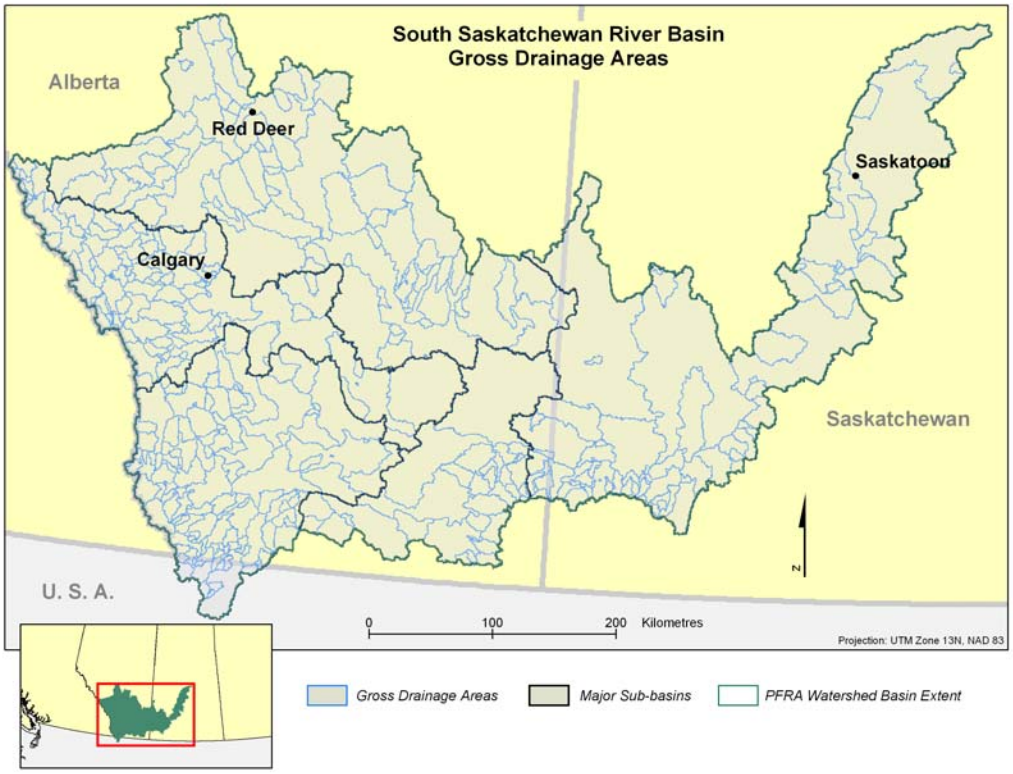


Figure 5.5 *Gross drainage areas by sub-basin.*
Source: AAFC-PFRA. Map produced by GIServices,
University of Saskatchewan.

5.3 Topography and Land Cover

Figure 5.6 shows a relief map of the SSRB and the surrounding region. Figure 5.7 shows an ecoregional map of the same area. The SSRB extends over three main geographic regions: the Cordillera, foothills, and the Great Plains. At the western end of the SSRB, the Continental Divide offers a boundary where the Rockies rise to about 3,200 m. The Continental Divide is characterized by two ecoregions: the Eastern Continental Ranges (in the northwestern portion) and the Northern Continental Divide (in the south-western portion). The mountains give way to the foothills which extend eastward for about 100 miles, with elevations ranging from about 1,000 to 1,400 m. This region contains ridges of hills, the Western Alberta Upland Ecoregion and a portion of the Aspen Parkland Ecoregion. The foothills form a transition between the mountains and the Great Plains region of the Prairies. Most of the SSRB is contained within the Great Plains where elevations range from less than 1,000 m to about 400 m.

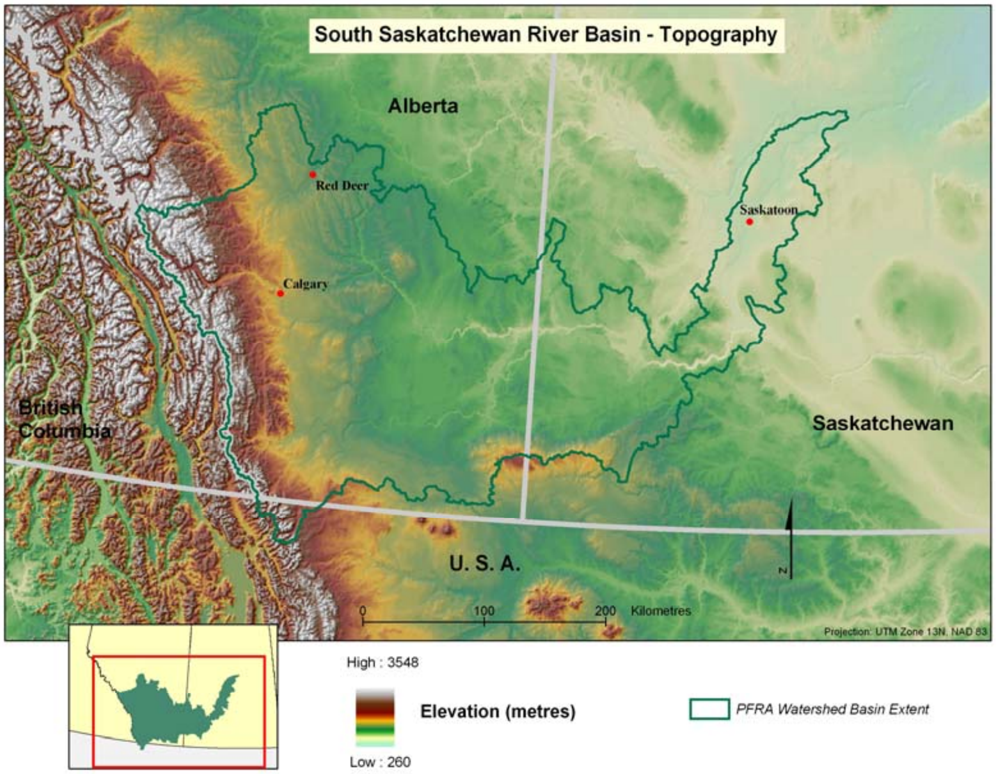


Figure 5.6 *Relief map of the SSRB.*
Map produced by GIServices, University of Saskatchewan.

Ecoregions within the Great Plains include: the Fescue Grassland, the Moist Mixed Grassland and the Mixed Grassland. A large area of the southern portion of the basin is characterized by the Cypress Upland Ecoregion which extends across the Alberta-Saskatchewan border. Towards the northeast portion of the basin, Mixed Grassland gives way to the Moist Mixed Grassland and the Aspen Parkland Ecoregions. A small portion of the northwestern and northeastern most parts of the basin are characterized by the Boreal Transition Ecoregion.

A generalized land use map for the SSRB is shown in Figure 5.8 (AAFC-PFRA). In general, the three main land uses within the SSRB are cropland, grassland, and forage.

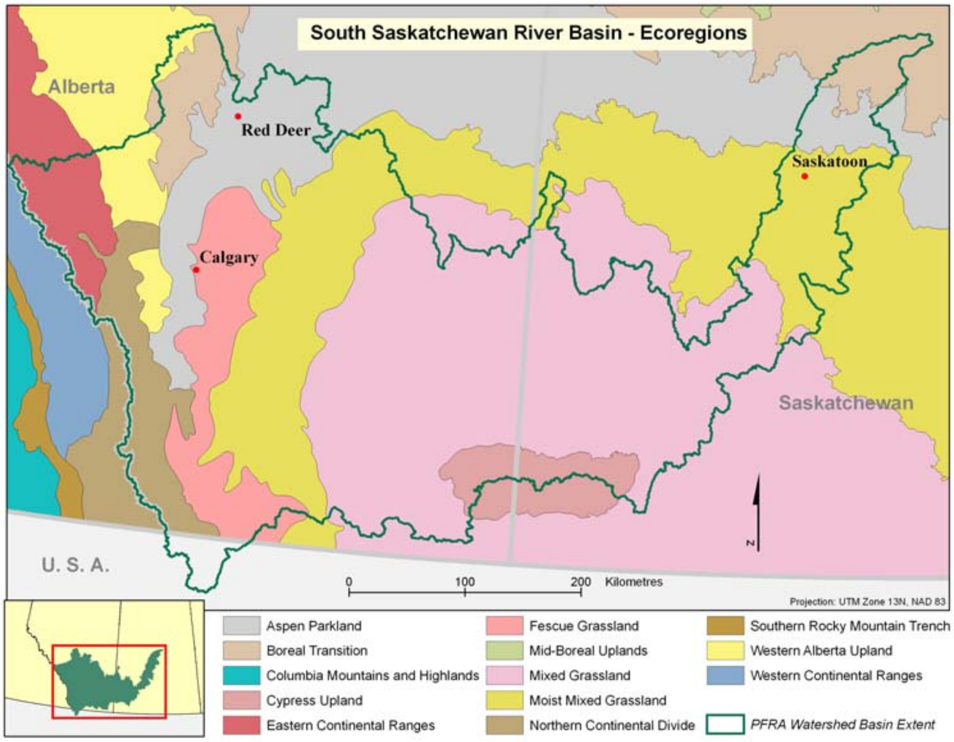


Figure 5.7 *SSRB ecoregions map.*
Map produced by GIServices, University of Saskatchewan.

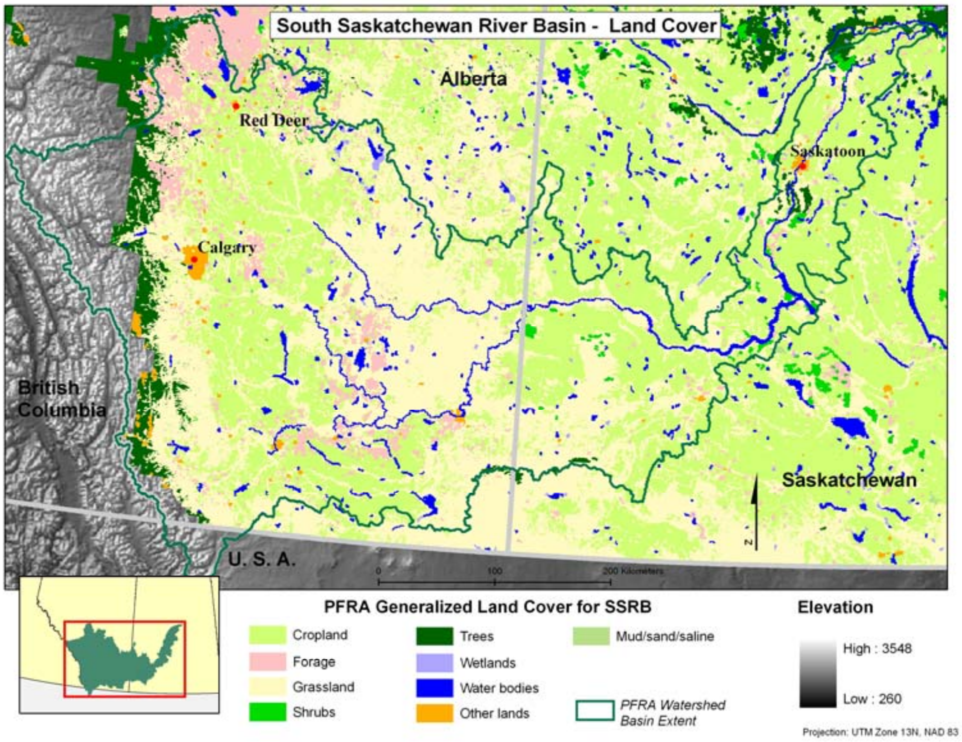


Figure 5.8 *Land use within the SSRB.*
Map produced by GIServices, University of Saskatchewan.

5.4 Major Rivers and Lakes

Figure 5.9 shows the hydrology of the SSRB. As stated prior, the major rivers of the SSRB include the Red Deer, Bow, Oldman and South Saskatchewan Rivers. The constructed reservoir, Lake Diefenbaker, is the largest water body within the SSRB at an estimated area of 430 km^2,

The South Saskatchewan River (SSR) is not only an important water resource for those who depend on it from within the basin but also for others outside the basin. For example, water from the SSR is diverted to the Qu'Appelle River through the Qu'Appelle River Dam and into Buffalo Pound Lake to supply water to the cities of Moose Jaw and Regina, as well as to mining operations outside the SSRB. Figure 5.10 shows the Qu'Appelle River Diversion as well as other water developments for several communities to the east and northeast of Saskatoon which utilize water from the SSRB.

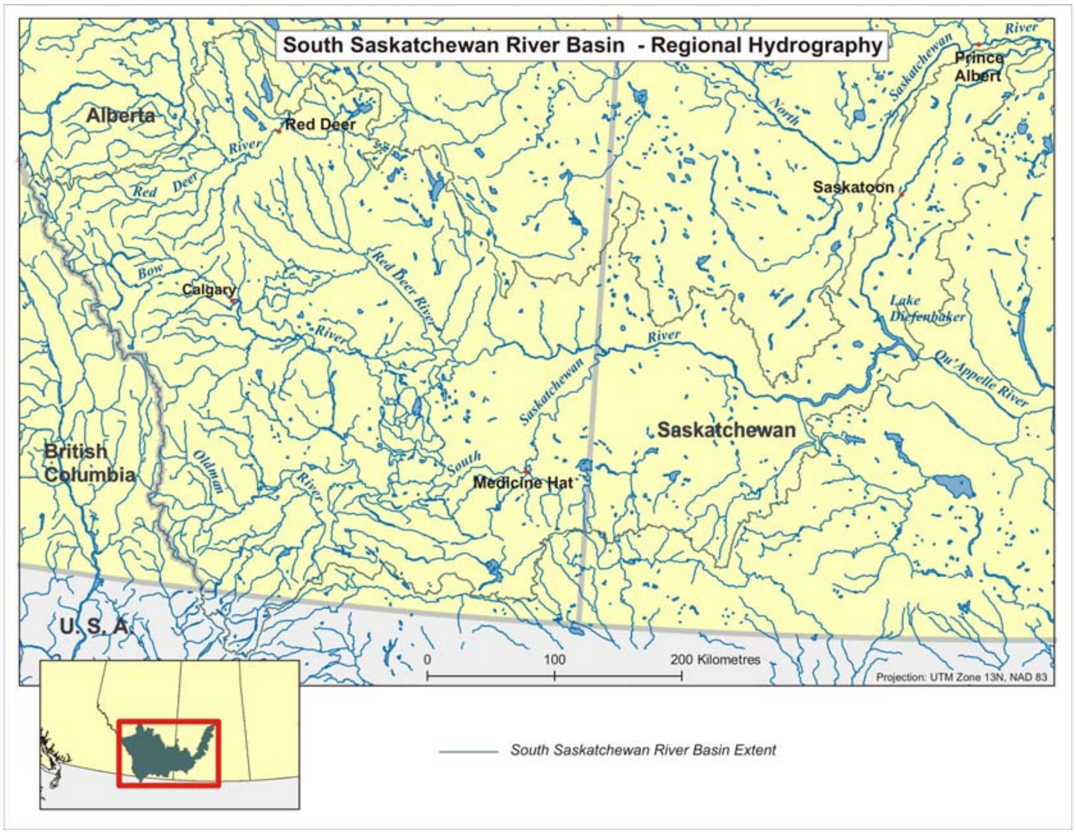


Figure 5.9 *SSRB regional hydrography.*
Map produced by GIServices, University of Saskatchewan.

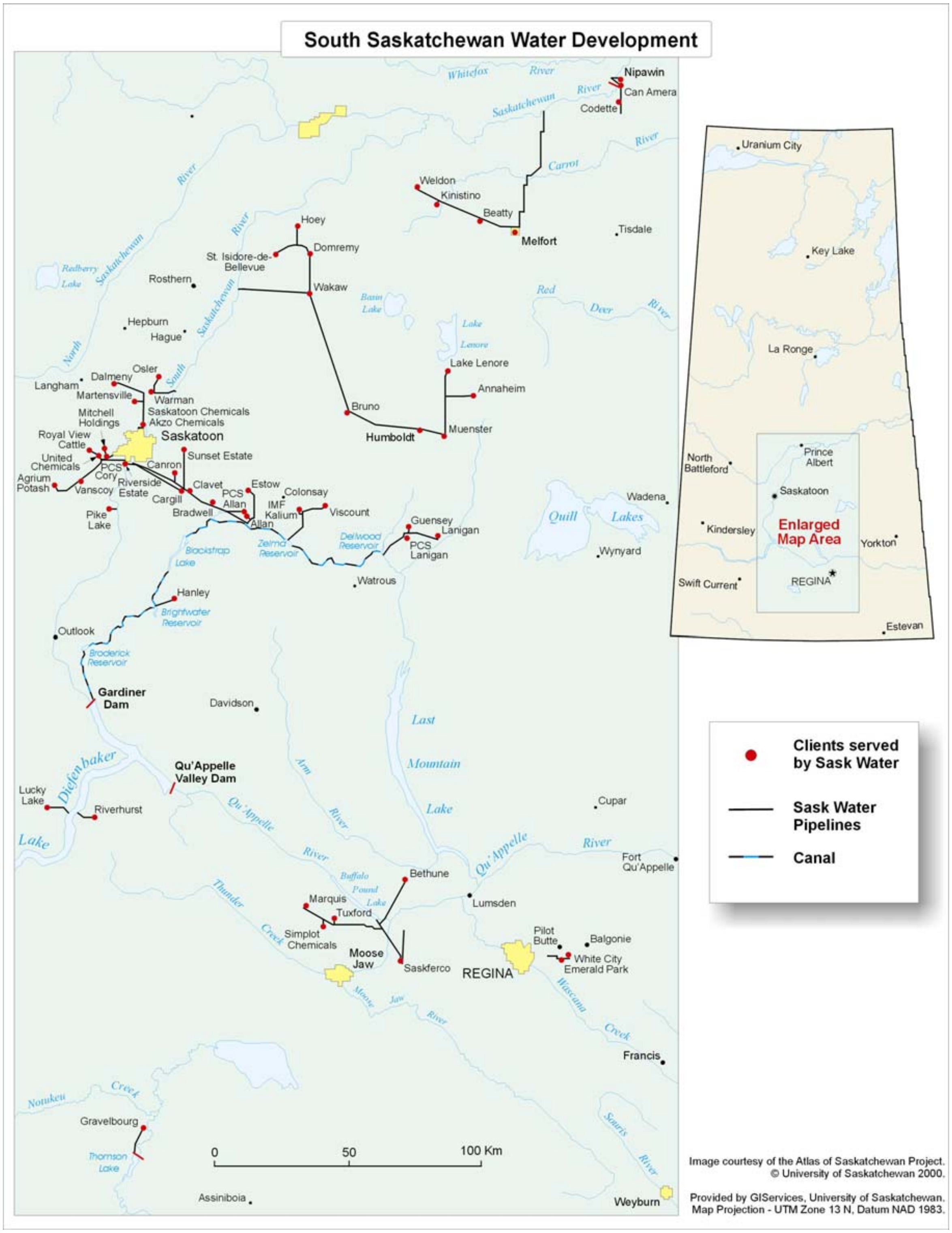


Figure 5.10 *SSRB Qu'Appelle Diversion and other water developments.*
Image courtesy of the Atlas of Saskatchewan Project and GIServices (University of Saskatchewan).

5.5 Wetlands

Table 5.2 gives some information about the estimated number and size of wetlands within the SSRB at a given point in time. This information was obtained from the socio-economic database (Sobool and Kulshreshtha, 2003) as well as two other sources (PFRA and PPWB). Most of the wetlands in the SSRB tend to be less than one acre in area and approximately 73% of the wetlands were less than 3 acres in area. Figure 5.11 shows the location of wetlands in the SSRB region.

Basin	**# of Wetlands**	**Area (ha)**	**Mean Area Per Wetland (ha)**
Red Deer	5,055	372,271	73.5
Bow	1,057	9,453	8.7
Oldman	533	1,080	2.0
South Saskatchewan	78,283	121,452	1.5
Total	84,939	504,255	5.9

Table 5.2 *Estimated number and size of wetlands in the SSRB.*

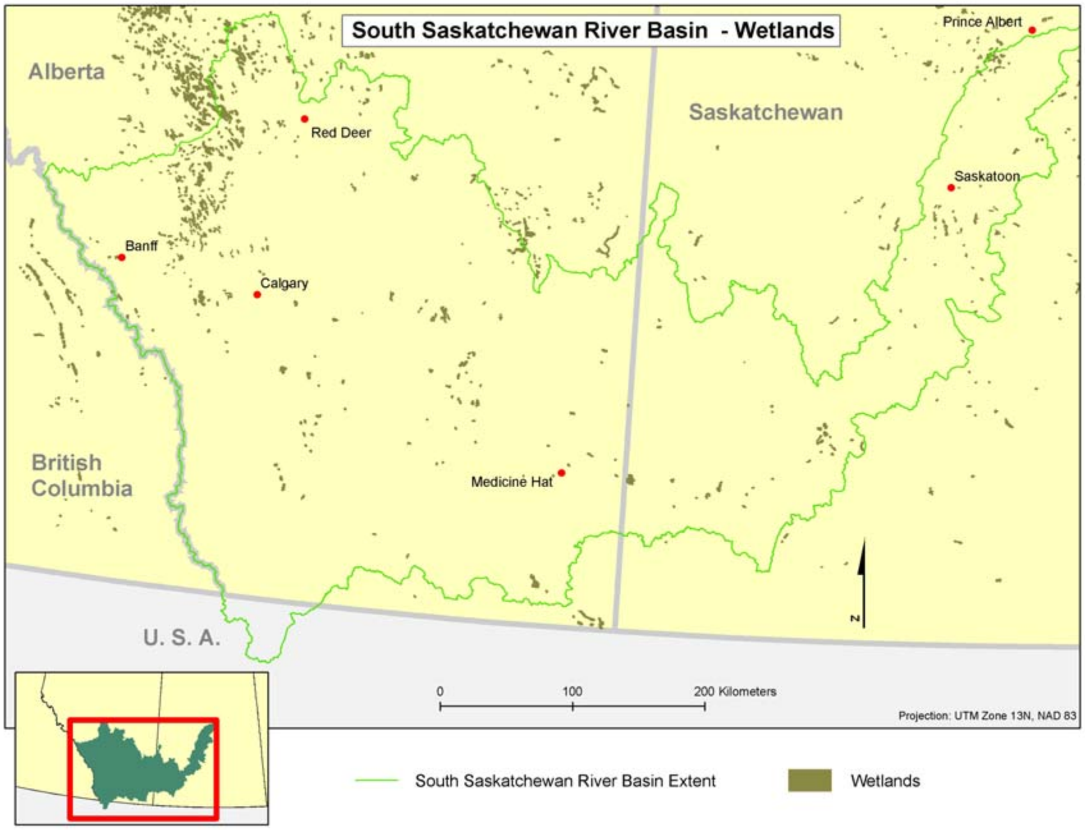


Figure 5.11 *Location of wetlands within the SSRB.*
Map produced by GIServices, University of Saskatchewan.

5.6 Internal Drainage

As shown in Figure 5.12, large portions of the SSRB contain internal drainage or non-contributing areas. These areas are considered *closed basins* which generally do not contribute runoff to the main river system.

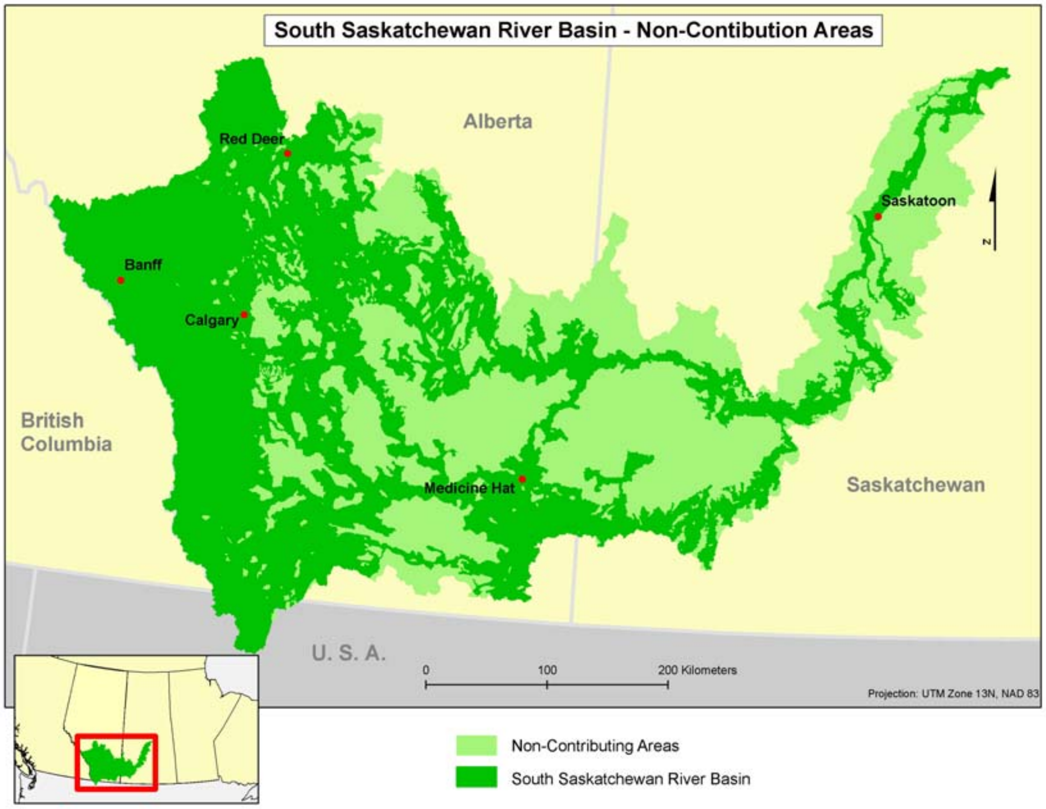


Figure 5.12 *Internal drainage or non-contributing areas in the SSRB.*
Map produced by GIServices, University of Saskatchewan.

References:

Lane, R. and Sykes, G., (1982). Nature's Lifeline: Prairie and Northern Waters. A Report Prepared for Canada West Foundation and Devonian Group of Charitable Foundations. Canada West Foundation. Calgary, Alberta. Pp 468.

Saskatchewan-Nelson Basin Board, (1972). Water supply for the Saskatchewan-Nelson basin. Report of the SNBB, Canada, Alberta, Saskatchewan and Manitoba. Regina, Sask.

Sobool, D. and Kulshreshtha, S. 2003. Socio-Economic Database: South Saskatchewan River Basin (Saskatchewan and Alberta). Dept. of Agricultural Economics, University of Saskatchewan, Saskatoon.

6 Determining Water Use in the South Saskatchewan River Basin (SSRB)

Water use reflects not only instream flows, storage capacity and net water demand (intake minus return flows) but also the capacity of a large integrated system to redirect flows or draw upon reservoirs to meet sub-basin or local circumstances. The physical component of this study was used to model future water availability in the SSRB under the potential impact of climate change, but does not as yet take into account any physical watercourse, land use or infrastructure adjustments over the study period. These physical characteristics could, nevertheless, be modeled as an extension of this base exercise, which has focused to date on the calibrated calculation of instream flows and coupled projection of down-scaled GCM climate change forecasts under the basin's existing inter-basin agreements, configuration and capabilities. It should be noted that any adaptive physical or infrastructure adjustments could in turn have an impact upon the hydrological response to climate change: any further modeling would thus require an iterative approach. The role of the socio-economic component here is to assess the impact of the future water availability on key water withdrawal and in-situ use sectors within the SSRB. To start, this section documents the current water use patterns for the SSRB under the base year 1996, in light of historical developments of water resources within the basin.

6.1 Background to Determining Water Use

Climate change has the potential to impact various aspects of water resources the world over. The impacts would not only have consequences for water supplies but also for water use. This is of major importance in Canada and in particular within the SSRB given that the region receives low annual precipitation. From an environmental perspective, the future availability of water is of major concern. The potential for changes in precipitation, warmer temperatures with increased evapotranspiration, and greater frequencies of extreme events will affect both water quantity and quality. Impacts on the environmental system would also affect the economic and social systems that depend on water resources within the SSRB.

A change towards a warmer climate could potentially have severe impacts on the economy and society within the SSRB. A reduction or change in the timing of precipitation, coupled with increased evapo-transpiration may result in changes to annual streamflow level and timing, and possibly lead to large declines in summer streamflow. This would have implications for the environment, economy, and society, and as well pose policy challenges for the governing of water resources within the SSRB. A warmer climate could also result in a higher potential for extreme events such as drought and increased aridity; this would have implications for land use and, importantly, agricultural production, a major economic practice within the SSRB. Further to impacts on the agriculture sector, a shift towards a warmer climate could result in changes to irrigation demands. Irrigation is the largest water use within the SSRB, and increases in demand could have significance impacts upon the agriculture sector generally, streamflow, water quality and groundwater as well.

Evaluating the potential impacts of changes in future water availability on the society within the SSRB, requires an understanding of a baseline period of water supply and use. Once the baseline period and the nature of changes to water resources have been established, changes in future water use may be estimated. Depending on the estimated changes to water use, adaptation strategies may be explored to prepare for periods where water resources are scarce. Any consideration of adaptive strategies must take into account existing arrangements and historical expectations.

6.2 Historical Importance of Water Resources in the South Saskatchewan River Basin

The availability of water resources within the South Saskatchewan River Basin has been an important issue dating back as far as the mid 1800's to John Palliser's exploration of the region and European settlement (Fung, Ed., 1999). A large portion of the South Saskatchewan River basin is covered by the Palliser Triangle, which is the driest region of the basin. Droughts remain a major concern within the Palliser Triangle, with some of the most severe droughts occurring during the 1920s, 1930s and 1980s. These droughts had serious consequences on the environment, economy and society.

Between 1942 and 1967, several major water development projects involving the South Saskatchewan River Basin were completed (PFRA, 2004) including: the St. Mary Irrigation Project, Bow River Irrigation Project, and Buffalo Pound Water Supply Project. The most significant development, the South Saskatchewan River Basin Project (the building of the Gardiner Dam at Lake Diefenbaker), was started in 1958 and completed in 1967. Within this timeframe (in 1948), the Prairie Provinces Water Board (PPWB) was established. The mandate of this board was to recommend the best use of interprovincial water based on the resources of each prairie province and flow apportionment between the provinces.

From 1968 to 1972, a major study was undertaken by the Saskatchewan-Nelson Basin Board involving the management of water resources within the region. The scope of this study included the Saskatchewan-Nelson Basin and enlisted the aid of the PFRA Engineering Service. The study examined the surface water resources of the basin and the possibility of increasing water supplies through storage and diversions, as well as the feasibility of engineering and associated costs to undertake construction. The overall objective was to provide possible alternative ways to meet future needs, while taking into consideration prevailing economic and social circumstances.

In the 1980s two major studies were conducted on the status of water resources within the region. Lane and Sykes (1982) provided a comprehensive overview of water supplies and uses, quality, and policy and institutional arrangements in regard to water resources in Western Canada. The study also examined future water use patterns, and water resource planning and management. *A Water Use and Value Study* (1989) was published by the Saskatchewan Water Corporation. The main objective of the report was an understanding water value concepts and considerations in a period where conservationist strategies, in regard to scarce resources, were becoming increasingly important.

In 2002, a two phase *South Saskatchewan River Basin Water Management Plan* was established by Alberta Environment (see Alberta Environment 2002 and 2003). The plan examines water management practices in the Alberta portion of the SSRB. In Phase One, it was found that water resources in the Alberta portion of the SSRB were reaching their limits; in Phase Two, the managers sought a balance between protecting the environment and water consumption within the SSRB.

6.3 Taxonomy of Water Use

In the context of determining water use, several important distinctions are needed, between terms like water use, water intake, water demand, water requirement and water consumption. Similarly there is the need to differentiate between withdrawing water from a source for a specific activity and using water within a source without withdrawing it.

6.3.1 Distinctions Between Use, Intake, Demand and Requirement and Consumption

As defined in Kulshreshtha et al. (1988, 4-6):

Water Use: A broad term referring to the utilization of water in association with any activity, economic or otherwise. Utilization may consist of actual withdrawal of water from a source, as by industry or residences, or non-withdrawal utilization as in the case of recreation.

Water Intake: This refers to the amount of water which is physically transferred from a source to satisfy a certain need. The need may be for an economic activity. The intake of water may directly or indirectly contribute to the production of economic goods and services.

Water Demand: The demand for water is defined economically, as the amount of water for which individuals would sacrifice resources rather than go without. The resources they are willing to sacrifice, under appropriate circumstances, may be measured in terms of the price paid for the water.

Water Requirements: This is the quantity of water needed to sustain or to maintain an activity. It is distinct from water intake only if part of the requirement is satisfied from a source not usually measured. For example, the water requirements of a crop may be satisfied by rainfall, water available as soil moisture, or from irrigation.

Water Consumption: This is the volume of water lost during the production process by an economic activity, for example, the amount of water applied to a crop through irrigation that is not returned to a source.

6.3.2 Withdrawal and In-situ Water Use

The various uses of water can be broadly divided into two types: withdrawal use and in-situ or instream use. Under the first type of water use, water is withdrawn from its original source. The quantity withdrawn is commonly called water intake. Part of this water is lost (or consumed) in the specific use. The remaining quantity is returned to the original source in some form. The amount of water not returned back to the water body is commonly called water consumption.

The second type of water use refers to that use which is associated with activities that do not require the withdrawal of water from its original source. For example, water in rivers or lakes that is used during water-based recreation activities. In this case, water need not be withdrawn from the water body. This type of use is commonly referred to as "non-consumptive" or in-situ use of water.

6.4 Measurement of Water Use for the Base-Year (1996)

Several sources of data were used to develop an inventory of water use for the base year. The base year of 1996 was chosen because, at the time, it was the latest year for which complete data were available. Sources of data include government agencies and institutions. A summary of the data sources and their relevance are given below. Development of a customized inventory for the base year was necessary for the dove-tailed socio-economic modeling exercise (Sections 9.0 and 10.0) and to contribute to the Water Use Analysis Model (WUAM) database.

6.4.1 Socio-Economic Database

The development of a socio-economic database was begun for the Prairie Adaptation Research Collaborative (PARC), under a contract with Agriculture and Agri-Food Canada's Prairie Farm Rehabilitation Administration, as reported in March, 2003 (Sobool and Kulshreshtha, 2003). Much of the information contained within the socio-economic database was derived from a database provided by the Prairie Provinces Water Board (PPWB). Supplemental data sources for the database include: Statistics Canada; Alberta Agriculture, Food and Rural Development (AAFRD); the Prairie Farm Rehabilitation Administration (AAFC-PFRA); Canada Wildlife Service (CFS); the Government of Alberta; and

Saskatchewan Regional Parks. The socio-economic database contains information on population estimates for communities and water use, livestock populations and water use, irrigation water use, wetlands and recreation.

6.4.2 Municipal Water Use

Municipal water use data was obtained from the socio-economic database as well as from Environment Canada's 1996 *Municipal Water Use Survey*. The data was available by community. While PPWB data is limited to population and water use, Environment Canada's data has a large number of parameters, including the subdivision into domestic, industrial and commercial uses. Environment Canada data, however, was limited to communities with population in excess of 1,000 residents. Note that urban water use data as presented includes commercial and industrial uses supplied from the municipal system in addition to domestic uses. Further analyses of the data can later be undertaken to further subdivide the urban water uses into domestic, commercial and industrial uses.

6.4.3 Industrial Water Use

Industrial water use data were obtained from Environment Canada's 1996 *Industrial Water Use Survey*. The survey covers four sectors: manufacturing, mining, thermal power generation and hydropower generation. Note that: the municipal water use data may include industries which are supplied from the municipal system; as such, further analysis is required to ensure that industrial water use is not double counted.

6.4.4 Livestock Water Use

Livestock data were obtained from the 1996 *Census of Agriculture* database (Statistics Canada: 1996 Census of Agriculture CD-ROM: release 2.1). The data includes animal populations for ten animal types. Livestock populations were associated with census subdivisions (CSD). The associated livestock water uses were estimated, for each animal type, by applying water use coefficients provided by PPWB.

6.4.5 Irrigation Water Use

The amount of data required for irrigation water demand calculations is considerable. It has been collected in collaboration with the Alberta Irrigation Projects Association and Saskatchewan Agriculture. Given the importance of irrigation within the SSRB, a water sector consultant performed a detailed examination and update of the existing irrigation component of the WUAM model (Sandoz, 2004).

6.4.6 Instream Water Use

While not a consumptive use, instream water use is considered in relation to the minimum flow required to satisfy a particular instream use.

6.4.7 Interprovincial Flow Apportionment

The minimum flow that is required to be passed across the Alberta-Saskatchewan border is simulated by identifying boundary flow constraints. Within WUAM, these flows are represented by 50% of the natural flow for each month of the simulation period.

6.4.8 Evaporation

Evaporation is a consumptive water use, calculated only from reservoirs. Information on major reservoirs in Alberta was obtained from Alberta Environment. Evaporative information for Lake Diefenbaker, in Saskatchewan, was obtained from a previous WUAM application.

6.4.9 Hydroelectric Power Generation

Hydroelectric power generation is a non-consumptive water use. The Water Use Analysis Model (WUAM) estimates the monthly hydroelectric energy generation from simulated flows together with data on a plant's average operating head and efficiency of each plant; it does not, however, simulate demands for hydroelectric power. Thirteen hydropower plants within the SSRB were surveyed by Environment Canada's 1996 *Industrial Water Use Survey*.

6.4.10 Thermal Power Generation

Steam-thermal power plant water use is estimated given the monthly energy generation at the plant and the water intake and consumption coefficients. Two thermal power plants in the SSRB were surveyed in 1996 in Environment Canada's 1996 Industrial Water Use Survey.

6.5 Determining Water Withdrawal Use

As defined above, water withdrawal takes supply from its original source. There are many different factors determining withdrawal water use, particular to each sector, as explained in Section 9.3. For example, sub-basin population configurations and demographic characteristics impact on demands made for housing and rural or municipal water systems. Physical constraints, economic feasibility and other concerns (such as conservation) determine the extent to which freshwater is available and relied upon versus how much wastewater is recycled and dedicated to various uses. Similarly, economic feasibility and environmental standards impact decisions made for water withdrawal use or recycling for commercial and industrial uses, as determined cyclically by both immediate and more remote population and societal demands. Note that in-situ water use and non-use values associated with instream flows are typically assessed separately from land-based withdrawal use, despite the evident implications upon riparian zones, i.e. through water quality or scenic value.

6.6 Potential Applications of Water Use Data

6.6.1 Contributions to the Water Use Analysis Model (WUAM)

The water use information, identified in Section 6.4.1 above, was intended for input, calibration and ongoing analyses performed using the Water Use Analysis Model (WUAM). The initial intent was to contribute not only an overall picture of current water use patterns within the SSRB, but to tap into some of the WUAM's simulation capabilities. The development of socio-economic and climate change forecast scenarios constituted an important component of this collaborative contribution. Forecast data provided to Environment Canada for the WUAM model runs include: population and industrial growth information; agriculture development forecasts; power generation forecasts and water development projects. For the scenarios simulated, assessments could then be made of the impacts on these projected water uses and the resulting water balance within the basin, assuming no corrective management and infrastructure adjustments are made. Deficits as identified and quantified at pre-specified locations would, as such, only be indications of potential vulnerability and an impetus to develop new or restricted institutional arrangements, determine more sophisticated means of monitoring instream ecology, and/or set targets for more reservoir or diversion capacity. Any such deficits could also be simulated according to particular water use sectors, such that the valuation of water use between sectors could also be more closely examined.

This research is closely linked and coordinated with the Water Availability in the South Saskatchewan River Basin under Climate Change study which provides the physical information related to water supply. This includes natural streamflow (for current and future climates) as well as precipitation and other climatic parameters under potential climate changes. With "climatically altered" streamflows and demand conditions available, WUAM will be used to produce water balance statistics at pre-specified locations, including statistics about the frequency and severity of water shortages, if any.

6.6.2 Capabilities of the Water Use Analysis Model (WUAM)

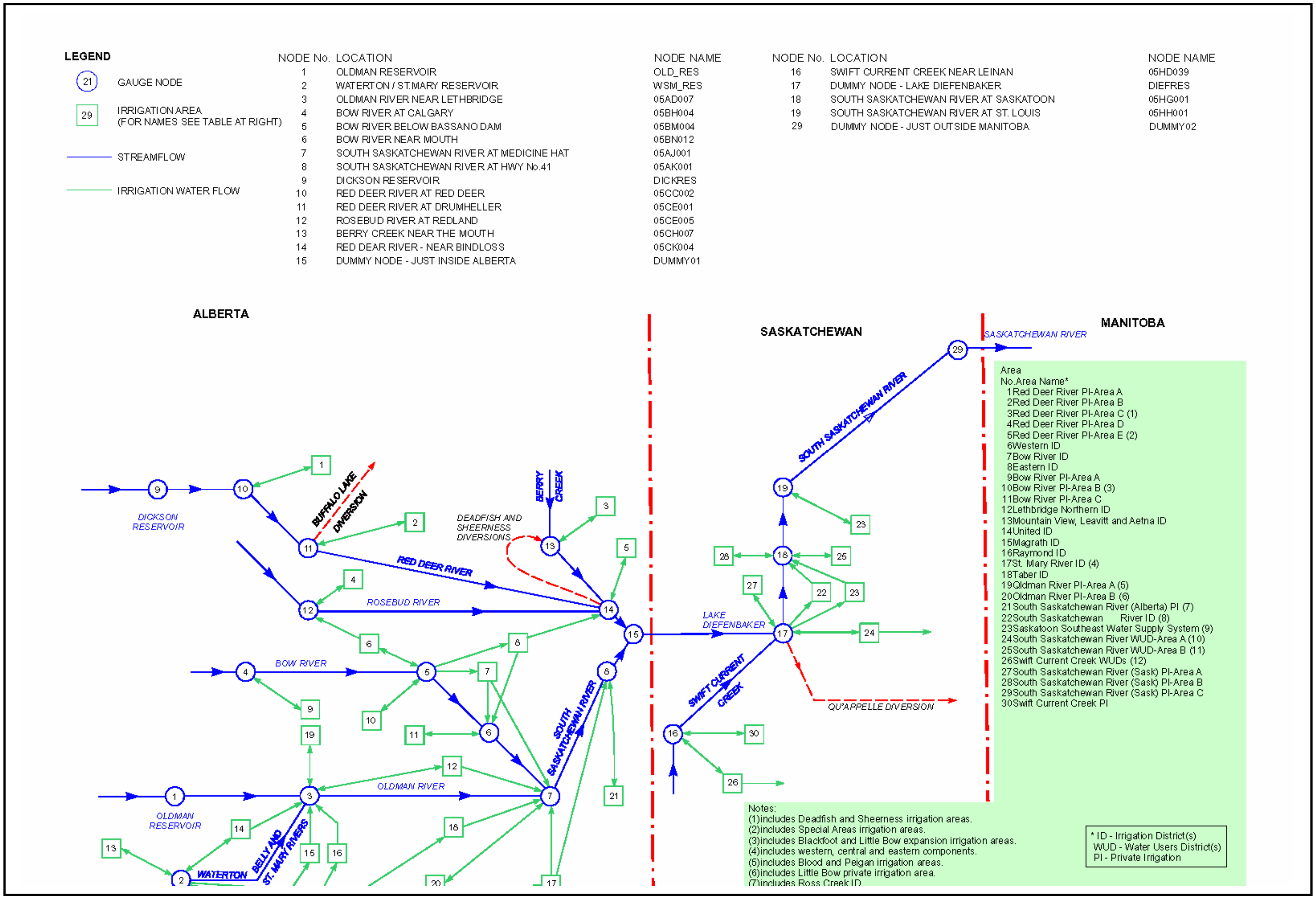
A detailed description of the WUAM can be found in Kassem (1992) and Kassem *et al* (1994). The WUAM integrates socio-economic, physical, hydrologic and climatic data, and is capable of analyzing a wide range of physical, economic, social, hydrologic and climatic conditions through water demand and water balance components. The WUAM allows the consideration of several water management issues including: impacts of water pricing on water demands, impacts of water diversions, and adjustments to inter-jurisdictional flow apportionment. The WUAM is also capable of analyzing the effect of water rationing and consumptive use cutbacks when available supplies are simulated to be exceeded.

The WUAM gives equal consideration to water supply and demands, placing special emphasis on the modeling of water demands while incorporating most of the important variables affecting water use. As such, the use of WUAM allows for the investigation of the impacts of socio-economic and policy scenarios on future water demands and water balance. Water use forecasting is the primary focus of the WUAM which considers both withdrawal or consumptive uses and non-withdrawal (or instream) water use. A second focus of the WUAM is simulated water supplies, derived using a time series of natural streamflow at various points within the drainage basin. A reservoir component of the model simulates the effects of regulation on water availability. A third component of the model compares projected water uses against simulated available supplies.

In WUAM, a river basin is represented by nodes, denoting sub-basins and links, denoting the flow path from one node to another (See Figure 6.1). Each sub-basin has a (natural) streamflow record at or near its outlets, which is used as a measure of the available water supplies. A long period of record is needed to allow for the analysis of natural variability of water supplies. The WUAM uses a monthly time increment for all calculations. It forms the basis of forecasting future multi-sectoral water uses and the assessment of the vulnerability of water users to current water availability, and to future water availability.

References:

Alberta Environment, (2002). South Saskatchewan River Basin Non-Irrigation Water Use Forecasts Alberta Environment, March 2002.
Alberta Environment, (2003). South Saskatchewan River Basin Water Management Plan Phase Two: Background Studies. Alberta Environment, June 2003.
Fung, K., (Ed.), (1999). *Atlas of Saskatchewan – Millennium Edition.* Saskatchewan: University of Saskatchewan.



NODE No.	LOCATION	NODE NAME
1	OLDMAN RESERVOIR	OLD_RES
2	WATERTON / ST.MARY RESERVOIR	WSM_RES
3	OLDMAN RIVER NEAR LETHBRIDGE	05AD007
4	BOW RIVER AT CALGARY	05BH004
5	BOW RIVER BELOW BASSANO DAM	05BM004
6	BOW RIVER NEAR MOUTH	05BN012
7	SOUTH SASKATCHEWAN RIVER AT MEDICINE HAT	05AJ001
8	SOUTH SASKATCHEWAN RIVER AT HWY No.41	05AK001
9	DICKSON RESERVOIR	DICKRES
10	RED DEER RIVER AT RED DEER	05CC002
11	RED DEER RIVER AT DRUMHELLER	05CE001
12	ROSEBUD RIVER AT REDLAND	05CE005
13	BERRY CREEK NEAR THE MOUTH	05CH007
14	RED DEAR RIVER - NEAR BINDLOSS	05CK004
15	DUMMY NODE - JUST INSIDE ALBERTA	DUMMY01

NODE No.	LOCATION	NODE NAME
16	SWIFT CURRENT CREEK NEAR LEINAN	05HD039
17	DUMMY NODE - LAKE DIEFENBAKER	DIEFRES
18	SOUTH SASKATCHEWAN RIVER AT SASKATOON	05HG001
19	SOUTH SASKATCHEWAN RIVER AT ST. LOUIS	05HH001
29	DUMMY NODE - JUST OUTSIDE MANITOBA	DUMMY02

Area No.	Area Name*
1	Red Deer River PI-Area A
2	Red Deer River PI-Area B
3	Red Deer River PI-Area C (1)
4	Red Deer River PI-Area D
5	Red Deer River PI-Area E (2)
6	Western ID
7	Bow River ID
8	Eastern ID
9	Bow River PI-Area A
10	Bow River PI-Area B (3)
11	Bow River PI-Area C
12	Lethbridge Northern ID
13	Mountain View, Leavitt and Aetna ID
14	United ID
15	Magrath ID
16	Raymond ID
17	St. Mary River ID (4)
18	Taber ID
19	Oldman River PI-Area A (5)
20	Oldman River PI-Area B (6)
21	South Saskatchewan River (Alberta) PI (7)
22	South Saskatchewan River ID (8)
23	Saskatoon Southeast Water Supply System (9)
24	South Saskatchewan River WUD-Area A (10)
25	South Saskatchewan River WUD-Area B (11)
26	Swift Current Creek WUDs (12)
27	South Saskatchewan River (Sask) PI-Area A
28	South Saskatchewan River (Sask) PI-Area B
29	South Saskatchewan River (Sask) PI-Area C
30	Swift Current Creek PI

Notes:
(1)includes Deadfish and Sheerness irrigation areas.
(2)includes Special Areas irrigation areas.
(3)includes Blackfoot and Little Bow expansion irrigation areas.
(4)includes western, central and eastern components.
(5)includes Blood and Peigan irrigation areas.
(6)includes Little Bow private irrigation area.
(7)includes Ross Creek ID

* ID - Irrigation District(s)
WUD - Water Users District(s)
PI - Private Irrigation

Figure 6.1 *Example of the WUAM river basin schematic*. Image courtesy of Atef Kassem, Environment Canada.

References, continued:

Kassem, A., (1992). The Water Use Analysis Model (WUAM), Program Documentation and Reference Manual, Economics and Conservation Branch, Ecosystem Sciences and Evaluation Directorate, Environment Canada, Ottawa, Ont.

Kassem, A., Tate, D. and Dossett, P., (1994). Water Use Analysis Model (WUAM) Demonstration, Social Science Series No. 28, ECS, Environment Canada, Ottawa, Ont.

Kulshreshtha, S., Brock, J., O'Grady, K. and Miller, S. 1988. Current Water Use Levels in Saskatchewan. Water Use and Value Study Report 3. Moose Jaw: Saskatchewan Water Corporation.

Lane, R. and Sykes, G. 1982. Nature's Lifeline: Prairie and Northern Waters. A Report Prepared for Canada West Foundation and Devonian Group of Charitable Foundations. Canada West Foundation. Calgary, Alberta. Pp 468.

PFRA. 2004. PFRA – A brief history. http://www.agr.gc.ca/pfra/pfhist_e.htm Accessed October, 2004.

Sobool, D. and Kulshreshtha, S. 2003. Socio-Economic Database: South Saskatchewan River Basin (Saskatchewan and Alberta). Department of Agricultural Economics, University of Saskatchewan, Saskatoon.

Statistics Canada. 1996. Census of Agriculture CD-ROM: release 2.1

Map Data Sources: Pietroniro, E. (2004) All of the maps listed below, excluding the Atlas of Saskatchewan map, were produced by E. Pietroniro, GIServices, University of Saskatchewan 2004.

SSRB Location Map (Figure 3.3). Data Source: National Atlas of Canada, National Scales Framework Hydrology, Natural Resources Canada, Government of Canada; Prairie Farm Rehabilitation Administration (PFRA), Agriculture and Agri-Food Canada, Government of Canada.

Major sub basins (Figure 3.4). Prairie Farm Rehabilitation Administration (PFRA), Agriculture and Agri-Food Canada, Government of Canada.

Detailed sub basins (Figure 3.5). Data Source: National Atlas of Canada, National Scales Framework Hydrology, Natural Resources Canada, Government of Canada; Prairie Farm Rehabilitation Administration (PFRA), Agriculture and Agri-Food Canada, Government of Canada.

Topography Map (Figure 3.6). Data Source: National Atlas of Canada, National, National Topographic Database, Canada 3D 30 DEM, Natural Resources Canada, Government of Canada; Prairie Farm Rehabilitation Administration (PFRA), Agriculture and Agri-Food Canada, Government of Canada.

Ecoregions map (Figure 3.7). Data Source: National Atlas of Canada, Natural Resources Canada, Government of Canada; Prairie Farm Rehabilitation Administration (PFRA), Agriculture and Agri-Food Canada, Government of Canada.

Land cover map (Figure 3.8). Data Source: National Atlas of Canada, National Scales Framework Hydrology, National Topographic Database - Canada 3D 30 DEM, Natural Resources Canada, Government of Canada; Prairie Farm Rehabilitation Administration (PFRA), Agriculture and Agri-Food Canada, Government of Canada.

Hydrology map (Figure 3.9). Data Source: National Atlas of Canada, National Scales Framework Hydrology, Natural Resources Canada, Government of Canada; Prairie Farm Rehabilitation Administration (PFRA), Agriculture and Agri-Food Canada, Government of Canada.

Qu'Appelle Diversion (Figure 3.10). Image courtesy of the Atlas of Saskatchewan Project, ©University of Saskatchewan 2000. Map Provided by GIServices, University of Saskatchewan.

Map Data Sources, Continued:

Wetlands (Figure 3.11). Data Source: National Atlas of Canada, National Topographic Data Base, Natural Resources Canada, Government of Canada; Prairie Farm Rehabilitation Administration (PFRA), Agriculture and Agri-Food Canada, Government of Canada.

Non-contributing area map (Figure 3.12). Data Source: National Atlas of Canada, Natural Resources Canada, Government of Canada; Prairie Farm Rehabilitation Administration (PFRA), Agriculture and Agri-Food Canada, Government of Canada.

Population Distribution and Population Change (Figure 3.13 & 3.14). Data Source: National Atlas of Canada, Natural Resources Canada, Government of Canada; Prairie Farm Rehabilitation Administration (PFRA), Agriculture and Agri-Food Canada, Government of Canada; Statistics Canada, Government of Canada; DMTI Spatial.

Power Plants (Figure 5.3). Data Source: National Atlas of Canada, National Scales Framework Hydrology, Natural Resources Canada, Government of Canada; Prairie Farm Rehabilitation Administration (PFRA), Agriculture and Agri-Food Canada, Government of Canada. South Saskatchewan River Basin Project (SSRB).

Irrigation Districts (Figure 5.9). Data Source: National Atlas of Canada, National Scales Framework Hydrology, Natural Resources Canada, Government of Canada; Prairie Farm Rehabilitation Administration (PFRA), Agriculture and Agri-Food Canada, Government of Canada; Saskatchewan Watershed Authority - Geomatics Unit; Alberta Agriculture, Food and Rural Development (AAFRD) - Irrigation Branch

Parks and Recreation Map (Figure 5.21). Data Source: Prairie Farm Rehabilitation Administration (PFRA), Agriculture and Agri-Food Canada, Government of Canada; Alberta Community Development, Parks and Protected Areas Division, Government of Alberta. Saskatchewan Environment, Government of Saskatchewan

7 Basin Water Use in Regional Economic Perspective: Rationale for Input-Output Analysis

7.1 Introduction to Economic Impact Analysis

7.1.1 Background and Need for Economic Impact Analysis

The assessment of socioeconomic impacts resulting from changes to water supply as a result of a changing climate can be considered on a regional, economic impact analysis basis. This approach is especially useful to regional or collective policy deliberation, where the impact of a new decision or program can be estimated in at least two ways. In economics, a major distinction is made between economic impact analysis, as dealt with in this section, and economic efficiency analysis which is dealt with in Section 9. The latter, according to Loomis (1993), is concerned with the allocative efficiency of resource allocation. The major emphasis here is on the use of the resource to maximize economic welfare of the society: the combination of resource uses that produce the greatest net gain to the society. This calculation requires consideration of both gains and losses to members of the society. No consideration, however, is as yet given to the distribution of that newly generated income. Economic impact analysis aims at estimating the effect of a decision or individual project on various parts of the society. Both local and non-local societies can be included in the analysis. Economic impacts of a project are required for water managers and policy decisions-makers to make informed decision about water use. How various members of the society would be affected by the decision is the key to this information.

The choice of water use in a region can have significant environmental and economic implications. Depending on the priorities of the water regulators, a trade-off often exists between the water needs of the environmental activities and that required for social and economic activities. A restriction on the use of water for the latter type of activities may have impacts in terms of regional economic development.

7.1.2 Tools for Economic Impact Analysis

This section discusses some of the tools commonly used for economic impact analysis. At least three types of tools have been applied in the literature to estimate impacts of a project, including: the *Economic Base* model, the *Income–Expenditure Accounting* model and the *Input-Output* model.

The *Economic Base* model is applied to a monolithic economy, that is, a single industry economy with a strong focus on exports. The industry with external trade is called the Export or Base sector, while the rest of the economy is called local or service (and therefore non-base) sector. It is assumed that the local sector exists only because of the export sector. A multiplier based on the ratio of the export base to the local sectors is used to predict economic impacts. Since most economies do not qualify to fit these conditions, with the exception of some mining towns or tourist places, this tool has limited applications.

The *income-expenditure accounting* model takes into account the role played by the government sector as well as imports. In addition, consumption patterns, in terms of the marginal propensity to consume, are also taken into account. However, the impact assessment derived from this model is limited to a small regional economy whose intersectoral interrelationships are too simplistic to be modeled without collecting substantial data (Davies, 1993, 39). However, estimation is limited to the level of regional income. Furthermore, no distinction can be made in turn so sectors are affective by the exogenous change.

An *input-output* (IO) model provides a substantially different method of analyzing regional economic impacts. It reveals the ways in which various regional sectors (or firms) interact with each other and generate economic effects from a given stimulus. Such economic stimuli could be in the form of higher consumer expenditures, new investment activity, government spending or export activities. The results obtained from the use of this type of model are disaggregate enough that distribution of impacts can be ascertained.

7.1.3 Study Method of Impact Estimation

In the context of Canada and the United States, studies analyzing the role of water in regional development have been few. A review of various studies in Canada and the US on regional economic development projects was thus undertaken in hopes of discovering possible methods to select appropriate methodology for this study. This review indicated that the main method of analysis in these studies is either benefit-cost analysis or economic impact analysis.

Examples of such studies are too many to list here, but studies such as Anderson, Leitch and Fegert (1985), Bangsund and Leistritz (1993), and Givers et al. (1994) are particularly illustrative of such applications. In addition, the effect of direct water use on other sectors (such as agricultural processing) has also been analyzed using economic impact analysis. Examples of these studies can be found in Bangsund and Leistritz (1993), Leistritz (1997), Leistritz and Sell (2000), MacMillan et al. (1992), and MacMillan and DeMatos (1992), to name a few.

Applications of the IO model have been made in the context of water resources and their impact on regional economies. Following international traditions, the availability of water and water resource development has also been recognized as a major ingredient for economic development in North America. A number of studies have attempted to link water resources as a factor determining the growth of various regions. Evidence has been mixed. The Tennessee Valley Authority was one of the first institutions created to develop water resources for economic development in North America. Economic benefits flowed from their projects by way of power, higher quality water in the reservoirs, flood control, and low-cost transportation channels. According to Krutilla (1956), many industries took advantage of these benefits. For example, availability of cheap power was used for the war and postwar period industrial expansion in the region, leading to a major boost to its economic development.

The IO method of impact assessment was selected for this study to analyze water reallocation among various sectors. Change in the water available to a given sector would likely affect its production level, which would ultimately affect its regional contribution to the level of activities of other industries, their contributions to gross domestic product, and regional economies. In addition, if the model is linked to an employment module, it could also generate employment contributions under a given scenario of water allocation.

7.1.4 Objectives and Scope of the Study

The major objective of this study component was to demonstrate the use of an input-output model in making water allocation decisions in the South Saskatchewan River Basin (SSRB) of Alberta and Saskatchewan. This objective is further divided into the following sub-objectives:

1. To describe the economies of the sub-basins (Saskatchewan and Alberta) to guide the development of the appropriate model;
2. To design an appropriate model to represent the economies of the two sub-basins;
3. To estimate the model parameter for economic impact assessment; and
4. To demonstrate the application of the model to a given water use scenario.

The model was based on Statistics Canada data for the provinces of Saskatchewan and Alberta. The development of the model for the SSRB followed standard methods of regionalization. Results therefore are applicable to the Basin only and any indiscriminate extension to other regions should be avoided.

7.2 Location and Nature of Water Use in the SSRB

As described in Section 5, the South Saskatchewan River Basin (SSRB) is shared between the provinces of Alberta and Saskatchewan. Across the Basin, two types of water-based activities should be considered when determining the economic impact of water development. The first is “consumptive” water use such as irrigation, household and industrial use; the second is “in-situ” water use, such as for recreation and wildlife habitat.

The SSRB is primarily located in an agricultural region and irrigation represents a large portion of water usage in the Basin. Along with the irrigation of crops, the livestock, supported by the forage grown in the Basin, have an impact on economic activities in the region. Several communities rely on the creeks and rivers in the Basin for their water supply. Without this easily accessible and reliable surface water supply, it is likely that several of the industries existing in this region would not have chosen their current location. The availability of non-consumptive water uses such as recreation and wildlife habitat also influences the decisions of residents and businesses to locate here.

In this preliminary exercise, total withdrawal water use in the Basin was calculated as shown in Figure 7.1. The use of water for irrigation and livestock constitutes over four-fifths of the total use. Although municipal water use is significant, it was determined to represent only 14% of the total (including industrial) water use.

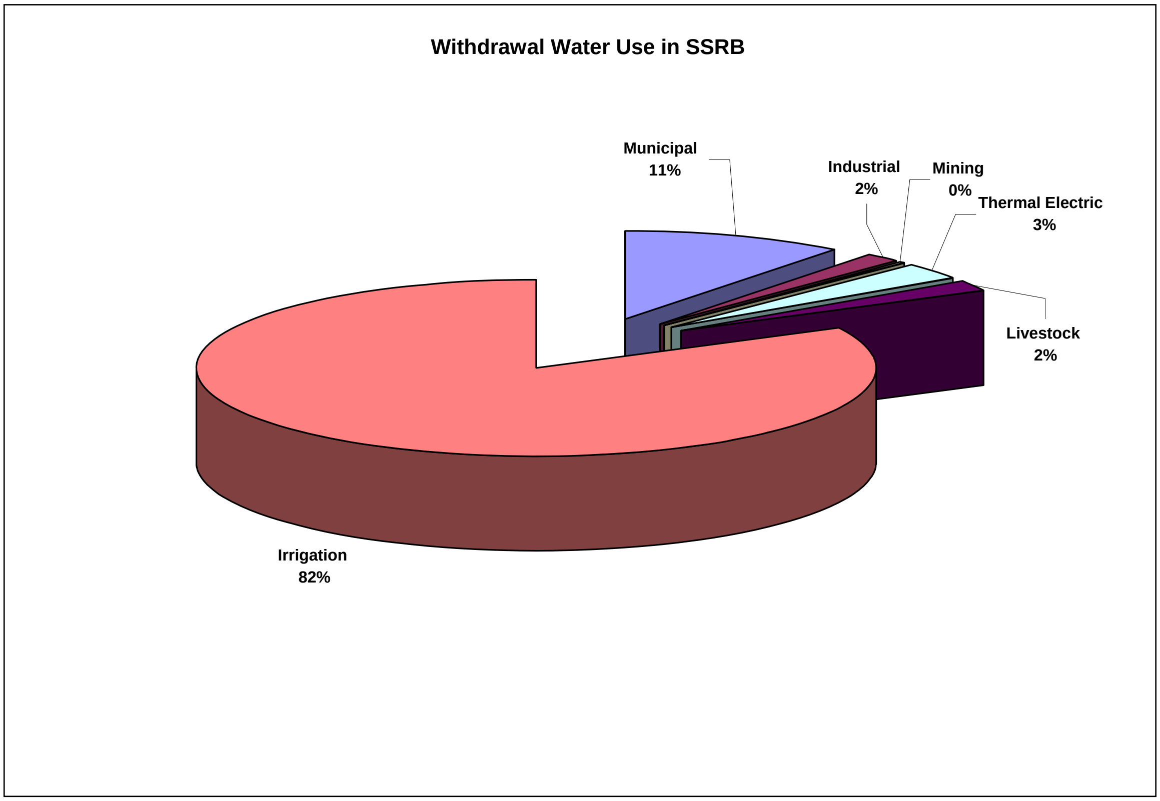


Figure 7.1 *Distribution of Withdrawal Water Use in the South Saskatchewan River Basin*
Source: Armstrong et al. 2004.

1. Agricultural Water Use

There are several economic activities occurring in the agricultural industry which are directly or indirectly dependant upon the availability of water in the Basin. The most significant activity is irrigation. Two distinct types of irrigation activity occur in the SSRB. The first type of irrigation is dedicated to crops (including cereals, pulses, oilseeds, and fruits and vegetables). The production of these agricultural products may result in further processing in the region. An example of this type of secondary industry is the potato processing plant in Taber, Alberta. The second type of irrigation concentrates on pastures and forage areas. Increased forage production – when compared to dryland production – increases the number of dairy and beef cattle. These additional cattle have a direct economic impact on the region by increasing the need for the processing of animal products. There are clear economic impacts for each of the regions that make up the SSRB.

2. Manufacturing Water Use

The manufacturing industry includes a number of diverse activities and demands within the SSRB. The manufacturing sector is located, for the most part, in and around larger metropolitan centres such as Calgary and Saskatoon, although smaller centers do house some manufacturing activities. A significant amount of water usage in the SSRB may be attributed to these manufacturing activities. Many manufacturing technologies rely on water and these activities need a reliable water supply to continue operations. The lack of a reliable water supply would force businesses in the manufacturing sector to either relocate or reduce their activities. The manufacture of various agricultural and food products are clearly impacted by the SSRB, just as the entire manufacturing centre is dependant on a reliable supply of available water, so is the agriculture and food sectors.

3. Power Generation Water Use

The power generation sector, which is made up of thermal electric as well as hydroelectric power, is another major water user. As determined by Lane and Sykes (1982, 393), the Basin had a potential of 630 MW of hydroelectric power. In 1980, 110 MW were developed in Alberta and another 100 MW in Saskatchewan. It should be noted that hydroelectric power generation does not consume any water; water is simply released through the turbines for other users downstream. There are two thermal power stations in Saskatchewan that are located in the Basin: A. L. Cole and Queen Elizabeth. (Both are in the City of Saskatoon). In Alberta, power is supplied through two private electric power utilities. They operate several thermal power stations, one of which is located in Medicine Hat. The exact water use of these two plants is not known at the time of this report.

4. Domestic Water Use

The SSRB is a home to some 1.78 million inhabitants. According to the Census of Canada (public release plus some preliminary release data, 2001), a large majority of the Basin population (totaling 85%) resides in urban areas, that is, with centers with populations of 1,000 or more. The largest population centres include Calgary and Lethbridge in Alberta, and Saskatoon in Saskatchewan. The most recent fifty year period (1951 to 2001) has seen the population of the Basin grow from 519,000 to its present level of 1.78 million, an increase of almost two hundred and fifty percent. The majority of the increase in the Basin population occurred in the urban and rural non-farm centers. As a result, population composition shifted to more urban (urban and rural non-farm) centers. Figure 7.2 shows the farm population constituting a third of the total basin population in 1951; however, by 2001, as urban areas expanded, this population declined to a mere 3.2% of the total. Much of the water use for domestic purposes, which constitutes 12% of total usage in the Basin, is provided through municipal governments.

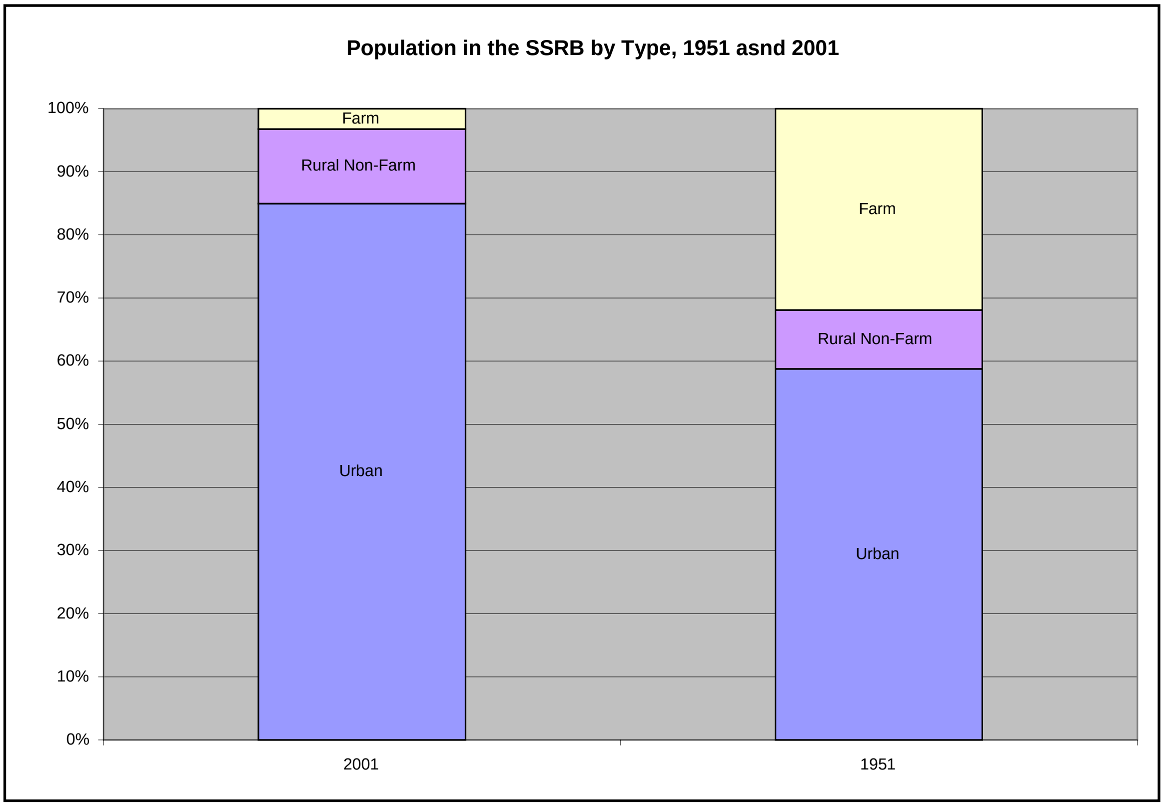


Figure 7.2 *Change in Basin Population by Type of Population, Comparison of 1951 and 2001*

7.3 Conceptual Overview of the Input-Output Model

As noted above, one approach to assessing the value of a resource is to evaluate its contribution to the economic welfare of society at large. This approach is directly applicable to the water supply, especially when problems or shortages occur and the economic welfare of a society is seriously compromised. The contributions of a resource to the economic welfare of a region can be addressed through regional economic analysis. Regional economic impact analysis is designed to answer questions such as:

- What is the nature of the region in terms of its various economic activities?
- What is the nature of its dependence on regions, either in Canada or internationally, to meet its needs?
- What is the nature of interdependence among its various types of economic activities?
- Are the changes resulting from a certain stimulus confined to few sectors or generally widespread?
- What is the nature of sales and purchases among various economic agents?
- How might the future of the region look under alternative policy regimes or development paths?

These same questions can be used to answer valuation-related questions if one is able to also answer the following:

- What are the major water use activities in the SSRB?
- What direct economic contributions are made by various water-using activities?

- Are there economic interdependencies that exist between sets of activities in the economy?
- Would allocating water to a certain activity increase the total water usage in the economy?
- How large a contribution is made by the water-use sector to the income and employment of the people in the Basin?

Questions like these require more complex models of economic activity. As noted earlier, one such model is the input-output model. This section presents a conceptual description of the IO model and standard economic impact analysis, as could be applied to the SSRB.

7.3.1 Concept of an Input-Output Model

The economic input-output model is based on the General Equilibrium theory developed by Walras in 1874. Leontief developed and published the first transactions tables for the 1919 and 1929 economy of the United States in 1936 based on Walras' theory. These transactions tables served as the foundation on which the input-output model for the economy was constructed. It was not until the late 1940s that input-output models were developed for regions smaller than nations (Isard, 1975). Since the 1940s, several studies have examined regional economies using input-output models.

The input-output model (IO) provides a method for estimating the total economic impact of a decision being made by a policy maker. A decision on policy may generate new economic activity or reduce current economic activity. The IO model attempts to assess the impact of a decision, not only on the activities it directly affects, but also on other economic agents in a community. This type of model is capable of estimating the economic impacts of a decision for small as well as larger regions. Since every economic activity has a unique affect on resource use, the total impact each individual activity makes must account for its specific set of circumstances. This method is also capable of predicting the economic impacts of some exogenous changes, such as consumer spending, exports, or purchases by other sectors.

In economic terms, there are two common methodologies which address regional economies. The first method examines the resources used to meet the needs of the society (as called *inputs*). The second model investigates the sales figures of various economic agents (as called *outputs*). The input-output model is a representation of both the input-related and output-related activities in a region. This model is intimately linked with macroeconomic accounting of the national income.

In macroeconomics, the value of the net output of an economy is estimated using one of two methods. The first, the "income approach," estimates the gross domestic product (GDP) of a region. The second, the "expenditures approach," estimates gross domestic expenditures (GDE). In theory, both GDP and GDE must be the same value. The income approach based GDP is estimated as follows:

$$GDP = W + CP + INT + NFI + UCI + INV \qquad \text{(Equation 1)}$$

Where, W = Wages, salaries and supplementary labor income;
CP = Corporate profits before taxes;
INT = Interest and miscellaneous investment income;
NFI = Accrued net income of farm operators from farm production;
UCI = Net income of non-farm unincorporated businesses including rent;
INV = Inventory valuation adjustment.

The expenditures approach calculates GDE with the following equation:

$$GDE = C + G + INVT + EXP - IMP + INV \quad \text{(Equation 2)}$$

Where, C = Personal expenditures on consumer goods and services;
G = Current governmental expenditure on goods and services;
INVT = Gross fixed capital formation;
EXP = Export of goods, margins and services;
IMP = Import of goods, margins and services;
INV = Value of physical change in inventories (farm and non-farm)

By definition the entities are equal. In other words,

$$GDP = GDE \quad \text{(Equation 3)}$$

In the IO model, both accounting approaches are applied to account for the regional net output. In addition, the model includes the sales and purchases of various goods and services by firms within the region. The study attempts to quantify the economic interdependencies that exist in the economy at a precise moment. Firms are classified into homogenous groups, called *sectors*, and various goods and services are referred to as *commodities* in this model.

Economic activities are divided into one of two types of sectors: “production” sectors or “final demand” sectors. A producing sector is comprised of firms that produce similar goods and services using similar production technologies. Production sectors (such as agriculture, mining, manufacturing, construction) represent establishments in a region that produce a product or service for use by either another sector or final demand sectors. These sectors purchase goods and use them in their own production process thereby adding value to the product.

Final demand sectors are represented in Equation 1 and include: household (or consumers), governments, investment activity, and foreign trade. Activity levels for the final demand sector are exogenous to the model. In fact, “final demand” drives all economic activities in the region. For this reason, the IO model is called a demand-driven model.

7.3.2 Assumptions of the Input-Output Model

An IO model is based on several assumptions. Of particular note are:

1. The Constant Technology and Fixed Technical Coefficients Assumption. The IO model assumes that the input structure of a sector remains fixed during the period of analysis. Inputs are used in constant proportion to output. In other words, the technology coefficients are fixed and the proportions do not change with the level of production. This production function is shown in Figure 7.3. In order to increase production from X0 to X1 level, the firm would increase both the inputs in a constant proportion, as shown by the expansion path. The slope of this line cannot change during the period of analysis.

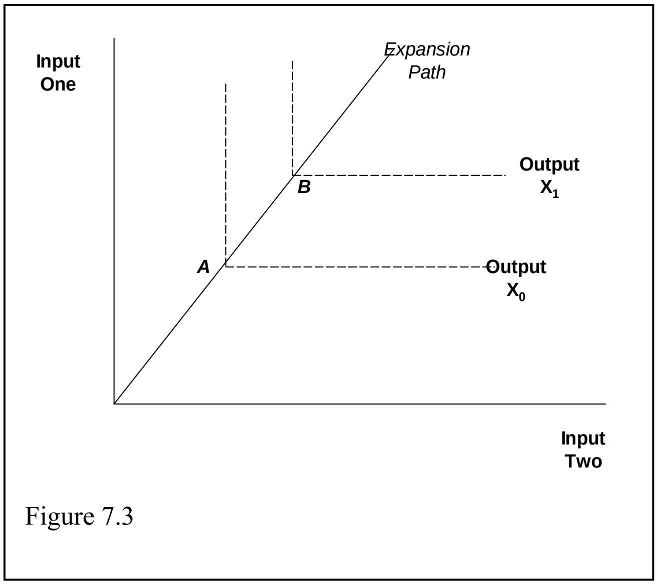


Figure 7.3 *Leontief Production Function used in the Input-Output Model*

2. The Homogeneity of Sectors. The concept of a sector or industry in an input-output model is fundamentally important to the construction of the empirical model. In reality, there are diverse types of economic activities, which are not homogenous either in terms of the product produced or the nature of production technology used. Since it is not possible to have a separate sector for each of these economic activities, they are grouped into *sectors*. In this aggregation process, it is assumed that there is a single production process for each product.

3. Additivity and Divisibility. The outputs of various firms are assumed to be additive to the formation of the regional output. The assumption is that the total effect of several different activities is the sum of their separate effects. Furthermore, it is assumed that the output of any firm included in the sector is completely divisible. Thus, it is not possible for a sector to produce any incremental change.

4. No change in Technology. The model assumes that the technology used by firms in the study remains unchanged during the period of impact estimation. For this reason, the IO model is not used for making long-term forecasts unless information is updated. The model is considered accurate for a time period of 5 years after which it must be updated.

5. No Supply Constraints. The IO model assumes that there are no supply constraints, that is, if demand is present, the economy will produce the required quantity of goods and services.

These assumptions have several implications, as listed below. Although some of these assumptions are often violated in reality, this does not fully negate the usefulness of the IO models. They still remain a viable means of assessing a decision at a particular point in time.

(a) No allowance is made for technological change which could alter factor-factor or factor-product relationships;
(b) Sectors cannot substitute inputs from one sector for inputs from another sector;
(c) There is no scale or size economies in production; and
(d) The relative prices of all goods and services remain constant.

7.3.3 The Transactions Table

The heart of an IO model is the Transactions Table. This table presents all the sales and purchases of commodities by various sectors. A typical transactions table has four major components. A rudimentary transactions table is shown in Figure 7.4.

Part A Goods Producing Sector to Sector Purchases	Part B Final Demand Sectors Purchases from Good Producing Sectors	Total Sales of Sectors
Part C Goods Producing Sectors Purchases from Resource Owners	Part D Final Demand Sectors Purchases from Resource Owners	Total Value Added
Total Sector Output	Total Final Demand	

Figure 7.4 *Rudimentary Input-Output Model*

The table is divided into the following four parts:

Part A: Transactions among various goods-producing sectors, called intermediate demand or intermediate sales;
Part B: Transactions between goods-producing sectors and final demand sectors, called final sales;
Part C: Transactions involving purchases of primary resources by goods-producing sectors, and
Part D: Transactions involving purchases of primary resources by final demand sectors.

Accordingly, the columns in the transactions table are divided into two types of purchasers:

(1) Firms in the region that require raw materials from other industries called "intermediate purchases" or "sales;" and
(2) Purchases by final demand agencies, called "final sales."

There is a clear distinction between these two types of purchasers. Intermediate sales attempt to add value to products. These products will enter the economy in a somewhat modified shape or form. The final demand agencies purchase goods for final consumption: they are not allowed to enter into the economy again. Four types of final demand agencies are typically included in a transactions table: consumers, government expenditures (including new investment), business investment, and exports.

Across the rows are shown various industries/agents that sell their goods and services. Thus, in Part A are the same sectors as the purchasing sectors, except these are now selling their goods and services (as against purchasing). In Part C are included the owners of land, labor (and management) and capital resources that are needed in the production of goods and services by various industries and/or by final demand agencies for the delivery of their goods and services.

The results of the IO model are based on a "double-counting" of economic activities. The estimate of the GDP is provided by the sum of all entries in Part C and D, whereas the GDE is estimated by totaling all final demand transactions. Thus both Equations 1 and 2 are satisfied by the IO model.

7.3.4 Square versus Rectangular Input-Output Models

There are two types of accounting systems used in the development of IO models, defined as the Square IO model and the Rectangular IO model. In a Square IO model, a goods-producing sector is limited to the production of one, and only one, commodity: each sector sells a single product. The number of selling sectors will therefore be equal to the number of goods-producing sectors. (This results in the square transactions table unique to the Square IO model).

The removal of the assumption that a single good or service is produced by each industry (sector) results in the Commodity by Industry IO model. An alternative name for this type of model is "rectangular input-output model". In a rectangular IO model, an industry (belonging to a given sector) can produce a number of goods (called commodities). Typically, the number of goods produced is higher than the number of economic sectors. In this type of IO model, data is arranged in two distinct classification systems:

(1) *Commodity Account:* Data is compiled in terms of characteristic products defined by the NACCC (North American Commodity Classification Code) whether the product is produced as a primary or a secondary good or service.

(2) *Industry or Sectoral Accounts:* Data is compiled and assigned to various industry accounts using a NAICC (North American Industry Classification Code).

Using these two sets of accounts, the rectangular input-output model can be represented by five parts of information:

Part A: Make Matrix: This matrix contains the production of various commodities by various sectors. The rows contain various industries and the columns represent of commodities. Each row contains the total number of commodities produced by a given sector.

Part B: Use Matrix: This matrix provides a partial picture of commodities that are used by various industries (sectors) in their production processes. These requirements are determined by the nature of the production function for each sector; this matrix may also be described as the "Technology" or "Absorption" matrix. This matrix illustrates the interdependencies existing between various sectors in the region.

Part C: Purchases by Final Demand Agencies: This matrix is similar in nature to the "Use Matrix," differing in that it displays the purchases (or sales) classified as 'final demand' agencies. These include consumers, governments, investors, and exports. All transactions are shown in terms of value of commodities.

Part D: Value-Added Purchases by Sectors: This matrix accounts for the remaining purchases of various inputs for the production of commodities by sector. It records the expenditures made by a sector on land, labor and capital resources.

Part E: Value-Added Activity by Final Demand Agencies: This matrix completes the requirements for meeting various final demands. The rows for this matrix are the same as for the previous matrix.

7.3.5 Taxonomy of Input-Output Models

It is theoretically possible to construct a variety of IO models. The most relevant models would illustrate the total versus local requirements, single versus multiple regions, and endogenized sectors. Each IO model version is described in detail below.

1. Total versus Local Requirements Based Models

This model represents the needs of various sectors and final demand agencies in a region. The needs, depicted through the transactions table, can be met through either local production or imports. Typically the situation is a combination of the two, with imports supplementing local production when needed. Adjustments for imports totals in the requirements are necessary to obtain an accurate picture of the local area impacts.

2. Regional versus Multi-Regional Input-Output Models

Although the IO model was originally designed for nation states, recent developments in methodology (particularly the development of non-survey methods) have facilitated the use of IO models for smaller regional areas. There are typically three types of regional models: single region models, multi-region models, and inter-regional models. In the past, IO models have traditionally focused on the economic activities of one region. Such studies include Brockman and Kulshreshtha (1987), Kulshreshtha, Shalley and Russell (1993), and Thompson (2002).

The nature of the transactions in single region IO models is identical to that of a larger region with the exception of the necessary distinction between foreign imports and imports from other parts of the country. This model does not evaluate the impacts of transactions between regions and the feedback effect. This limitation can be rectified by using a multi-regional IO (MRIO) model or an inter-regional IO (IRIO) model.

In the MRIO models, regions within a country (or state) are represented by their respective technology and production patterns. They are not, however, allowed to trade among themselves. The MRIO model, as developed by Leontief and Strout in 1963, does not distinguish commodities by region. Instead, a region's outputs are defined as a combination of outputs from its economic activities. The flow of outputs between regions is pooled so that an individual commodity's region of origin cannot be determined and there is a resulting inability to determine the feedback effect and inter-regional flows using this model. While MRIO models are less data-intensive and, therefore easier to build, they are limited by the fact that the entire inter-regional flow and the feedback effect of the transactions between regions is not captured. This is because the MRIO model does not have a matrix to analyze trade between regions.

The IRIO framework accounts for a region's ability to not only produce goods and services, but also to trade with each other regions in a reciprocal manner. Thus, a three regional IRIO model will contain nine different sets of coefficients. The IRIO requires detailed information on the trade flows among various regions; the size of the model increases almost exponentially as more regions are added.

3. Closed versus Open Input-Output Model Systems

An IO model can be solved with or without endogenizing (i.e. adding an additional row and column in the multiplier matrix) a selected final demand agency. There are two conventionally used methods to solve this model. In the first, no agent is endogenized; in the second the consumers' figures are endogenized. The first model is called an "open" model. The only economic impacts captured are those that result from the purchase of goods and services by various industries. The multipliers are called *Type I multipliers*.

If personal incomes and household expenditures are endogenized, the model becomes “closed” with respect to households. As workers’ incomes increase, their expenditures increase as well affecting the various goods and service producing sectors. The resulting economic impacts are called *Type II Impacts* and include both Type I and “induced” impacts.

7.3.6 Mathematics of Economic Impact Analysis

The mathematics of economic impact analysis are summarized in Appendix IO-1.

7.3.7 Economic Impact Analysis in a Regional Setting

When a sectoral change occurs in an economy, two distinct types of impacts can be identified: *Direct Impacts* and *Secondary Impacts*. *Direct Impacts* are defined as those impacts experienced by the goods-producing sector itself resulting from the project or decision in question. If, for example, water usage for irrigation is reduced, the irrigation-production sector is identified as the Direct Impact sector.

Secondary Impacts are generated by Direct Impacts; they are the “economic ripples” created by a change in the economy. Since these impacts are felt by sectors other than those experiencing the direct impact, secondary impacts are called *economic externalities*. Externalities are defined as those effects experienced by a (third) party resulting from the decision of another party.

Whatever the cause associated with a Direct Impact may be, there will usually be Secondary Impacts created. Exceptions occur when, for example, the change results in capital being spent solely outside the region. Secondary Impacts are generated through two types of linkages: (1) backward linkages, and (2) forward linkages. *Backward linkages* occur when an industry experiencing a direct change adjusts its purchases of raw material from other industries as well as its investment in primary resources (such as land, labor and capital).

If, for example, irrigation levels are altered, a number of linkages become readily apparent. If water availability decreases, irrigators would be forced to decrease the size of their irrigated land. The resulting reduction in crop yield would impact negatively on the farmers’ net revenue and ability to purchase inputs. This would affect inputs such as fertilizer and chemical dealers, machinery and equipment dealers, and the transportation industry. The industries that suffer as a result of small volume of business required by the irrigators are feeling the effects of backward linkages.

These backward-linked impacts can be divided into two types. The first encompasses those impacted by the lower or higher levels of goods and services purchased by the directly impacted sector. The second impact is seen in the payment of wages, salary and other personal income(s) generated by the directly impacted and backward-linked sectors. One example of a Direct Impact is the hiring workers to facilitate additional economic activity. These workers receive wages and other remuneration for their services while firms make profits which are then distributed to owners of resources. These individuals then spend this additional money on consumer goods. This produces an increased demand for consumer goods which, in turn, forces industries to increase production to meet the demand for additional goods. Both industrial and consumer demand affects the total impact of a direct change on any sector of an economy. This is the essence of input-output analysis.

Forward linkages include economic transactions whereby an industry sells its products to another industry which, through further processing, will add value the product. This type of linkage occurs between the irrigation and livestock industries. If the irrigation farmers reduce the production of forages, they impact the size of the livestock herd maintained on these farms (as well as on neighboring farms). These reductions impact, for example, the livestock slaughtering and meat-processing industries as both rely on livestock as their major input. These industries, in turn, affect other inputs as they reduce their purchases related to the production of meat and meat products; the linked industries would include packaging material, machinery and equipment, etc. Thus, the livestock-slaughtering industry is linked in a forward manner with the irrigated agriculture industry. A schematic of the total economic impacts of a water reallocation is shown in Figure 7.5. In summary, the total economic impacts of an alteration in water allocation would be derived from a sum of the following five components:

(1) Direct impacts;
(2) Indirect impact from backward-linked industries;
(3) Indirect impacts from forward-linked impacts;
(4) Induced impacts through backward-linked industries; and
(5) Induced impacts from forward-linked industries.

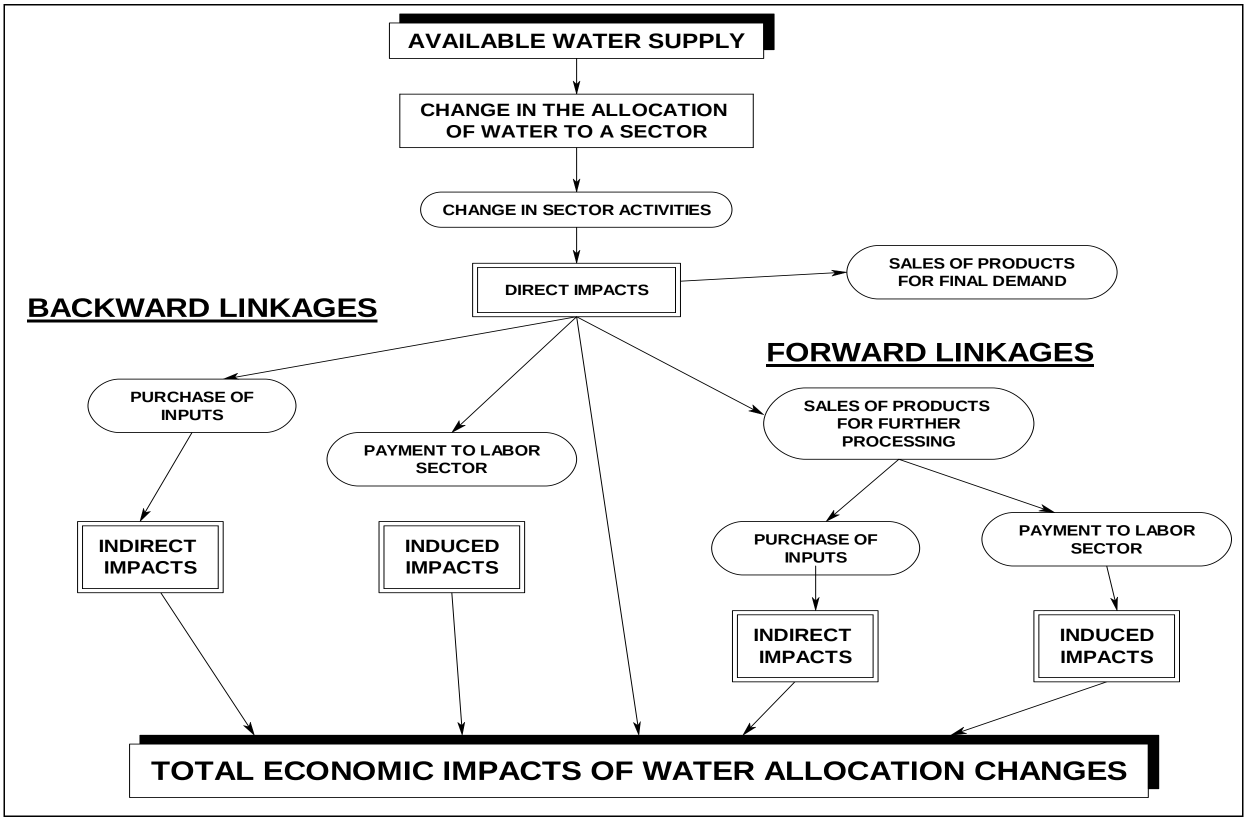


Figure 7.5 *The Total Economic Impacts of a Water Reallocation*

As noted above, the fundamental premise of IO analysis is that the level of goods and services produced by a sector in a region is determined by the total purchases by the users of that good or service. The analysis is as such “demand-driven”. The production sectors will respond positively to changes in the final demand sectors. This analysis assumes that there are no capacity constraints for any production sector; if demand exists, supply will follow.

7.3.8 Limitations of Input-Output Model Based Economic Impact Analysis

Since IO models are based on a specific set of assumptions, they are not without limitations. The following limitations are noteworthy:

(1) The technology matrix coefficients and market share coefficients remain fixed during the period of analysis. No structural change is allowed in this model. For short to medium terms (up to a period of five years) this analysis has proven to be reasonably accurate. Any forecasts using this model beyond the five year period requires it be updated to a different base year.

(2) The model assumes constant consumption and import levels for the period of analysis or forecast. If consumption functions change, or if the sources of supply undergo major modifications, the model must be updated. The introduction of new industries, the closing of existing relevant industries, and other factors affecting the structure of the regional economy would also require an update of the model.

(3) The analysis assumes that no capacity or labour constraints exist in any sector of the economy. This assumption requires that an assessment of supply constraints from external methods be made.

(4) It is also assumed that all sectors in the region adjust to the new situation almost instantly. No time lag for adjustment is accounted for. As final demand changes, the output of various sectors responds instantly. The same pattern applies to changes in the expenditure patterns of consumers. In other words, no lags in investment, production, or consumption exist in the region.

(5) The effects of investment and government activity are treated exogenously. If a scenario is associated with a new investment or government activity it must be combined and analyzed as a single scenario. Since most of the connections are typically not commonly encountered, this limitation remains somewhat obscure.

(6) All IO models require a large quantity of primary data needs, and are very expensive to build.

7.3.9 Summary

In summary, an Economic Impact Analysis of regions can be undertaken using a variety of input-output models. The core of each model is its accounting system bifurcation: square versus rectangular. Once an input-output model has been chosen it is necessary to make a determination as to whether the model will be based on multi-regional (MRIO) or inter-regional (IRIO) analysis. It is then necessary to decide whether the model will be “open” or “closed.” Many of these questions are resolved in light of the objective of the analysis. The construction of an appropriate input-output model for the SSRB using this information is described in the following chapter.

7.4 Methodology of Estimation for the Study Model

A study model was developed by Kulshreshtha and Thompson in 2004 to show economic transactions, employment and water use in the SSRB. It was given an acronym SSRBIEW: the **S**outh **S**askatchewan **R**iver **B**asin (**A**lberta and **S**askatchewan) **I**nput-Output, **E**mployment and **W**ater Use Model. The specification details, construction and manipulation of the transaction tables and procedures for disaggregating the agricultural and manufactured sectors for both Saskatchewan and Alberta, the trade flows and estimation of the propensity to spend are all laid out in Appendix IO-2. Appendix IO-2 also sets out the final specification of the SSRBIEW model, listing the study sectors and commodities in the study model, and discussing the estimation of the regional models.

7.5 Methodology for the Development of Resource Use Modules

As noted earlier, the production of goods and services requires the employment of hired workers and self-employed operators (as well as the procurement of various intermediate goods). Natural resources, including water, fuel and lubrication, energy, and others are also used in the production processes. Any change in the final demand for a commodity alters the production level for the sector producing goods and services, and affects the resource uses in other sectors through backward linkages. For the SSRBIEW model, the task of estimating employment and water usage by various sectors, functioning under differing scenarios, is extremely important. The procedures followed to arrive at these estimates are described here.

7.5.1 Development of the Employment Model

The employment module contained the employment coefficient is based on Leontief employment function. The ratio consists of the employment statistics in a sector divided by the total sales (output) of that sector and is expressed in terms of number of workers per thousand dollars worth of output in the sector, shown in equation (5.1).

$$\begin{array}{l} \textit{Employment} \\ \textit{Coefficient for} \\ \textit{Sector } j \end{array} = \frac{\textit{Number of Workers in Sector } j}{\textit{Value of Output in Sector } j} \; X \; (1000) \qquad (5.1)$$

These coefficients were estimated for the entire province, since regional output levels were not available. The employment data for various sectors was obtained from Statistics Canada (2003c). These coefficients are presented in Table 7.1 for Saskatchewan, and in Table 7.2 for Alberta. In some sectors there was no detailed data available. In these circumstances, similar coefficients were used: notable examples are the mining sector and the petroleum and natural gas sector. Data was not available for many public and dummy sectors. Again, similar coefficients were used.

7.5.2 Development of Water Use Coefficients

7.5.2.1 Concept of Water Use

Water use is a broad term encompassing the requirements of a wide variety of production systems that use water. In reality there are a number of methods employed to measure water usage. Some commonly used terms include: water requirements, water withdrawal, water consumed, water demand, water re-circulated, and water discharged. Water use is therefore, relatively speaking, a confusing term. In an attempt to provide clarity the following is a discussion of key terms (based on Kulshrestha *et al*., 1988).

Table 7.1 *Estimated Employment Coefficients for Saskatchewan, by Sectors, 1999*

Sector #	**Sector Description**	**Worker Employment per $1,000 Output**
1	Grain Farms	0.0119
2	Irrigation Farms	0.0050
3	Dairy Cattle Farms	0.0078
4	Beef Cattle Farms	0.0113
5	Hog Farms	0.0055
6	Poultry Farms	0.0048
7	Livestock Combination Farms	0.0214
8	Miscellaneous Products Farms	0.0047
9	Non-Commercial Farms	0.0445
10	Forestry and Logging	0.0033
11	Fishing, Hunting and Trapping	0.0460
12	Support Activities for Agriculture and Forestry	0.0466
13	Mining and Oil and Gas Extraction	0.0020
14	Utilities	0.0041
15	Construction	0.0057
16	Animal Food Manufacturing	0.0046
17	Grain and Oilseed Milling Manufacturing	0.0013
18	Sugar and Confectionery Product Manufacturing	0.0016
19	Fruit and Vegetable Preserving & Specialty Food Manufacturing	0.0016
20	Dairy Product Manufacturing	0.0061
21	Meat Product Manufacturing	0.0055
22	Seafood Product Preparation and Packaging Manufacturing	0.0019
23	Bakeries and Tortilla Manufacturing	0.0104
24	Other Food Manufacturing	0.0050
25	Beverage Manufacturing	0.0047
26	Tobacco Manufacturing	0.0000
27	Textile Mills Manufacturing	0.0038
28	Textile Product Mills Manufacturing	0.0018
29	Clothing Manufacturing	0.0203
30	Leather and Allied Product Manufacturing	0.0009
31	Wood Product Manufacturing	0.0065
32	Paper Manufacturing	0.0034
33	Printing and Related Support Activities	0.0141
34	Petroleum and Coal Products Manufacturing	0.0053
35	Chemical Manufacturing	0.0026
36	Plastics and Rubber Products Manufacturing	0.0080
37	Non-Metallic Minerals Manufacturing	0.0087
38	Primary Metal Manufacturing	0.0258
39	Fabricated Metal Product Manufacturing	0.0094
40	Machinery Manufacturing	0.0084
41	Computer and Electronic Product Manufacturing	0.0083
42	Electrical Equipment, Appliance and Component Manufacturing	0.0013
43	Transportation Equipment Manufacturing	0.0072
44	Furniture and Related Product Manufacturing	0.0198

Table 7.1, Cont.		
Sector #	**Sector Description**	**Worker Employment per $1,000 Output**
45	Miscellaneous Manufacturing	0.0012
46	Wholesale Trade	0.0072
47	Retail Trade	0.0234
48	Transportation and Warehousing	0.0089
49	Information and Cultural Industries	0.0095
50	Finance, Insurance, Real Estate and Renting and Leasing	0.0028
51	Professional, Scientific and Technical Services	0.0169
52	Administrative and Other Support Services	0.0352
53	Educational Services	0.5628
54	Health Care and Social Services	0.0731
55	Arts, Entertainment and Recreation	0.0355
56	Accommodation and Food Services	0.0261
57	Other Services (except Public Administration)	0.0390
58	Operating, Office, Cafeteria and Laboratory Supplies	0.0390
59	Travel and Entertainment, Advertising and Promotion	0.0390
60	Transportation Margins	0.0390
61	Non-Profit Institutions Serving Households	0.0390
62	Government Sector	0.0042

Table 7.2 *Estimated Employment Coefficients for Alberta, 1999, by Sectors*

Sector #	**Sector Description**	**Worker Employment per $1,000 Output**
1	Grain Farms	0.0149
2	Irrigation Farms	0.0041
3	Dairy Cattle Farms	0.0066
4	Beef Cattle Farms	0.0083
5	Hog Farms	0.0050
6	Poultry Farms	0.0052
7	Livestock Combination Farms	0.0259
8	Miscellaneous Products Farms	0.0030
9	Non-Commercial Farms	0.1443
10	Forestry and Logging	0.0050
11	Fishing, Hunting and Trapping	0.0450
12	Support Activities for Agriculture and Forestry	0.0270
13	Mining and Oil and Gas Extraction	0.0026
14	Utilities	0.0040
15	Construction	0.0058
16	Animal Food Manufacturing	0.0026
17	Grain and Oilseed Milling Manufacturing	0.0011
18	Sugar and Confectionery Product Manufacturing	0.0073
19	Fruit and Vegetable Preserving and Specialty Food Manufacturing	0.0118
20	Dairy Product Manufacturing	0.0109

Table 7.2 Cont.		
Sector #	**Description**	**Worker Employment per $1,000 of Output**
21	Meat Product Manufacturing	0.0021
22	Seafood Product Preparation and Packaging Manufacturing	0.0066
23	Bakeries and Tortilla Manufacturing	0.0028
24	Other Food Manufacturing	0.0124
25	Beverage Manufacturing	0.0000
26	Tobacco Manufacturing	0.0000
27	Textile Mills Manufacturing	0.0658
28	Textile Product Mills Manufacturing	0.0244
29	Clothing Manufacturing	0.0035
30	Leather and Allied Product Manufacturing	0.0022
31	Wood Product Manufacturing	0.0046
32	Paper Manufacturing	0.0030
33	Printing and Related Support Activities	0.0106
34	Petroleum and Coal Products Manufacturing	0.0008
35	Chemical Manufacturing	0.0013
36	Plastics and Rubber Products Manufacturing	0.0075
37	Non-Metallic Minerals Manufacturing	0.0057
38	Primary Metal Manufacturing	0.0037
39	Fabricated Metal Product Manufacturing	0.0090
40	Machinery Manufacturing	0.0058
41	Computer and Electronic Product Manufacturing	0.0031
42	Electrical Equipment, Appliance and Component Manufacturing	0.0146
43	Transportation Equipment Manufacturing	0.0121
44	Furniture and Related Product Manufacturing	0.0120
45	Miscellaneous Manufacturing	0.0154
46	Wholesale Trade	0.0080
47	Retail Trade	0.0227
48	Transportation and Warehousing	0.0084
49	Information and Cultural Industries	0.0082
50	Finance, Insurance, Real Estate and Renting and Leasing	0.0021
51	Professional, Scientific and Technical Services	0.0145
52	Administrative and Other Support Services	0.0221
53	Educational Services	0.3198
54	Health Care and Social Services	0.0534
55	Arts, Entertainment and Recreation	0.0266
56	Accommodation and Food Services	0.0209
57	Other Services (except Public Administration)	0.0317
58	Operating, Office, Cafeteria and Laboratory Supplies	0.0317
59	Travel and Entertainment, Advertising and Promotion	0.0317
60	Transportation Margins	0.0317
61	Non-Profit Institutions Serving Households	0.0317
62	Government Sector	0.0037

Water Use: A broad term, simply referring to the utilization of water in association with any activity – economic or otherwise. Utilization may take alternative shapes: it could be withdrawal, consumption or *in situ* water use.

Water Withdrawal or Intake: This refers to the amount of water that is physically removed from a source and transferred to another location to satisfy a certain anthropogenic activity.

Water Requirements: This is the quantity of water needed to sustain a given economic, biological, or ecological activity. Requirement estimates are based on either observation or scientific methods. Requirements differ from water intake, since a part of the requirements may be satisfied by such withdrawals. Similarly water intake may also be at a higher level than is required to sustain the process in question.

Water Consumption: This is the quantity of water lost during the production process. It is typically measured as the difference between the water withdrawal and water returned (discharged) to a source.

Water Demand: Water demand is an economic concept. It is the breakdown of water quantities obtained by a given consumer at various sets of prices. The price of water is a key component in to the measure of water demand. Since, in many situations, water is an un-priced good, water demand estimation is replete with problems. Cost to the user could be construed as a proxy for water, which often requires primary data collection.

Water Re-circulation: This is the amount of water that is used more than once in the same economic activity. The amount of recirculation is often taken as a proxy for water conservation; however, the processes associated with this kind of usage are very much dependent on technology.

Water Discharged: This is the amount of water that is returned to some ambient source of water for use by other potential users, including in-situ users. The quality of water is totally disregarded in these figures. Part of this discharge may be leaching to the groundwater sources, while some water may be returned to the surface water bodies.

While each of the concepts outlined above is important, water withdrawal is the focus of this study model. It is withdrawal water use that is the most relevant concept in water allocation decisions. Although net water use (Total intake minus water discharged) may be a better water management tool, it is used very seldom for two reasons:

(1) Amount of discharge water is too complex to measure, since some of this may be through seepage.

(2) Discharge may occur at a location where water may not be a constraint--this does not aid water managers attempts at making appropriate water allocation decisions.

Details of the methods used to calculate water intake employed in this study are presented below.

7.5.2.2 Source of Data for Estimation

Ideally the estimation of water use coefficients would include primary data collection on two aspects of the economy: value of production by various industries in the SSRB, and the amount of water intake (withdrawn) from source. This technique was beyond the resources available for this project and alternative sources of data were secured.

The only set of data that was available referenced Canada as a whole. Using personal contacts, water use data was obtained for a number of industries from Statistics Canada (2004). Data on gross domestic product for various industries at the Canadian level was obtained from Statistics Canada (CANSIM Table 379-001).

7.5.3 Method of Estimation

Agricultural Sectors: Provincial-level data was used to estimate the water use coefficients for the nine agricultural production sectors in the Basin. Data on water use for various enterprises was obtained from Kulshreshtha, Sobool and Grant (2004). For livestock farms, these coefficients were multiplied by the number of head (in livestock and poultry) inventoried July 1, 2000 for each province. Dividing the cash farm receipts from those enterprises, coefficients were converted on a per thousand dollar worth of output (sales). Water use (per acre) for irrigation was obtained from the same source. The value of production for irrigated areas in Saskatchewan was obtained from Kulshreshtha and Russell (1995) and was adjusted to reflect the value of production in 2000. For Alberta, these values were obtained from Irrigation Water Management Study Committee (2002). These coefficients are shown in Table 7.3.

Non-Agricultural Sectors: For the non-agricultural sectors, water use data and gross domestic product data for various industries were used to create a GDP water use coefficient (per $1,000 units). The next step involved using the provincial input-output transactions tables and estimating a ratio of GDP to output. Multiplying the previously estimated coefficient by the ratio yielded the water use coefficients per $1,000 worth to sales (output) of the industry.

Since the number of industries included in the above calculation was 167, these were aggregated to suit the classification used for the SSRBIEW model. These coefficients are presented in Table 7.3.

Table 7.3 *Estimated Water Use (Intake) Coefficients for Saskatchewan and Alberta, by Sectors, SSRBIEW Model in dam^3 per Thousand Dollar Output*

Sector #	Sector Description	Saskatchewan	Alberta
1	Grain Farms	0.000991	0.000991
2	Irrigation Farms	5.673416	2.972064
3	Dairy Cattle Farms	0.008352	0.008186
4	Beef Cattle Farms	0.013834	0.008010
5	Hog Farms	0.009382	0.007400
6	Poultry Farms	0.003571	0.003793
7	Livestock Combination Farms	0.011608	0.007705
8	Miscellaneous Products Farms	0.000991	0.000991
9	Non-Commercial Farms	0.013834	0.008010
10	Forestry and Logging	0.000300	0.000320
11	Fishing, Hunting and Trapping	0.000000	0.000000
12	Support Activities for Agriculture and Forestry	0.001290	0.000971
13	Mining and Oil and Gas Extraction	0.015815	0.018162
14	Utilities	0.353576	0.369100
15	Construction	0.183424	0.208013
16	Animal Food Manufacturing	0.001722	0.000211
17	Grain and Oilseed Milling Manufacturing	0.007933	0.007933
18	Sugar and Confectionery Product Manufacturing	0.035343	0.042231
19	Fruit & Vegt. Preserving, Specialty Food Manu.	0.008133	0.007412
20	Dairy Product Manufacturing	0.002139	0.000003
21	Meat Product Manufacturing	0.002281	0.002311
22	Seafood Product Preparation and Packaging Manufacturing	0.052640	0.036543
23	Bakeries and Tortilla Manufacturing	0.000000	0.001737
24	Other Food Manufacturing	0.000000	0.004808
25	Beverage Manufacturing	0.012906	0.011592
26	Tobacco Manufacturing	0.000000	0.000000
27	Textile Mills Manufacturing	0.028047	0.018641
28	Textile Product Mills Manufacturing	0.028047	0.018641
29	Clothing Manufacturing	0.001425	0.001829
30	Leather and Allied Product Manufacturing	0.002918	0.000704
31	Wood Product Manufacturing	0.002814	0.002754
32	Paper Manufacturing	0.128353	0.144606
33	Printing and Related Support Activities	0.000435	0.000857
34	Petroleum and Coal Products Manufacturing	0.013156	0.013156
35	Chemical Manufacturing	0.046191	0.046470
36	Plastics and Rubber Products Manufacturing	0.001789	0.000891
37	Non-Metallic Minerals Manufacturing	0.008482	0.016103
38	Primary Metal Manufacturing	0.027655	0.036842
39	Fabricated Metal Product Manufacturing	0.001891	0.002432
40	Machinery Manufacturing	0.000984	0.001993

Sector #	Sector Description	Saskatchewan	Alberta
41	Computer and Electronic Product Manufacturing	0.003009	0.001935
42	Electrical Equipment, Appliance and Component Manufacturing	0.001088	0.000699
41	Computer and Electronic Product Manufacturing	0.003009	0.001935
42	Electrical Equipment, Appliance and Component Manufacturing	0.001088	0.000699
43	Transportation Equipment Manufacturing	0.001198	0.001722
44	Furniture and Related Product Manufacturing	0.001189	0.000824
45	Miscellaneous Manufacturing	0.000989	0.001052
46	Wholesale Trade	0.000593	0.000646
47	Retail Trade	0.002462	0.002579
48	Transportation and Warehousing	0.000479	0.000458
49	Information and Cultural Industries	0.000199	0.000207
50	Finance, Insurance, Real Estate and Renting and Leasing	0.000285	0.000312
51	Professional, Scientific and Technical Services	0.000654	0.000624
52	Administrative and Other Support Services	0.000868	0.000816
53	Educational Services	0.000106	0.000119
54	Health Care and Social Services	0.002329	0.002259
55	Arts, Entertainment and Recreation	0.005164	0.005601
56	Accommodation and Food Services	0.004819	0.005121
57	Other Services (except Public Administration)	0.007160	0.007337
58	Operating, Office, Cafeteria and Laboratory Supplies	0.000000	0.000000
59	Travel and Entertainment, Advertising and Promotion	0.000000	0.000000
60	Transportation Margins	0.000000	0.000000
61	Non-Profit Institutions Serving Households	0.000984	0.000935
62	Government Sector	0.004293	0.004055

7.6 Economic Impact Analyzer

Once all the data matrices have been constructed, it is possible to create an economic impact assessment framework. Construction of the framework involves the creation of several transformed matrices,-similar to those discussed in Section 7.3. This was accomplished through the development of the 'Economic Impact Analyzer' program. This program performs all necessary calculations and presents the results of the impact in a report form. The development of this Impact Analyzer program is described here. Section 7.8 describes the application of this model to a hypothetical scenario, and includes a results table.

7.6.1 Development of the Impact Analyzer Program

The Impact Analyzer Program is the mathematical solver component of the IO impact methodology for estimating the impacts of a given set of changes in the SSRBIEW model's regional economy. All values in the model are dollar values relative to the units used in the input matrix. All transactions are recorded in $1,000 units, based on dollar values in 1999. The program is made up of a set of macros that are designed to invert the coefficients matrix allowing them to be used in the impact assessment. This requires several steps:

1. Using the use matrix data, per unit requirements of various commodities were calculated. The resulting matrix was called "B-Mat". This matrix reflected producer's prices, and did not require any adjustment for margins.

2. Market shares of various sectors in the production of each commodity were estimated using the "make" matrix for the region. These results were called "D-Mat".

3. Using the "B-Mat," the proportion of a commodity that was supplied from imports (from other parts of Alberta, Canada or internationally) were netted out.

4. Other leakages (including inventory adjustments, and government sales) were also netted out from various sectors' commodity requirements. The resulting matrix, called "Adjusted B-Mat" (B*), was represented in terms of producers prices and reflected local purchases of commodities.

5. The D-Mat was multiplied by the adjusted B-Mat to produce a sector-by-sector coefficient matrix which reflected the technology of production for each sector.

6. The resulting matrix was used to generate an inverted matrix [$(I\text{-}DB^*)^{-1}$]. This matrix is the final demand multiplier matrix for each sector.

7. The primary input requirements for each sector along with the multiplier matrix in Step 6 were used to create impact of a change in final demand on various value-added items in the economy.

8. The employment coefficients and water use coefficients, along with the multiplier matrix, were used to create an "impact of a change in final demand" on the level of employment and water use (intake) for the regional economy.

The program was developed separately for each province and then regionalized for the SSRB region. The Saskatchewan impact program can, therefore, be run to estimate the impacts of a scenario for the SSRB region or for the province as a whole. This also applies to the Alberta model. In addition, the Impact Analyzer Program is able to combine the results of the two provinces to produce results for the entire Basin.

7.6.2 Preparation of Scenarios

When consumers or business concerns purchase a commodity, they pay for the various services associated with it as well as the payment to producers. The differences between the purchaser's prices and the producer's prices are called margins. There are seven margins that generated by the purchase of a commodity. These margins must be netted out in order to prepare a scenario and to allocate to goods producing sectors, as shown in Table 7.4**.** Each margin is collected by the sector that provides the service. The retail margins are allocated to the Retail Trade sector; similarly, the wholesale margin is allocated to the Wholesale Trade sector.

	Margin No.	**Margin**	**Sector No.**	**Sector Description**
	1	Retail margin	47	Retail Trade
	2	Wholesale margin	46	Wholesale Trade
	3	Tax margin	*	Indirect Tax
	4	Transportation margin	60	Transportation Margins
	5	Pipeline margin	60	Transportation Margins
	6	Storage Margin	48	Transportation and Warehousing
	7	Gas margin	60	Transportation Margins

* Primary resource sector

Table 7.4 *Margins in Purchases Prices and their Allocation to Various Economic Sectors*

The Impact Analyzer Program includes the algorithms necessary to make these calculations and allocate margins to appropriate sectors. The program contains tables for both the sets of margins for inputs, as well as for final demand commodities.

7.6.3 Features of the SSRBIEW Model

The SSRBIEW model is designed to provide impact analysis for a number of unique situations, some of which are listed below:

(1) The model is capable of estimating the impact of changes to either the "final demand" for a product (i.e. a change in consumer expenditures, government current expenditures, government investment expenditure, business expenditures, or exports) and /or changes in the level of output for a sector.

(2) Any sector that an analyst decides should not be affected by a given scenario can be exogenized. Once a sector is exogenized, its output is fixed at the pre-scenario level and will not undergo any further changes.

(3) The program provides flexibility in the nature of direct impacts. At the present it has the following choices:

> (i) Final (or intermediate) demand in commodity format in purchaser's prices and total purchases (Local plus imports). The program will remove imports from the scenario and convert the purchases into producers' prices.

(ii) Final (or intermediate) demand in commodity format in purchaser's prices for local purchases only. The program will remove the margins and convert the purchaser's prices into producers' prices.

(iii) Final (or intermediate) demand in commodity format in producers' prices and total requirements (purchases). The program will not remove the imports from the scenario.

(iv) Final (or intermediate) demand in commodity format in producer's prices in local purchases. The program will not make any adjustments in the transactions.

7.6.4 Types of Impacts Generated from the SSRBIEW Model

The SSRBIEW model is capable of generating figures relating to two types of economic impacts generated by an economic development activity:

(1) Type I economic impacts include direct and indirect changes (through the sale of goods and services to the direct impact sector) in various sectors of the economy. In this model household income is exogenous, it is not assumed to be spent within the economy instantaneously.

(2) Type II economic impacts include direct, indirect and induced effects from the economic activity. This model assumes that household earnings (wages, salaries and other sources of income) are spent concurrently within the economy. It is possible to make the argument that this model is misleading based on the fact that consumer purchases are not made instantaneously. This feature is not included in the model at this time but can be added if desired.

The procedure for producing an estimate of the indirect and induced effects of a single economic development activity, as well as forward-linked effects, is as follows. To yield indirect impacts, deduct from Type I economic impacts estimated direct impacts. Similarly, to obtain induced impacts, deduct Type I impacts from the Type II impacts. In order to estimate forward-linked effects the model is run twice. Once for the sector that has forward links, and the second time for the forward linked sector. However, in running the second part of this scenario, all inputs purchased from the first sector must be eliminated to avoid double counting.

7.7 Economic Baseline of the South Saskatchewan River Basin

The transactions table for the SSRBIEW model can be used to develop a regional economic profile of the SSRB region in Saskatchewan and Alberta. This chapter presents this profile.

7.7.1 Method of Estimation

The following methodologies were employed to represent the regional economy of the SSRB. Identical procedures were undertaken for the two provinces in the creation of the Regional Basin Economy.

(1) The 1990 balanced transactions table (Matrix "*DB*") was the staring point for this analysis.
(2) It was assumed that, other than trade flows and sources of region's requirements for various industries and final demand agencies, technology of production for various sectors in the SSRB is identical to that of the province.

(3) Employment data for various sectors within the provinces and the SSRB region was obtained from Statistics Canada.
(4) The proportion of output in the SSRB was estimated using the proportion of employment for given industries in the Basin. Please note that this assumes identical labor productivity for the SSRB and its surrounding region.
(5) The ratio of gross domestic product to output was estimated for various sectors using table in step (1).
(6) Using the ration estimated in step (5) and multiplying it by the level of output, gross domestic product of the region was estimated.

These models provide estimates of three economic indicators for each of the 62 sectors: Output (Value of sales), Gross Domestic Product, and Employment.

7.7.2 Overview of the Basin Economy: Output

The SSRB consists of two distinct political parts as it is located within the boundaries of both Saskatchewan and Alberta. These distinct political parts have serious implications for impact analyses related to water resources.

The SSRB region industries produce almost $141 billion worth of economic goods and services, measured in terms of the value of sales made by various industries. These sales could be to other industries or to final demand agencies. As Table 7.5 illustrates, the Alberta portion of the SSRB region is dominant with over four-fifths of the industrial sales taking place within its borders. The other feature of this region is the service and "other tertiary industries" dominance of the production scene. These industries contribute almost two-thirds of the total value of sales in the entire basin. Primary industries (including agriculture) contribute roughly 19% of the total industrial sales.

Nature of Production Industries in the South Saskatchewan River Basin, in Thousand Dollars

Type of Production	SSRB Basin in		Total Basin
	Sask.	Alberta	
Primary	4,182	22,215	26,396
Secondary	3,031	19,357	22,388
Tertiary	16,105	76,089	92,194
Total	23,318	117,661	140,979

Source: Estimated transactions table for the SSRB (Alberta and Saskatchewan)

Table 7.5 *Value of Production by Industry Type in the SSRB*

The Basin generates a large amount of economic activity in the two provinces. Its share for the province of Alberta is 37.9% of the total provincial activity; in Saskatchewan the total is 40.4%. These proportions are based on employment share in the SSRB regions in the two provinces.

7.7.3 Generation of Value Added by the Region

All the economic activities in the region produce some gross domestic product. In fact, the economic growth of the region is typically measured as the new wealth created, one measure of which is the gross domestic product (GDP). Total GDP generated in the SSRB region is estimated at $68.9 billion (almost half of the gross production – actually 48.9% of the total value of output).

The distribution of GDP in the SSRB (Saskatchewan and Alberta combined) is shown in Figure 7.6. Service industries still top of the list of contributions to the economic wealth of the region. After the Service sector, descending order are the industry groups such as Other Primary Products (18% of the total), Government sector and Trade sector (at 10% each of the total) and Other Manufacturing industries (at 6% of the total).

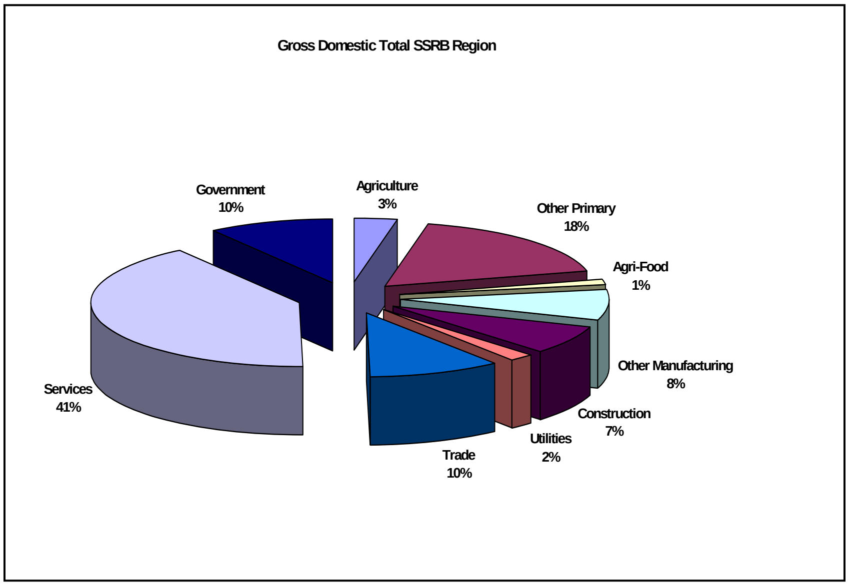


Figure 7.6 *Distribution of Gross Domestic Product by Sectors, SSRB Region*

7.7.4 Employment in the SSRB Region

The region employs slightly over one million workers (1,095,182). As the economic activity figures suggest, over 80% of the workers are stationed in the province of Alberta. The Saskatchewan portion of the SSRB contains 214,814 workers. Despite differences in the level of economic activity and workforce size, there are very few discernible differences between the Alberta and Saskatchewan portions of the SSRB. Service industries employ over half of the workforce in both the regions.

One significant difference between the regions is the fact that 6% Saskatchewan's total workforce is employed by the Provincial government, as compared to 3% in Alberta. In Saskatchewan, the agriculture sector employs a higher proportion of workers (at 9% of the total) against only 4% in the Alberta portion of the SSRB. In addition, primary industries other than agriculture make up a slightly larger share of employment totals in Alberta than in Saskatchewan. This larger number may be attributed to the oil and gas industry, a large employer in Alberta.

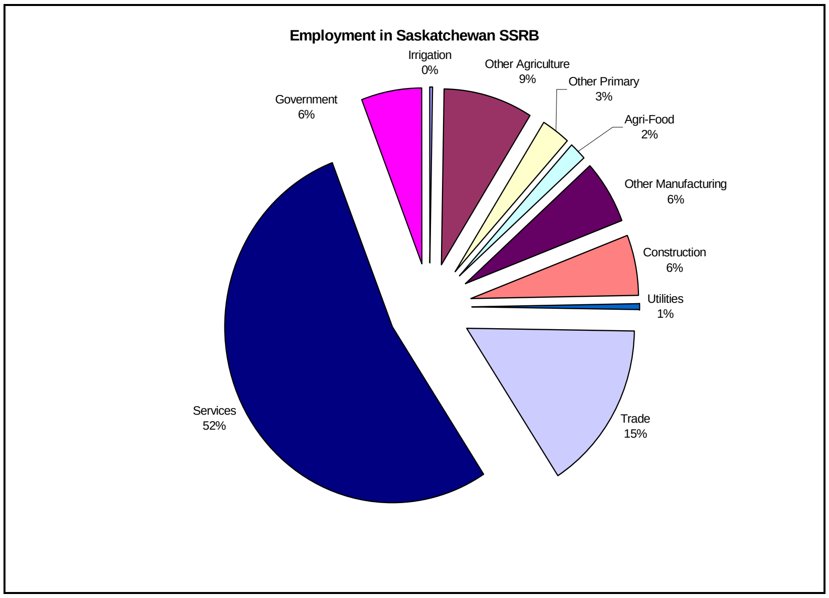


Figure 7.7 *Employment in Saskatchewan SSRB*
(Distribution of Employment by Sectors, Saskatchewan (Top) and Alberta (Bottom))

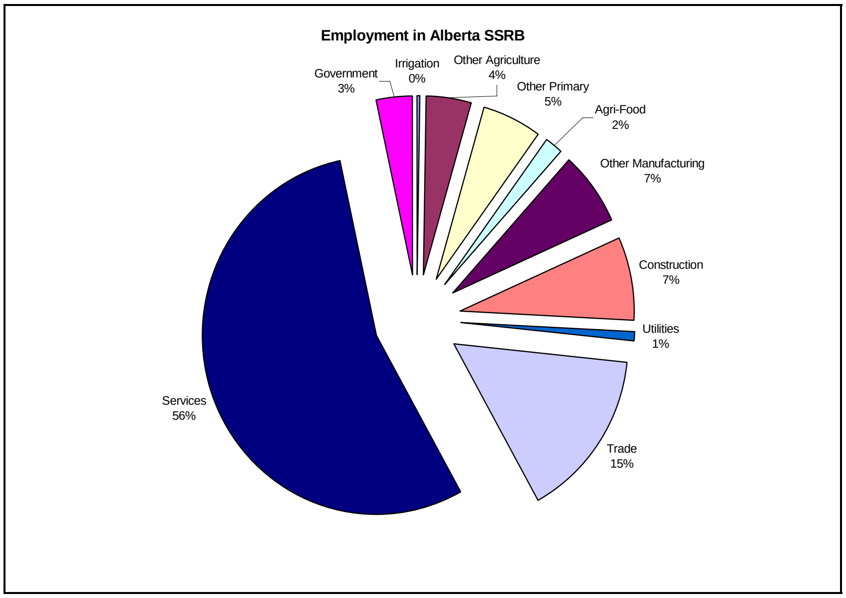


Figure 7.8 Employment in Alberta SSRB
(Distribution of Employment by Sectors, Saskatchewan (Top) and Alberta (Bottom))

The composition of employment in both provinces is described as follows, and reflected in Table 7.6. Overall, the largest employer of workers in the SSRB is the Retail trade sector. The Retail sector is the second leading employer in Saskatchewan with the Health Care and Social Services Sector topping the list. The top five individual employers in both the provincial portions of the SSRB are service industries. Grain farms are the sixth largest employer in Saskatchewan, whereas, in Alberta, agriculture is not a significant employer. In Alberta the Mining and oil gas extraction industry ranks ninth in the province.

7.8 Economic Impact Estimation of a Water Shortage Scenario

This section will describe the ways that the SSRBIEW model can be used to assess the economic impacts of water shortages and related economic phenomenon.

7.8.1 Formulation of a Hypothetical Scenario

It should be noted that this hypothetical scenario, highly speculative in nature, was adopted for this analysis due to its simplicity. The water shortages are assumed to be limited to small regions of the Alberta portion of the SSRB. The total shortage is estimated at 5,000 dam^3. The Water Management Authority of the region decides to reduce the allocation of water for irrigation. All other agricultural enterprises in the region, as well the allocation levels of water for non-agricultural concerns, remain unchanged by this shortage.

South Saskatchewan River Basin		**Saskatchewan SSRB**		**Alberta SSRB**	
Rank	**Sector**	**Rank**	**Sector**	**Rank**	**Sector**
1	47 Retail Trade	1	54 Health Care and Social Services	1	47 Retail Trade
2	54 Health Care and Social Services	2	47 Retail Trade	2	54 Health Care and Social Services
3	56 Accommodation and Food Services	3	53 Educational Services	3	51 Professional, Scientific and Technical Services
4	51 Professional, Scientific and Technical Services	4	56 Accommodation and Food Services	4	56 Accommodation and Food Services
5	15 Construction	5	62 Government Sector	5	15 Construction
6	53 Educational Services	6	1 Grains	6	53 Educational Services
7	48 Transportation and Warehousing	7	15 Construction	7	48 Transportation and Warehousing
8	50 Finance, Insurance, Real Estate and Renting and Leasing	8	48 Transportation and Warehousing	8	50 Finance, Insurance, Real Estate and Renting and Leasing
9	57 Other Services (except Public Administration)	9	57 Other Services (except Public Administration)	9	13 Mining and Oil and Gas Extraction
10	13 Mining and Oil and Gas Extraction	10	50 Finance, Insurance, Real Estate and Renting and Leasing	10	46 Wholesale Trade

Table 7.6 *Ranking of the Ten Top Employing Industries in the SSRB, by Province*

7.8.2 Method of Economic Impact Estimation: Direct Impacts under the Hypothetical Scenario

In order to estimate the regional impacts of the water shortage it is necessary to ascertain the nature of the "direct impacts". This was accomplished in the following manner:

(1) The Water Use coefficient for irrigation was employed to provide an estimate of the total water used in the Alberta portion of the SSRB. Irrigation produced $946.4 million worth of goods and services in the region. Using the water use coefficient of 2.972 dam^3 per $1,000 of output, total water use of 2.81 million dam^3 was estimated.

(2) A shortage of 5,000 dam^3 of water amounted to be 0.18% of the total water use.

(3) Assuming identical water production function for the region in shortage as the rest of the SSRB, it was estimated that $1.682 million worth of goods and services would not be produced on irrigated farms.

(4) Using the Alberta transactions table as an input matrix, the initial set of lost purchases related to this reduction in output was estimated.

(5) Using the Employment coefficient of 0.0041 per $1,000 worth of output, a loss of 6.9 workers was also estimated from this water shortage.
Employing the Economic Impact Analyzer program, this set of information was used to estimate the total economic impacts associated with this scenario.

7.8.3 Estimation of Total Economic Impacts

The Economic Impact Analyzer requires the information related to direct economic impacts and the prices and quantities of commodities associated with the impacts. The nature of process and quantities refer to whether the transactions are in producer's prices or in purchaser's prices. It is important to know whether the quantities are from local supplies or the total requirements.

The estimates of the "direct impacts" reflect the total requirements and are measured in terms of purchaser's prices. The total economic impacts were estimated using the following steps:

(1) The "SSRB Impact Screen" was the starting point for this estimate.

(2) The program includes the option to select 'disenable macros' or 'enable macros'. 'Enable macros' was selected, thereby activating all the macros available for various matrix multiplications and inverses.

(3) The first selection to be made in the opening "Window" is "region." The region "AB99-SSRB" – (SSRB region of Alberta) was selected as it represents the area where the economic impacts would be realized.

(4) All commodities that are not purchased under the scenario are entered against each specific commodity. The list includes 66 intermediate goods, 4 primary goods, 12 different regions of imports (including foreign imports) and other leakages.

(5) The program also requires an estimated total value of output, employment and water use. These are estimated exogenously and then inserted on this window.

(6) After data entries are completed, the model is ready to convert values in the following manner:

(a) Margins are removed since the prices are in purchaser's prices.
(b) Imports are removed from the quantities entered and shown as separate entries.
(c) The Commodities vector is pre-multiplied by the D-matrix to convert into industry space.
(d) The program seeks information on whether any sector needs to be exogenized. Since water shortages in the region may trigger some purchases in other parts of the basin, this sector was not exogenized (its output level was not fixed at the original level).
(e) The "Run Impact" tab is pressed and the estimate of economic impacts proceeds.

Results are now saved in a different file, which can be saved for future reference.

7.8.4 Estimated Total Economic Impacts of Water Shortage

The estimated direct impacts under this imagined scenario represented in a "commodity format" are shown in Table 7.7. The second column represents the inputs. The third column contains various margins which were removed and allocated to appropriate sectors. The last column shows the process by which imports are removed and allocated to the appropriate import source. Table 7.8 shows the same information in a sectoral space. It should be noted that, due to water shortages, these purchases are reduced (and could have been given a negative sign).

The SSRBIEW model is capable to estimating both Type I (Direct plus Indirect) and Type II (Direct, Indirect and Induced) economic impacts, both of which are presented here. Table 7.9 shows the Type I impacts, and Table 7.10 shown the Type II impacts.

If the study is limited to direct and indirect impacts, the total output of the region decreases by \$2.5 million – gross domestic product (GDP) at market prices by \$1.28 million and household income by \$0.29 million. When induced impacts are included the impact is \$4.57 million in output, \$1.48 million for the GDP at market prices, and \$0.4 million is lost through household income. A job loss totaling19 is estimated, 7 of which are in the irrigation sector. Total water use under Type II impacts is estimated at 5,169 dam^3, of which only 169 dam^3 is from other non-irrigated sectors.

7.8.5 Estimation of Value of Water

This set of information can be used to estimate the regional economic development value of water shortages. Income losses are taken as the measure of economic welfare and therefore, the value of water. Results are shown in Table 7.11.

Table 7.7 *Direct Commodity Purchases under Scenario: Irrigation Water Shortage of 5,000 dam^3, Alberta SSRB*

Commodities	Initial Demand Vector	Initial & Margins Removed	Margins & Imports Removed
1 Oilseeds and Grains	153.4	120.2	109.6
2 Vegetable and Melon, Fruit and Tree Nut, Greenhouse	0.0	0.0	0.0
3 Hay Farming	6.7	6.2	1.2
4 Other Crop	0.0	0.0	0.0
5 Cattle	135.4	124.3	103.5
6 Dairy	0.0	0.0	0.0
7 Hog	0.0	0.0	0.0
8 Poultry	0.0	0.0	0.0
9 Sheep	0.0	0.0	0.0
10 Other agricultural products	0.0	0.0	0.0
11 Forestry products	0.0	0.0	0.0
12 Fish, seafood and trapping products	0.0	0.0	0.0
13 Metal ores & concentrates	0.0	0.0	0.0
14 Mineral fuels	0.0	0.0	0.0
15 Non-metallic minerals	0.0	0.0	0.0
16 Services incidental to mining	0.0	0.0	0.0
17 Dairy Products	0.0	0.0	0.0
18 Meat Products	0.0	0.0	0.0
19 Seafood Products	0.0	0.0	0.0
20 Animal Food Manufacturing	0.0	0.0	0.0
21 Grain and Oilseed Milling	0.0	0.0	0.0
22 Sugar and Confectionary Product Manufacturing	0.0	0.0	0.0
23 Fruit & Vegetable Preserving & Specialty Food Manu.	0.0	0.0	0.0
24 Bakeries and Tortilla Manufacturing	0.0	0.0	0.0
25 Other Food Manufacturing	0.0	0.0	0.0
26 Soft drinks and alcoholic beverages	0.0	0.0	0.0
27 Tobacco and tobacco products	0.0	0.0	0.0
28 Leather, rubber, and plastic products	1.3	0.8	0.1
29 Textile products	0.0	0.0	0.0
30 Hosiery, clothing and accessories	0.0	0.0	0.0
31 Lumber and wood products	0.0	0.0	0.0
32 Furniture and fixtures	0.0	0.0	0.0
33 Wood pulp, paper and paper products	0.0	0.0	0.0
34 Printing and publishing	0.0	0.0	0.0
35 Primary metal products	0.0	0.0	0.0
36 Other metal products	0.0	0.0	0.0
37 Machinery and equipment	69.0	44.4	2.0
38 Motor veh., oth. transport equip. and parts	0.0	0.0	0.0
39 Electrical, electronic and communic. prod.	0.0	0.0	0.0
40 Non-metallic mineral products	0.0	0.0	0.0
41 Petroleum and coal products	57.9	48.0	40.9
42 Chemicals, pharmaceuticals & chemical prod.	135.1	110.0	34.2

43 Other manufactured products	0.0	0.0	0.0
44 Residential construction	0.0	0.0	0.0
45 Non-residential construction	0.0	0.0	0.0
46 Repair construction	6.7	6.6	6.6
47 Transportation and storage	18.5	9.3	6.8
48 Communications services	17.2	15.9	11.1
49 Other utilities	43.1	42.4	41.3
50 Wholesaling margins	0.0	51.3	36.0
51 Retailing margins	0.0	15.5	14.5
52 Gross imputed rent	0.0	0.0	0.0
53 Other finance, insurance, and real estate services	136.1	135.2	104.5
54 Business and computer services	6.6	6.6	4.7
55 Private education services	0.0	0.0	0.0
56 Health and social services	0.0	0.0	0.0
57 Accommodation services and meals	0.0	0.0	0.0
58 Other services	0.0	0.0	0.0
59 Transportation margins	0.0	22.7	13.8
60 Operating, office, cafeteria and lab. supplies	0.0	0.0	0.0
61 Travel & entertainment, advertising & promotion	0.0	0.0	0.0
62 Non-profit institutions serving households	0.0	0.0	0.0
63 Government sector services	0.0	0.0	0.0
64 Non-competing imports	0.0	0.0	0.0
65 Unallocated imports and exports	0.0	0.0	0.0
66 Sales of other government services	0.0	9.5	9.4
67 Indirect taxes	18.2	18.2	18.2
68 Subsidies	0.0	0.0	0.0
69 Labour Income	116.6	116.6	116.6
70 Other operating surplus	760.5	760.5	760.5
71 Imports NFLD	0	0	0.102334
72 Imports PEI	0	0	0.071922
73 Imports NS	0	0	0.610592
74 Imports NB	0	0	0.514388
75 Imports QU	0	0	13.92628
76 Imports ON	0	0	48.08861
77 Imports MN	0	0	10.13648
78 Imports SK	0	0	21.13232
79 Imports AB	0	0	0
80 Imports BC	0	0	22.01897
81 Imports Terr	0	0	0.387016
82 Imports Foreign	0	0	111.3042
83 Other Leakages	0	0	0
84 Total Employment	6.9	6.9	6.9
85 Total Water Use	5000	5000	5000

Table 7.8 *Commodity Purchases in Sectoral Space, under the Study Scenario*

Sectors	Initial Sectoral Demand
1 Grains	59.2
2 Irrigation	38.7
3 Dairy Cattle	3.1
4 Beef Cattle	92.9
5 Hog	3.0
6 Poultry	0.4
7 Livestock Combination	7.3
8 Miscellaneous	3.0
9 Non-Commercial	0.5
10 Forestry and Logging	1.2
11 Fishing, Hunting and Trapping	0.0
12 Support Activities for Agriculture and Forestry	1.8
13 Mining and Oil and Gas Extraction	13.8
14 Utilities	32.4
15 Construction	7.0
16 Animal Food Manufacturing	0.0
17 Grain and Oilseed Milling Manufacturing	0.1
18 Sugar and Confectionery Product Manufacturing	0.0
19 Fruit and Vegetable Preserving and Specialty Food Manufacturing	0.0
20 Dairy Product Manufacturing	0.0
21 Meat Product Manufacturing	0.3
22 Seafood Product Preparation and Packaging Manufacturing	0.0
23 Bakeries and Tortilla Manufacturing	0.1
24 Other Food Manufacturing	0.0
25 Beverage Manufacturing	0.0
26 Tobacco Manufacturing	0.0
27 Textile Mills Manufacturing	0.0
28 Textile Product Mills Manufacturing	0.0
29 Clothing Manufacturing	0.0
30 Leather and Allied Product Manufacturing	0.0
31 Wood Product Manufacturing	0.2
32 Paper Manufacturing	0.1
33 Printing and Related Support Activities	0.0
34 Petroleum and Coal Products Manufacturing	27.1
35 Chemical Manufacturing	34.1
36 Plastics and Rubber Products Manufacturing	0.1
37 Non-Metallic Minerals Manufacturing	0.1
38 Primary Metal Manufacturing	0.1
39 Fabricated Metal Product Manufacturing	0.1
40 Machinery Manufacturing	1.8
41 Computer and Electronic Product Manufacturing	0.1
42 Electrical Equipment, Appliance and Component Manufacturing	0.0
43 Transportation Equipment Manufacturing	0.0

Table 7.8, cont.	
Sectors	**Initial Sectoral Demand**
44 Furniture and Related Product Manufacturing	0.0
45 Miscellaneous Manufacturing	0.0
46 Wholesale Trade	34.9
47 Retail Trade	13.5
48 Transportation and Warehousing	9.0
49 Information and Cultural Industries	9.9
50 Finance, Insurance, Real Estate and Renting and Leasing	98.78568
51 Professional, Scientific and Technical Services	6.761754
52 Administrative and Other Support Services	3.646661
53 Educational Services	0.004527
54 Health Care and Social Services	0.022872
55 Arts, Entertainment and Recreation	0.410117
56 Accommodation and Food Services	1.7381
57 Other Services (except Public Administration)	0.666286
58 Operating, Office, Cafeteria and Laboratory Supplies	0
59 Travel and Entertainment, Advertising and Promotion	0
60 Transportation Margins	13.83407
61 Non-Profit Institutions Serving Households	0.026941
62 Government Sector	18.31384
63 Indirect Taxes	18.23
64 Subsidies	0
65 Labour Income	116.58
66 Oth. Oper. Surplus	760.54
67 Imports NFLD	0.102334
68 Imports PEI	0.071922
69 Imports NS	0.610592
70 Imports NB	0.514388
71 Imports QU	13.92628
72 Imports ON	48.08861
73 Imports MN	10.13648
74 Imports SK	21.13232
75 Imports AB	0
76 Imports BC	22.01897
77 Imports Terr	0.387016
78 Imports Foreign	111.3042
79 Other Leakages	0
80 Total Employment	5000
81 Total Water Use	6.9

Table 7.9 *Total Economic Impacts of the Scenario, Type I*

Sectors	Output	GDP at Factor Cost	GDP at Market Price	Imports	Labour Income	Employment	Water Use
1 Grains	66.9	8.2	6.3	23.4	9.5	1.0	0.1
2 Irrigation	46.0	24.0	24.5	7.0	3.2	0.2	136.8
3 Dairy Cattle	7.1	0.5	0.6	1.8	0.5	0.0	0.1
4 Beef Cattle	124.7	49.4	49.6	21.9	8.6	1.0	1.0
5 Hog	5.6	1.3	1.4	1.3	0.5	0.0	0.0
6 Poultry	0.6	0.3	0.3	0.1	0.1	0.0	0.0
7 Livestock Combination	9.6	2.3	2.3	2.4	1.0	0.2	0.1
8 Miscellaneous	4.7	-1.1	-1.1	1.9	0.7	0.0	0.0
9 Non-Commercial	0.7	0.0	-0.1	0.2	-0.2	0.1	0.0
10 Forestry and Logging	1.5	0.5	0.5	0.2	0.3	0.0	0.0
11 Fishing, Hunting and Trapping	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12 Support Activities for Agriculture and Forestry	2.6	1.5	1.6	0.3	1.4	0.1	0.0
13 Mining and Oil and Gas Extraction	56.5	34.4	35.2	4.5	7.6	0.1	1.0
14 Utilities	41.2	25.7	29.0	3.3	4.8	0.2	15.2
15 Construction	18.2	6.4	6.7	5.3	5.6	0.1	3.8
16 Animal Food Manufacturing	1.2	0.1	0.1	0.7	0.0	0.0	0.0
17 Grain and Oilseed Milling Manufacturing	3.6	-0.4	-0.4	1.3	0.7	0.0	0.0
18 Sugar and Confectionery Product Manufacturing	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19 Fruit and Vegetable Preserving and Specialty Food Manufacturing	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20 Dairy Product Manufacturing	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21 Meat Product Manufacturing	1.6	0.2	0.2	0.2	0.2	0.0	0.0
22 Seafood Product Preparation and Packaging Manufacturing	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23 Bakeries and Tortilla Manufacturing	1.4	0.7	0.7	0.3	0.3	0.0	0.0
24 Other Food Manufacturing	0.1	0.0	0.0	0.0	0.0	0.0	0.0
25 Beverage Manufacturing	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26 Tobacco Manufacturing	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27 Textile Mills Manufacturing	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28 Textile Product Mills Manufacturing	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29 Clothing Manufacturing	0.1	0.0	0.0	0.0	0.0	0.0	0.0

Sectors	Output	GDP at Factor Cost	GDP at Market Price	Imports	Labour Income	Employment	Water Use
30 Leather and Allied Product Manufacturing	0.1	0.0	0.0	0.0	0.0	0.0	0.0
31 Wood Product Manufacturing	0.5	0.2	0.2	0.1	0.1	0.0	0.0
32 Paper Manufacturing	0.4	0.2	0.2	0.1	0.0	0.0	0.1
33 Printing and Related Support Activities	1.1	0.6	0.6	0.3	0.3	0.0	0.0
34 Petroleum and Coal Products Manufacturing	34.3	1.2	2.5	3.4	1.3	0.0	0.5
35 Chemical Manufacturing	47.0	18.1	17.9	11.6	3.5	0.1	2.2
36 Plastics and Rubber Products Manufacturing	0.4	0.1	0.1	0.2	0.1	0.0	0.0
37 Non-Metallic Minerals Manufacturing	0.6	0.3	0.3	0.1	0.1	0.0	0.0
38 Primary Metal Manufacturing	0.6	0.3	0.3	0.2	0.1	0.0	0.0
39 Fabricated Metal Product Manufacturing	0.8	0.3	0.3	0.3	0.2	0.0	0.0
40 Machinery Manufacturing	2.1	1.1	1.1	0.7	0.4	0.0	0.0
41 Computer and Electronic Product Manufacturing	0.3	0.1	0.1	0.1	0.1	0.0	0.0
42 Electrical Equipment, Appliance and Component Manufacturing	0.0	0.0	0.0	0.0	0.0	0.0	0.0
43 Transportation Equipment Manufacturing	0.0	0.0	0.0	0.0	0.0	0.0	0.0
44 Furniture and Related Product Manufacturing	0.1	0.0	0.0	0.0	0.0	0.0	0.0
45 Miscellaneous Manufacturing	0.1	0.0	0.0	0.0	0.0	0.0	0.0
46 Wholesale Trade	46.8	28.4	29.3	3.6	18.9	0.4	0.0
47 Retail Trade	17.1	10.4	10.6	1.3	8.4	0.4	0.0
48 Transportation and Warehousing	31.5	17.0	17.7	3.4	10.6	0.3	0.0
49 Information and Cultural Industries	18.6	11.6	11.9	1.8	5.7	0.2	0.0
50 Finance, Insurance, Real Estate and Renting and Leasing	134.5	82.2	93.9	6.7	39.9	0.3	0.0
51 Professional, Scientific and Technical Services	24.7	15.2	15.4	1.6	12.9	0.4	0.0
52 Administrative and Other Support Services	9.5	6.3	6.4	0.6	5.2	0.2	0.0
53 Educational Services	0.1	0.1	0.1	0.0	0.1	0.0	0.0
54 Health Care and Social Services	1.6	1.2	1.2	0.1	0.9	0.1	0.0
55 Arts, Entertainment and Recreation	2.1	0.8	0.9	0.1	0.7	0.1	0.0
56 Accommodation and Food Services	4.8	2.3	2.4	0.7	1.7	0.1	0.0

Sectors	Output	GDP at Factor Cost	GDP at Market Price	Imports	Labour Income	Employment	Water Use
57 Other Services (except Public Administration)	4.4	3.0	3.1	0.3	2.4	0.1	0.0
58 Operating, Office, Cafeteria and Laboratory Supplies	20.9	0.0	0.0	15.2	0.0	0.7	0.0
59 Travel and Entertainment, Advertising and Promotion	12.7	0.0	0.0	3.8	0.0	0.4	0.0
60 Transportation Margins	17.0	0.0	0.0	4.5	0.0	0.5	0.0
61 Non-Profit Institutions Serving Households	0.4	0.3	0.3	0.0	0.3	0.0	0.0
62 Government Sector	22.3	13.0	13.1	1.7	10.9	0.1	0.1
Exogenous Industry Direct	1,682.3	877.1	895.4	228.3	116.6	6.9	5,000.0
Total Impacts	2,533.9	1,245.5	1,282.7	367.1	286.5	13.5	5,161.2

Table 7.10 *Total Economic Impacts of the Scenario, Type II*

Sectors	Output	GDP at Factor Cost	GDP at Market Price	Imports	Labour Income	Employment	Water Use
1 Grains	67.5	8.2	6.4	23.6	9.6	1.0	0.1
2 Irrigation	46.7	24.4	24.9	7.1	3.2	0.2	138.9
3 Dairy Cattle	8.1	0.6	0.7	2.1	0.6	0.1	0.1
4 Beef Cattle	129.6	51.4	51.5	22.7	8.9	1.1	1.0
5 Hog	6.0	1.4	1.5	1.4	0.6	0.0	0.0
6 Poultry	0.8	0.3	0.4	0.1	0.1	0.0	0.0
7 Livestock Combination	10.0	2.4	2.4	2.4	1.1	0.3	0.1
8 Miscellaneous	5.0	-1.1	-1.2	2.1	0.8	0.0	0.0
9 Non-Commercial	0.7	0.0	-0.1	0.2	-0.2	0.1	0.0
10 Forestry and Logging	1.6	0.5	0.5	0.2	0.4	0.0	0.0
11 Fishing, Hunting and Trapping	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12 Support Activities for Agriculture and Forestry	2.7	1.6	1.7	0.3	1.5	0.1	0.0
13 Mining and Oil and Gas Extraction	65.9	40.1	41.1	5.2	8.9	0.2	1.2
14 Utilities	51.6	32.2	36.3	4.1	6.1	0.2	19.1
15 Construction	22.7	8.0	8.3	6.6	7.0	0.1	4.7

Sectors	Output	GDP at Factor Cost	GDP at Market Price	Imports	Labour Income	Employment	Water Use
16 Animal Food Manufacturing	1.7	0.1	0.1	1.0	0.0	0.0	0.0
17 Grain and Oilseed Milling Manufacturing	6.5	-0.7	-0.7	2.3	1.3	0.0	0.1
18 Sugar and Confectionery Product Manufacturing	0.1	0.1	0.1	0.0	0.0	0.0	0.0
19 Fruit and Vegetable Preserving and Specialty Food Manufacturing	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20 Dairy Product Manufacturing	1.0	0.0	0.0	0.3	0.0	0.0	0.0
21 Meat Product Manufacturing	7.2	0.9	0.9	0.9	0.9	0.0	0.0
22 Seafood Product Preparation and Packaging Manufacturing	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23 Bakeries and Tortilla Manufacturing	1.6	0.8	0.8	0.3	0.4	0.0	0.0
24 Other Food Manufacturing	0.4	0.1	0.1	0.0	0.0	0.0	0.0
25 Beverage Manufacturing	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26 Tobacco Manufacturing	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27 Textile Mills Manufacturing	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28 Textile Product Mills Manufacturing	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29 Clothing Manufacturing	0.1	0.1	0.1	0.0	0.0	0.0	0.0
30 Leather and Allied Product Manufacturing	0.3	0.0	0.0	0.1	0.0	0.0	0.0
31 Wood Product Manufacturing	0.7	0.3	0.3	0.2	0.2	0.0	0.0
32 Paper Manufacturing	0.7	0.4	0.4	0.2	0.1	0.0	0.1
33 Printing and Related Support Activities	2.2	1.3	1.3	0.5	0.6	0.0	0.0
34 Petroleum and Coal Products Manufacturing	37.9	1.3	2.8	3.8	1.4	0.0	0.5
35 Chemical Manufacturing	49.7	19.2	19.0	12.2	3.7	0.1	2.3
36 Plastics and Rubber Products Manufacturing	0.8	0.1	0.1	0.4	0.2	0.0	0.0
37 Non-Metallic Minerals Manufacturing	1.2	0.6	0.6	0.3	0.2	0.0	0.0
38 Primary Metal Manufacturing	0.8	0.4	0.4	0.3	0.1	0.0	0.0
39 Fabricated Metal Product Manufacturing	1.2	0.5	0.5	0.4	0.3	0.0	0.0
40 Machinery Manufacturing	2.3	1.2	1.2	0.8	0.5	0.0	0.0

Sectors	Output	GDP at Factor Cost	GDP at Market Price	Imports	Labour Income	Employment	Water Use
41 Computer and Electronic Product Manufacturing	0.4	0.1	0.1	0.2	0.1	0.0	0.0
42 Electrical Equipment, Appliance and Component Manufacturing	0.0	0.0	0.0	0.0	0.0	0.0	0.0
43 Transportation Equipment Manufacturing	0.1	0.0	0.0	0.0	0.0	0.0	0.0
44 Furniture and Related Product Manufacturing	0.5	0.2	0.2	0.2	0.2	0.0	0.0
45 Miscellaneous Manufacturing	0.2	0.1	0.1	0.1	0.1	0.0	0.0
46 Wholesale Trade	60.8	36.9	38.0	4.7	24.5	0.5	0.0
47 Retail Trade	57.5	34.9	35.8	4.4	28.2	1.3	0.1
48 Transportation and Warehousing	46.2	24.9	26.0	4.9	15.6	0.4	0.0
49 Information and Cultural Industries	31.0	19.3	19.9	3.0	9.5	0.3	0.0
50 Finance, Insurance, Real Estate Renting and Leasing	253.5	154.9	176.9	12.7	75.3	0.5	0.1
51 Professional, Scientific and Technical Services	34.9	21.5	21.7	2.3	18.2	0.5	0.0
52 Administrative and Other Support Services	14.5	9.6	9.8	0.9	8.0	0.3	0.0
53 Educational Services	1.7	1.2	1.2	0.1	1.2	0.5	0.0
54 Health Care and Social Services	10.0	7.1	7.3	0.6	5.5	0.5	0.0
55 Arts, Entertainment and Recreation	5.9	2.4	2.5	0.4	2.1	0.2	0.0
56 Accommodation and Food Services	28.1	13.2	14.1	4.2	10.0	0.6	0.1
57 Other Services (except Public Administration)	12.0	8.1	8.3	0.7	6.5	0.4	0.1
58 Operating, Office, Cafeteria and Laboratory Supplies	30.9	0.0	0.0	22.5	0.0	1.0	0.0
59 Travel and Entertainment, Advertising and Promotion	23.5	0.0	0.0	7.0	0.0	0.7	0.0
60 Transportation Margins	19.0	0.0	0.0	5.1	0.0	0.6	0.0
61 Non-Profit Institutions Serving Households	7.9	5.2	5.3	0.4	5.0	0.2	0.0
62 Government Sector	29.8	17.5	17.6	2.2	14.5	0.1	0.1
Exogenous Industry Direct	1682.3	877.1	895.4	228.3	116.6	6.9	5000.0
Total Impacts	4568.5	1430.9	1482.4	407.3	399.2	19.1	5169.0

Particulars	Unit	Value
Change in the amount of water for irrigation	dam^3	5,000
Change in the Direct Income from Irrigation	$1,000	116.6
Direct value per dam^3	$\$/dam^3$	23.32
Direct and Indirect Change in Income	$1,000	286.5
Value of Water Type I	$\$/dam^3$	57.30
Direct, Indirect and induced Change in Income	$1,000	399.2
Value of Water Type II	$\$/dam^3$	79.84

Table 7.11 *Estimate of the Value of Irrigation Water for Regional Economic Development under the Study Scenario*

The value of water in irrigation is estimated to be between \$23.32 per dam^3 to \$79.84 per dam^3. The increased value produced by the interdependencies that exist in the economy between irrigation and other economic activities. It should also be noted that this value is a gross value and does not taken into account the opportunity cost of the land use i.e., dryland farming which would be possible without any irrigation water.

References:

Anderson, Randall S., Jay A. Leitch and Cliff R. Fegert (1985), *Guidelines for Economic Evaluation of Public Sector Water Resource Projects*. Agricultural Economics Report. No. 201, Department of Agricultural Economics, Agricultural Experiment Station, North Dakota State University, Fargo, North Dakota.

Armstrong, Robert, Elise Pietroniro and J. Terry Rolfe (2004), *Water Use in the South Saskatchewan River Basin*. University of Saskatchewan. Saskatoon, Saskatchewan.

Bangsund, Dean A. and F. Larry Leistritz (1993), *Economic Impact of Expanded Calf Backgrounding and Expanded Irrigation: Applications of the Value-Added Agriculture Impact Assessment Model*. Agricultural Economics Report No. 300. Department of Agricultural Economics, Agricultural Experiment Station, North Dakota State University, Fargo, North Dakota.

Brockman, J.L. and S.N. Kulshreshtha (1987), *Saskatchewan River Basin Input-Output and Resource Use Model (SASKIO84.3*). Saskatchewan Water Corporation, Saskatchewan Water Use and Value, Report 7, Moose Jaw, Saskatchewan.

Davies, H. C. (1993), *Regional Economic Impact Analysis and Project Evaluation*. UBC Press, Vancouver.

Givers, David R., Dean A. Bangsund, F. Larry Leistritz, and Jay A. Leitch (1994), *Economic Impact of Expanded Irrigation Development in McKenzie County*, North Dakota. Staff Paper Series. Department of Agricultural Economics, Agricultural Experiment Station, North Dakota State University, Fargo, North Dakota

Isard, Walter (1975), *Introduction to Regional Science*. Prentice-Hall, Inc., Englewood Cliffs, NJ.

Irrigation Water Management Study Committee (2002), *South Saskatchewan River Basin Irrigation in the 21st Century. Volume 5: Economic Opportunities and Impacts*. Alberta Irrigation Projects Association. Lethbridge, Alberta.

Krutilla, J. (1956), "Economic Development: An Appraisal", In R. C. Martin (ed.), *TVA – The First Twenty Years*, pp. 219-23, The University of Alabama Press, Alabama.

Kulshreshtha, S. N. and K. D. Russell (1995), *Saskatchewan Irrigation Impact Analysis.* Saskatchewan Water Corporation, Moose Jaw, SK.

Kulshreshtha, S.N., D. Shalley and K.D. Russell (1993), *Economic Impacts of Irrigation Development in Southern Alberta*. Alberta Irrigation Projects Association, Lethbridge. April 1993.

Kulshreshtha, S. N., D. Sobool and C. W. Grant (2004), *Water Use Module for the Canadian Regional Agricultural Model*. A Report Prepared for the Strategic Policy Branch, Agriculture and Agri-Food Canada.

Kulshreshtha, S., J. Brockman, K. O'Grady and S. Miller (1988), *Current Water Use Levels in Saskatchewan.* Water Use and Value Study Report 3. Saskatchewan Water Corporation, Moose Jaw, SK.

Lane, R. K. and G. N. Sykes (1982), *Nature's Lifeline: Prairie and Northern Waters*. Calgary, Alberta.

Leistritz, F. Larry (1997), Assessing Local Socioeconomic Impacts of Rural Manufacturing Facilities: The Case of a Proposed Agricultural Processing Plant. *Journal of the Community Development Society*. 28(1): 43-64.

Leistritz, F. Larry and Randall S. Sell (2000), *Agricultural Processing Plants in North Dakota: Socioeconomic Impacts*. Agricultural Economics Report No. 437. Department of Agricultural Economics, Agricultural Experiment Station, North Dakota State University, Fargo, North Dakota.

Loomis, John B. (1993), *Integrated Land Management: Principles and Applications to National Forests, Parks, Wildlife Refuges and BLM Lands*. New York: Columbia University Press.

MacMillan, James A. and G. De Matos (1992), *Manitoba Red Meat Forum: Manitoba / Western Canada Red Meat Industries: Strategies and Impact Analysis*. University of Manitoba.

MacMillan, James A., B.T. Coyle, G. De Matos and N. Longmuir (1992), *Manitoba/Canada Impact Analysis: A Two Region Input-Output Model*. Research Bulletin No. 93-1, Department of Agricultural Economics and Farm Management, University of Manitoba, Winnipeg, Manitoba.

Statistics Canada (2003c), Special Tabulation: 1999 Employment Data by NAICS. Ottawa, ON.

Statistics Canada (2004), *Water Use by Sectors*. Environmental Accounts Division. Ottawa, ON.

Thompson, W.D. (2002), *Economic Study of the Federally Developed Water Supply Systems in Southwest Saskatchewan*. M.Sc. Thesis. Department of Agricultural Economics. University of Saskatchewan, Saskatoon, SK.

Supplementary Data Sources:

Alberta Agriculture, Food and Rural Development (2003), Alberta Farm Cash Receipts by Detailed Type, Edmonton, Alberta. Accessed in December 2003 at: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sdd4807. Edmonton, Alberta.

Statistics Canada (2000), *Provincial Economic Accounts*. Catalogue No. 13-213-PPB.

Statistics Canada (2001), *2001 Census of Agriculture: Farm Data and Farm Operator Data: Full Releases*. Catalogue 95F0345XCB. Ottawa, ON.

Statistics Canada (2002), *Manufacturing Industries of Canada: National and Provincial Areas*. Catalogue 31-203-XPB. Ottawa, ON.

Statistics Canada (2003a), *Provincial Transactions Tables, System of National Accounts*, I-O Division, Consulting and Marketing. Ottawa, ON.

Statistics Canada (2003b), Special Tabulation: 2001 Agriculture Data by Farm Type. Ottawa, ON.

Statistics Canada (2003d), *Trade Flow data*. Ottawa, ON.

Statistics Canada, CANSIM Table 379-001.

8 Estimated Water Use in the South Saskatchewan River Basin

8.1 Summary of Water Use

Given the extensive infrastructure and precision of water management in the SSRB, the variations of source and timing of runoff do not largely constrain activities by the key water sectors in terms of access to regulated flows. However, the natural resources mix available to different areas as well as the relative position of water resources within the Basin creates challenges for optimized surface water use. The results below show the proportion of water withdrawal by sector across the whole Basin, by key sector use in Alberta versus Saskatchewan, and then by key sectors for each sub-Basin.

The SSRB study at present is focused on *key* water use sectors, although in future analysis could incorporate impacts across the full water cycle. Details of the data sources for the full range of water use sectors have been described in Sections 6.4.2 through 6.4.10, but for our purposes here the following sectors have proven to be the key users in terms of the volume of water withdrawal, assuming agreement on inter-jurisdictional apportionment holds fast.

- Agriculture – irrigation and stock-watering
- Residential – urban domestic and rural
- Municipal (including urban residential, commercial and industrial)
- Industrial: mining, oil and gas
- Energy: thermal, hydro electric

Future work could nevertheless consider the impact of climate change on the full interface of physical and socio-economic spheres, reflecting the complex system dynamics underpinning water availability and quality. These additional water uses include:

- Biophysical and ecological processes (i.e. waste recycling, groundwater recharge, wetlands, evaporation, habitat)
- *In situ* uses (i.e. fishing, hunting, guiding, tourism, culture, aesthetics, spirituality)

Overall surface water withdrawal in the SSRB is predominantly agricultural at 86.5% as shown in Figure 8.1. In Alberta (Figure 8.2), there is greater agricultural use at 87.9% due to extensive irrigation, whereas in Saskatchewan (Figure 8.3), agriculture uses a lesser proportion (56.3%) as potential still exist to expand irrigation. The breakdown of water withdrawal by key water use sectors is quite different across the four major sub-basins, as depicted in Figures 8.4 through 8.8.

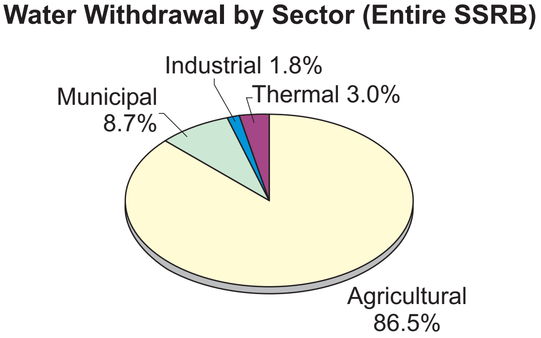


Figure 8.1 *Water Withdrawal by Sector for the SSRB.*

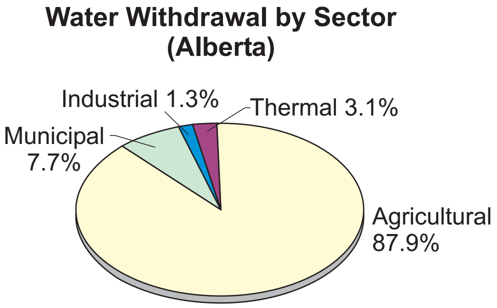


Figure 8.2 *Withdrawal By Sector, Alberta.*

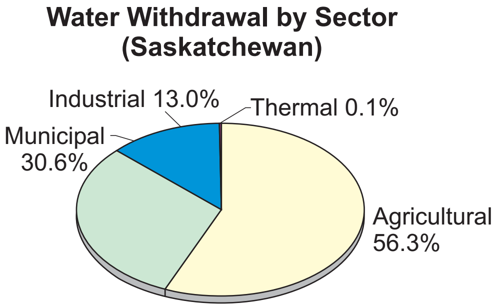


Figure 8.3 *Withdrawal By Sector, Saskatchewan.*

The following sub-Basin observations stand out. Surface water use by the agricultural sector is highly intensive in the Oldman River and Red Deer River basins (at 96.6% and 91.4%, respectively). The proportion of municipal use is the highest in the Bow River Basin at 19.7%, which includes the City of Calgary and its neighbouring communities. Thermal use is most significant in the South Saskatchewan River Basin where it draws 11.3% of surface water use.

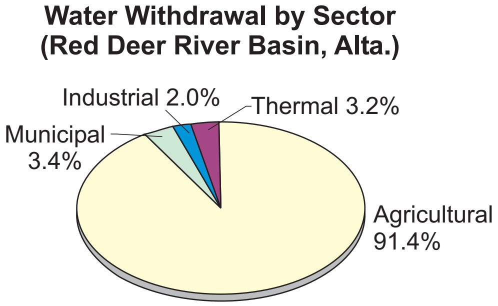


Figure 8.4 *Withdrawal By Sector,*
Red Deer sub-Basin.

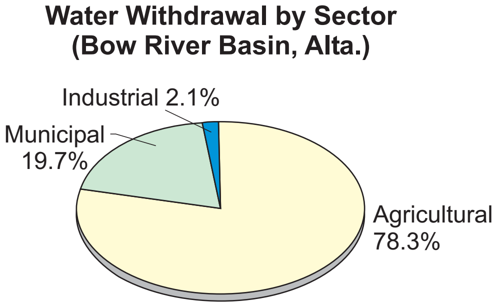


Figure 8.5 *Withdrawal By Sector,*
Bow River sub-Basin.

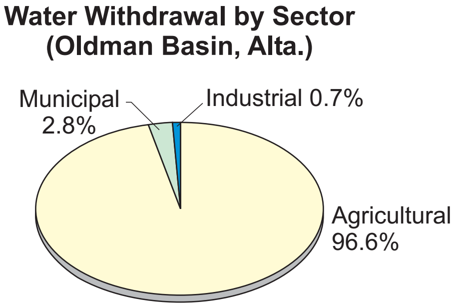


Figure 8.6 *Withdrawal by Sector,*
Oldman River sub-Basin.

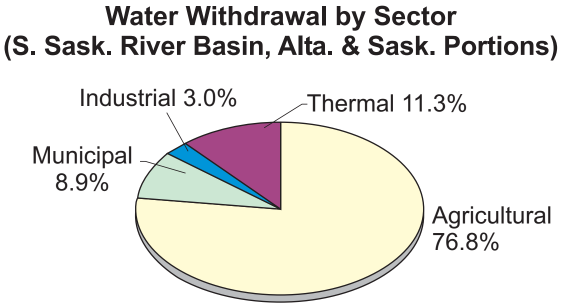


Figure 8.7 *Withdrawal by Sector, SSRB.*

In summary, the initial water use inventory for 1996 gives an overview of water use activities within the SSRB for major water user sectors. It also provides a base for assessing the impact of changes in water availability under climate change. Water use information for 1996 has also been previously reported by Alberta Environment for the Alberta portion of the SSRB, which includes the Oldman, Bow, Red Deer and SSR located in the Alberta (Alberta Environment, 2002). The following includes the extension of the water use information into the Saskatchewan portion of the SSRB. Differences in reported water use for basins in the Alberta portion may be accounted for by methodologies used, data sources and needs.

8.2 Domestic Water Use

Municipal water use data was obtained from the socio-economic database (Sobool and Kulshreshtha, 2003) as well as from Environment Canada's 1996 *Municipal Water Use Survey*. While the socio-economic data is limited to population and water use, Environment Canada's data has a large number of parameters including subdivision into domestic, industrial and commercial uses. Environment Canada data, however, was limited to communities with populations in excess of 1,000. Figure 8.7 shows the population distribution for selected communities within the SSRB for 1996. This population information was obtained from Census of Canada Community Profiles. Population information is divided into Urban Population and Rural Population. For this study, communities were considered "urban communities" if they had a population greater than 1,000 people, a criteria used by Statistics Canada in the past.

The 1996 population within the SSRB for selected communities is estimated at 1.4 million people. The change in population from 1991 to 1996 was about 8%. The majority of the urban population is concentrated within the Bow River and South Saskatchewan River basins; together, their combined population accounts for 82% of the total urban population within the SSRB. The greatest population overall resides in the Bow River Basin at an estimated 830,000, with an estimated 828,000 of those people residing in urban communities. About 300,000 people reside in urban communities in the South Saskatchewan River Basin. The Oldman River Basin has the lowest urban population at about 118,000. The majority of the rural population is split between the South Saskatchewan River and Red Deer River basins, accounting for about 82% of the total rural population within the SSRB. The largest rural population is found in the South Saskatchewan Basin, estimated at about 17,000, while the Red River Basin has an estimated population of 14,000. The Bow River Basin has the lowest rural population at about 2,000. Overall the Oldman River basin has the fewest people at about 123,000.

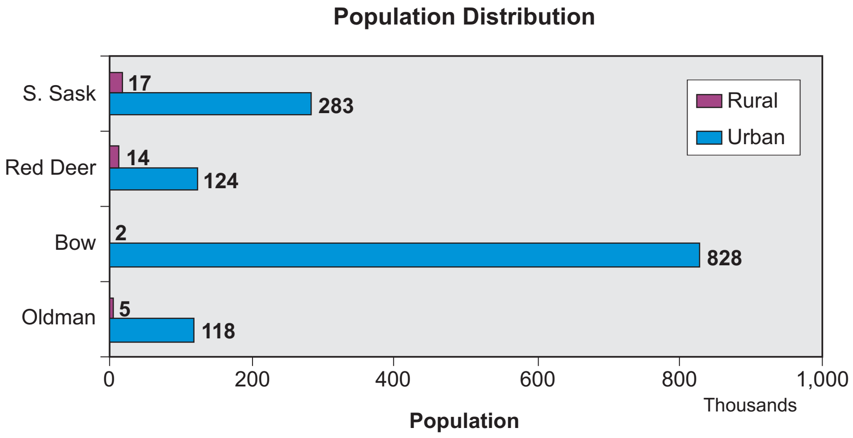


Figure 8.8 *Population distribution by sub-basin (1996).*

8.2.1 Urban Communities

In 1996 there were seven large urban communities within the SSRB with populations over 10,000 people. As shown in Table 8.1, these included: Calgary (768,802), Saskatoon (193,653), Lethbridge (63,053), Red Deer (60,080), Medicine Hat (46,783), Airdrie (15,946), Swift Current (14,890) and Brooks (10,093). Population growth between 1991 and 1996 ranged from 3% (in Red Deer, Alberta and Lethbridge, Alberta) to 28% (in Airdrie, Alberta). Population growth between 1991 and 1996 for these same urban centres ranged from 1% (Saskatoon, Saskatchewan) to 28% (Airdrie, Alberta), whereas Swift Current experienced a decrease (-0.5%) in the rate of growth. In Alberta, the overall rate of population growth in the large urban centres grew from 7.6% to 16.4%, from 1991-1996 to 1996-2001, respectively. Conversely, in Saskatchewan the overall rate of population growth declined from 3.8% to 1.48% over the same periods. For the SSRB, the overall rate of population growth for the large urban centres increased from 6.9% to 11.6% from 1991-1996 to 1996-2001, respectively.

Urban Centre	Province	Pop. 1991	Pop. 1996	Change 1991 (%)	Pop. 2001	Change 1996 (%)
Calgary	AB	710,677	768,082	8.1	878,866	14.4
Saskatoon	SK	186,058	193,653	4.1	196,811	1.6
Lethbridge	AB	60,974	63,053	3.4	67,374	6.9
Red Deer	AB	58,134	60,080	3.3	67,707	12.7
Medicine Hat	AB	43,625	46,783	7.2	51,249	9.5
Airdrie	AB	12,456	15,946	28.0	20,382	27.8
Swift Current	SK	14,815	14,890	19.5	14,821	-0.5
Brooks	AB	9,433	10,093	7.0	11,604	15.0

Table 8.1 Population of large urban centres in the SSRB.

8.2.2 Rural Communities

In 1996 there were 130 rural communities within the SSRB with reported populations of less than 1,000 people (Sobool and Kulshreshtha, 2003). Of these, 62 rural communities were in Alberta with a total population (1996) of 23,487 and 68 rural communities in Saskatchewan with a population of 14,683 (Table 8.2). Rural population growth for Alberta from 1991 to 1996 decreased 9.8% but increased from 1996 to 2001 by 7%. In Saskatchewan the population decreased by about 3% from 1991 to 1996 but increased by about 2% from 1996 to 2001. For the SSRB, the overall rate of population growth for the rural communities decreased by about 7% from 1991/1996 and increased by 5% from 1996/01 respectively.

Province	Rural Pop. (1991)	Rural Pop. (1996)	(%) change	Rural Pop. (2001)	(%) change
Alberta	26,029	23,487	-9.8	25,138	7.0
Saskatchewan	15,154	14,683	-3.1	14,927	1.7
Total	41,183	38,170	-7.3	40,065	5.0

Table 8.2 *Population of rural communities in the SSRB.*

8.2.3 Summary of Domestic Water Use by Sub-basin

Figure 8.9 shows the urban and rural community water use within the basin. The Bow River and SSR basins account for about 86% of the urban water use, with the highest use occurring in the Bow River Basin (~ 180 million m^3) while communities in the SSR use approximately 74 million m^3. The Oldman and Red Deer River basins use relatively similar volumes of water at about 21 million m^3. Rural water use within the SSRB is considerably less than that of urban water use. As with the urban water use, the Red Deer and SSR basins account for the largest use, at about 91% of the total rural water use. Water use for rural communities within the SSR basin is about 600,000 m^3 more than for communities within the Red Deer River Basin. Rural water use within the Bow (242,000 m^3) and Oldman (208,000 m^3) basins is also similar as was the case for the urban water use. It should be noted that the industrial water use has not yet been separated out from community water use information; this concern will be addressed in the future.

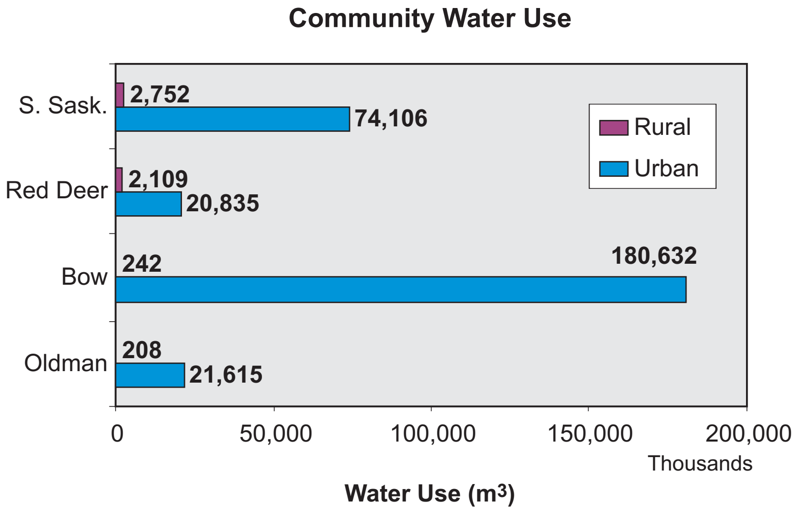


Figure 8.9 *Community water use by sub-basin (1996).*

8.3 Power Generation Water Use

Environment Canada's 1996 *Industrial Water Use Survey* includes thirteen hydropower plants in the SSRB. Twelve plants are located in Alberta and one plant in Saskatchewan. Two steam-thermal plants within the SSRB were also surveyed in this 1996 Survey, both located in Alberta. The location of the major plants within the SSRB is shown in Figure 8.9. Also shown is the monthly power generation as a percentage of the total power generated for 1996.

In 1996 the five largest producers of power included both of the steam-thermal (Alberta) plants and three hydropower plants. The largest producer of power was the Sheerness steam-thermal station, located in the Red Deer River basin near Hanna Alberta, producing over 5 million MWh. The second largest producer was the Coteau Creek hydropower plant, located within the Saskatchewan portion of the SSR basin at Lake Diefenbaker, producing over 1 million MWh. The Medicine Hat plant, also located in the South Saskatchewan River basin (Alberta portion), produced the third largest amount of power at over 675,000 MWh. The fourth and fifth largest were the Spray and Ghost stations hydropower plants, both within the Oldman River basin. The Spray station, located near Canmore, Alberta, produced over 265,000 MWh. The Ghost station, located near Cochrane, Alberta, produced about 190,000 MWh.

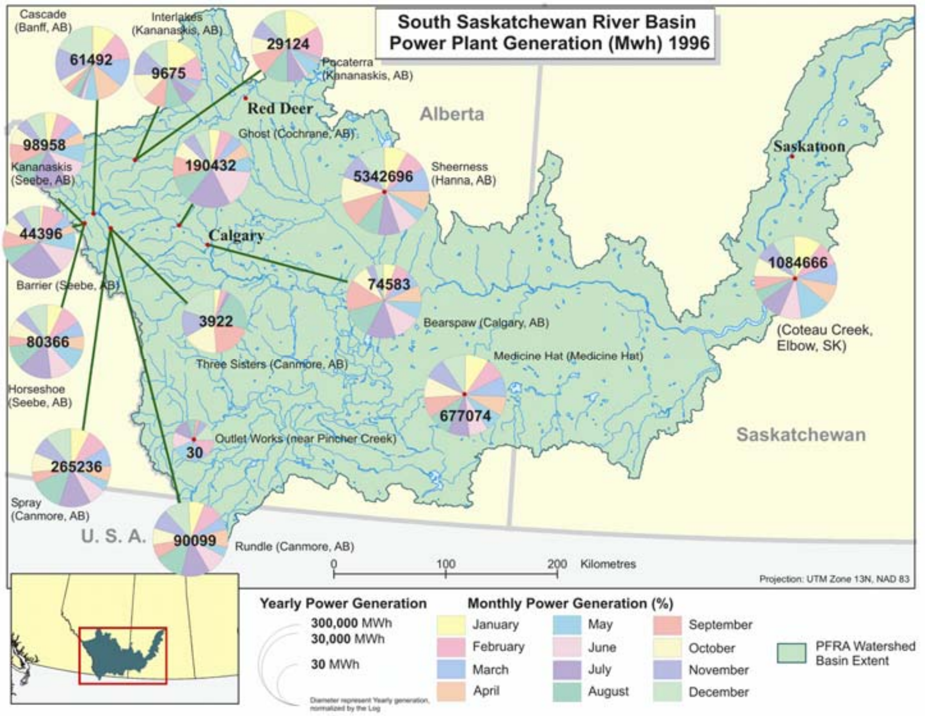


Figure 8.10 Power generation in the SSRB. Map by GIServices, University of Saskatchewan.

8.3.1 Thermal Power Generation

There are two thermal power plants in the SSRB: the Medicine Hat station in the Bow River Basin and the Sheerness station in the Red Deer River Basin. These plants were surveyed in Environment Canada's 1996 *Industrial Water Use Survey*. Steam-thermal power water use is estimated for each plant given the monthly energy generation at the plant and the water intake and consumption coefficients. Thermal power generation for the Sheerness and Medicine Hat plants is shown in Figure 8.11. In 1996, the Sheerness thermal plant produced over 5 million MWh while the Medicine Hat plant produced about 675,000 MWh.

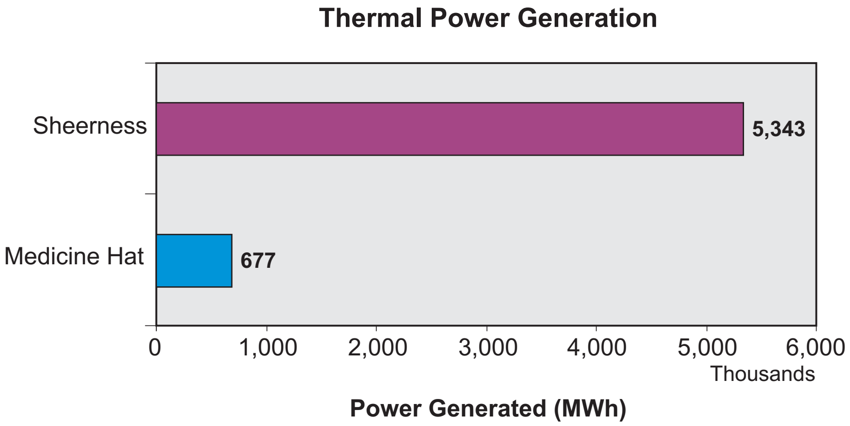


Figure 8.11 *Thermal power generation (1996).*

Steam-thermal plant water use for the Sheerness and Medicine Hat plants is given in Figures 8.12 and 8.13. Water use information for the Sheerness plant is limited to five months, May to September. Water use over these months was relatively similar with the largest volumes used in July and August (about 4 million m^3). May and June also showed similar volumes (about 3.5 million m^3). September showed the lowest volume used (about 2.7 million m^3).

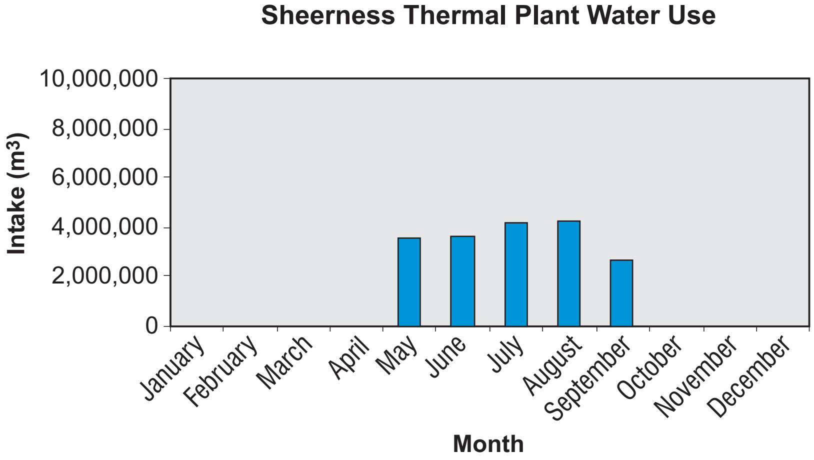


Figure 8.12 *Water intake by the Sheerness plant (1996).*

Water use information was available for all 12 months for the Medicine Hat thermal plant (Figure 8.13). Overall, the spring and summer months showed the greatest water intakes. In comparison to the Sheerness plant, water use was greatest for the Medicine Hat plant during same five month period (May to September). August showed the highest intake at about 9.5 million m^3. June and July showed similar intakes at about 8 million m^3. The intake for September was slightly less at about 7.1 million m^3 and May was the least at about 5.7 million m^3. Water intake was fairly similar throughout the winter months with least water being used in February (about 4 million m^3).

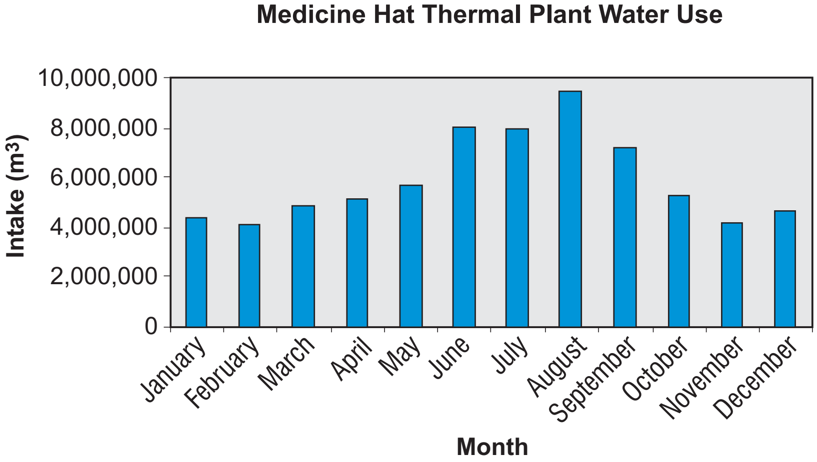


Figure 8.13 *Water intake by the Medicine Hat plant (1996).*

8.3.2 Hydroelectric Power Generation

Hydroelectric power generation is a non-consumptive water use. The demand for hydroelectric power is not simulated directly in this study; instead, monthly hydroelectric energy generation is estimated from simulated stream flows, together with data on average operating head and efficiency of each plant. The calculated energy output is restricted to the plant's maximum generating capacity.

Figure 8.14 shows the total power generated by each hydroelectric plant. In 1996, the Coteau Creek plant generated over 1 million MWh, accounting for over 50% of the total hydroelectric power generated within the SSRB (for the surveyed plants). Other major producers of hydroelectric power within the SSRB include the Spray (265,000 MWh) and Ghost (190,000MWh) stations. The remaining stations produced less than 100,000 MWh, with the least power produced by the Interlakes (10,000 MWh), Three Sisters (4,000 MWh), and the Outlet Works (30 MWh) stations.

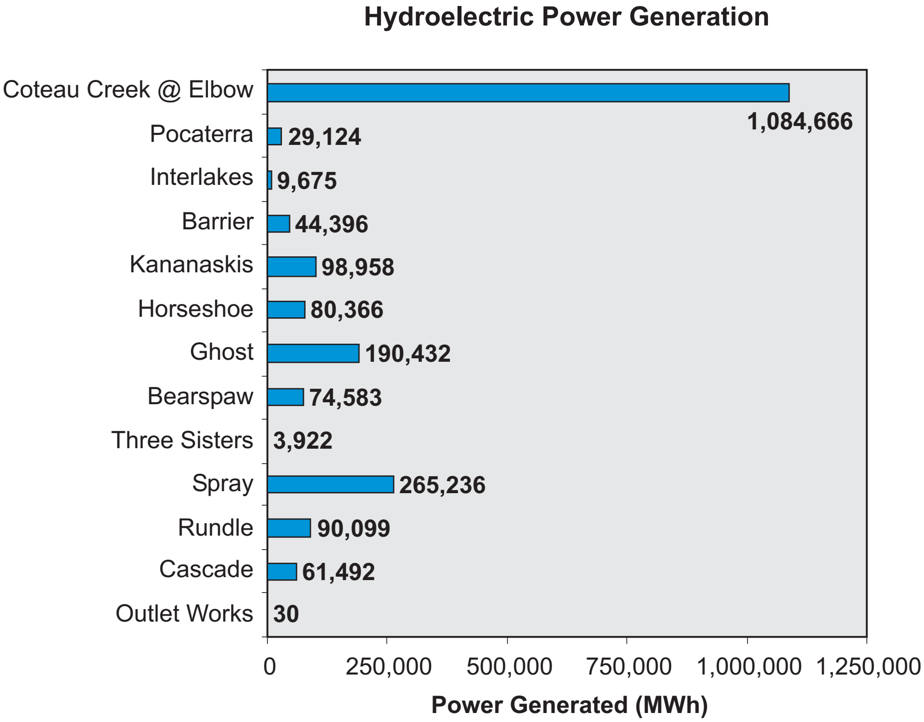


Figure 8.14 *Hydroelectric power generation (1996).*

8.3.3 Summary of Power Generation by Sub-basin

The amount of power generated by sub-basin for the surveyed plants is given in Figure 8.15. The largest amount of power generated was in the Red Deer Basin (over 5 million MWh) because of the Sheerness thermal power station. The SSR basin accounted for the second highest production, due to the Coteau Creek station with over 1 million MWh. The twelve stations within the Bow River Basin produced slightly less than the South Saskatchewan Basin at about 950 million MWh.

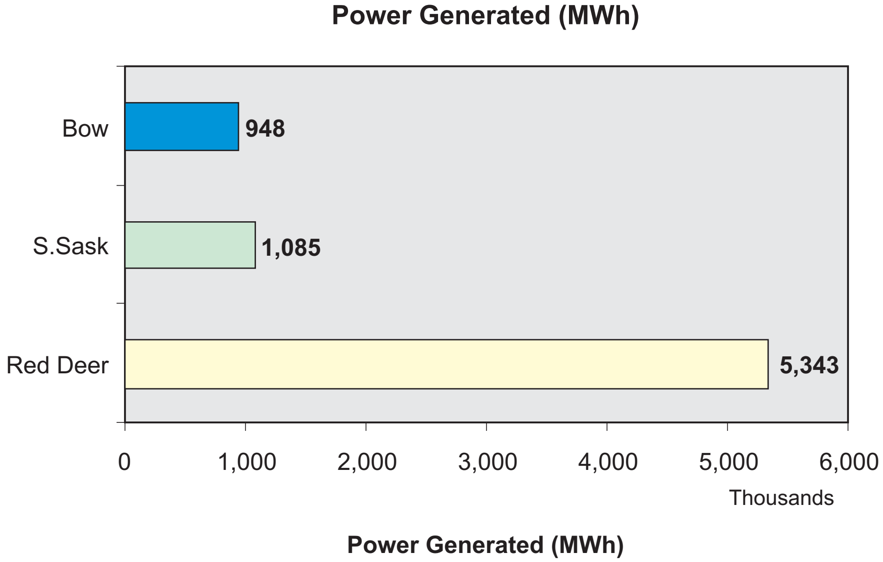


Figure 8.15 *Power generated by sub-basin (1996).*

8.4 Agricultural Water Use

8.4.1 Irrigation Water Use

Unlike other uses, the amount of water used for irrigation can be highly variable from year to year depending on climatic factors, namely precipitation and crop evapotranspiration. Other factors that influence irrigation demand include: the properties of various crops and soils, the type of irrigation system used and its efficiency in water application, and economic and social factors. Irrigation water demands are simulated for this study by taking into consideration irrigated areas, crop types, operational parameters, and climatic conditions. To account for the variability of irrigation demands over time, a long period of historical climatic record was also used. Such an approach allows for the investigation of climate changes on irrigation water demands for given irrigation areas and the combination of crops, soil types, irrigation systems and management practices under varied climatic conditions.

Information on the water use irrigation districts was provided by the Saskatchewan Watershed Authority, Agriculture and Agri-Food Canada, and the Government of Alberta. Table 8.3 lists the irrigation districts within the SSRB and the irrigated area for each. The total irrigated area of the SSRB, by user districts, is estimated to be about 500,000 hectares. The majority of this is within Alberta at about 475,000 hectares, while the Saskatchewan portion contains roughly 28,000 hectares. The largest districts within the Alberta portion of the SSRB include: the St. Mary (137,000 hectares), Eastern (110,000 hectares), Bow River (79,000 hectares), Lethbridge Northern (58,000 hectares), Taber (30,000 hectares) and Western (28,000 hectares) user districts. At this time there is not enough information to provide an estimate of private irrigation within the SSRB. The location of the irrigation districts is shown in Figure 8.16.

Alberta			Saskatchewan		
District	**Abbrev.**	**Area (Ha)**	**District**	**Abbrev.**	**Area (Ha)**
Aetna	AID	868	Chesterfield	CWUD	280
Bow River	BRID	79,374	Grainland	GWUD	1,047
Eastern	EID	109,747	Hillcrest	HIWUD	1,291
Leavitt	LID	1,732	Luck Lake	LLWUD	3,307
Lethbridge Northern	LNID	57,954	Macrorie	MWUD	847
Magrath	MID	5,806	Miry Creek	MCWUD	675
Mountain View	MVID	1,358	Moon Lake	MLWUD	616
Ross Creek	RCID	297	Riverhurst	RWUD	2,912
Raymond	RID	16,057	South Sask River	SSRID	15,272
St. Mary	SMRID	137,287	North Waldeck	WWUD	667
Taber	TID	30,270	River Lake	RLID	985
United	UID	5,723	Maple Creek	MCIP	n/a
Western	WID	27,818			
Total		**474,291**	**Total**		**27,899**

Table 8.3 *SSRB irrigation district areas.*

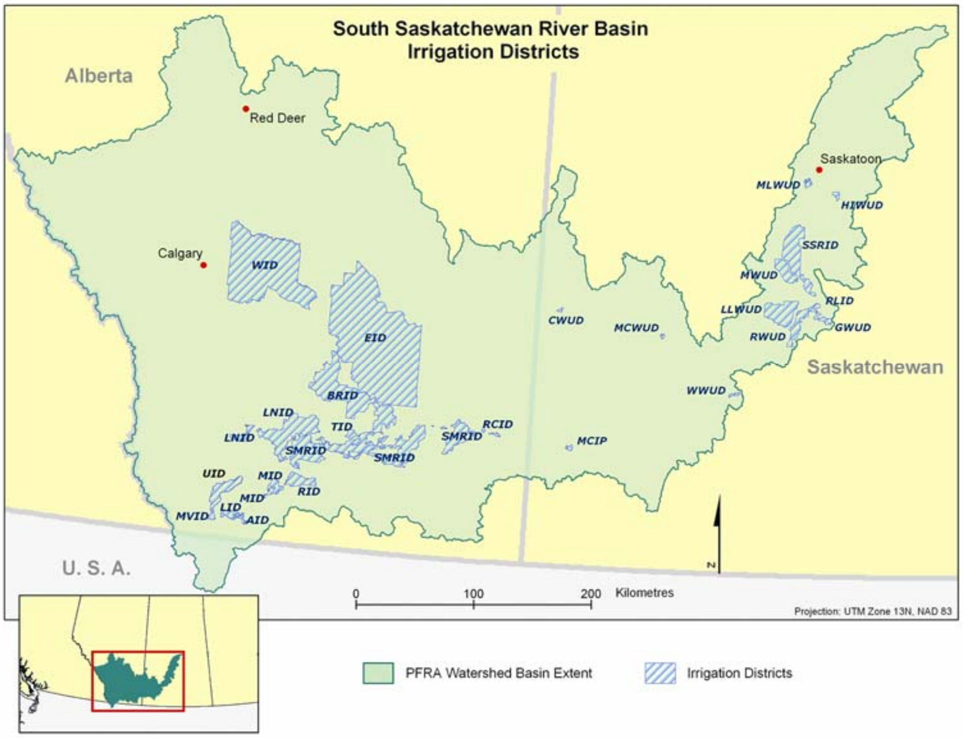


Figure 8.16 *Irrigation district locations. Map produced by GIServices, University of Saskatchewan.*

The proportion of water used for irrigation by sub-basin is given in Figure 8.17. Figure 8.18 shows the total water used for irrigation by sub-basin. Due to the overwhelming volume of water used for irrigation in all basins, irrigation water use is by far the largest of all uses within the SSRB, estimated at about 2.5 billion m^3. Irrigation water use is highest in the Oldman River Basin at 37% of the total (about 932 million m^3). The Bow River Basin accounts for about 24% of the total water use (about 612 million m^3). Irrigation water use within the Red Deer Basin accounts for 20% (499 million m^3) of the total, with the least amount, 19% (about 478 million m^3), being used in the SSR Basin.

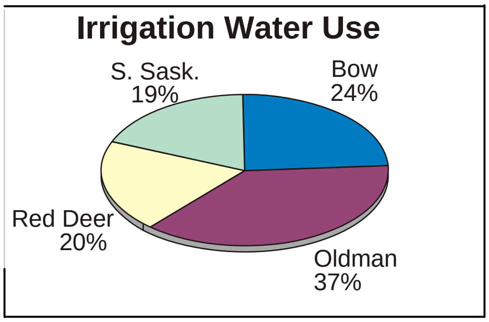


Figure 8.17 *Proportion of irrigation water use by sub-basin (1996).*

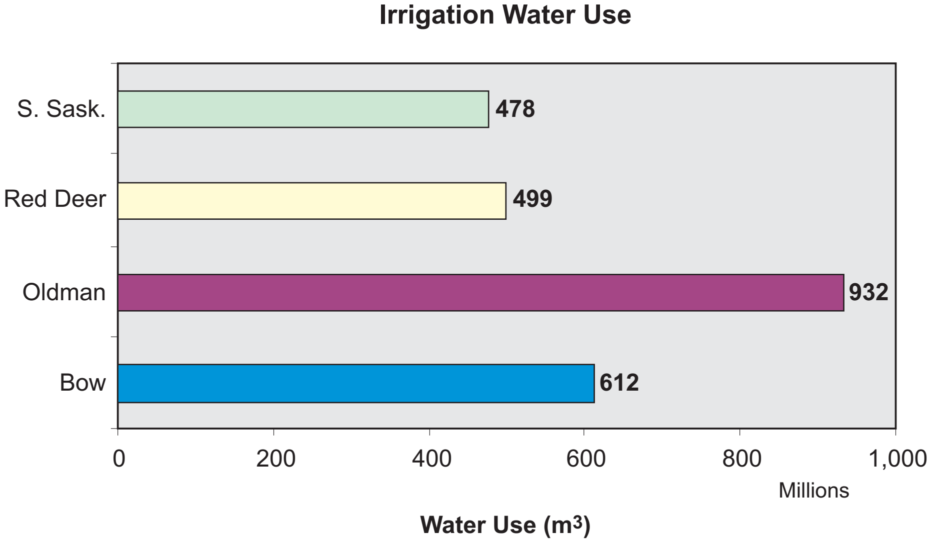


Figure 8.18 *Irrigation water use (1996).*

8.4.2 Livestock Water Use

Livestock data was obtained from the 1996 Census of Agriculture database (Statistics Canada: 1996 Census of Agriculture CD-ROM: release 2.1). The data includes animal population by animal type for ten animal types. Livestock populations were associated with census subdivisions (CSD). The associated livestock water uses were estimated, for each animal type, by applying water use coefficients provided by the Prairie Provinces Water Board (PPWB). Livestock considered in this study include: cattle (dairy, beef, bulls, steers and calves), pigs, sheep, horses, hens and chickens, and other poultry.

The proportion of water used for livestock is shown in Figure 8.19 and the livestock water use by sub-basin in Figure 8.20. Overall, the total amount of water used for livestock watering is estimated at about 84 million m^3. Livestock watering is highest in the Red Deer River Basin, accounting for 45% of the total (about 40 million m^3). The South Saskatchewan River Basin accounts for the second highest use at 38% (about 31 million m^3). The Bow River Basin accounts for 11% of the total (about 9 million m^3), while the Oldman River Basin uses the least amount of water for livestock at 3% (about 2 million m^3). The largest volume of water used for livestock is in the Red Deer River Basin at approximately 40 million m^3, with the SSR Basin following at about 31 million m^3. The Bow River Basin uses just over 9 million m^3, while the least amount of water is required for livestock in the Oldman River Basin at about 2 million m^3.

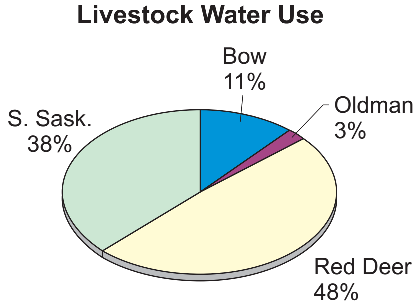


Figure 8.19 *Proportion of livestock water use by sub-basin (1996).*

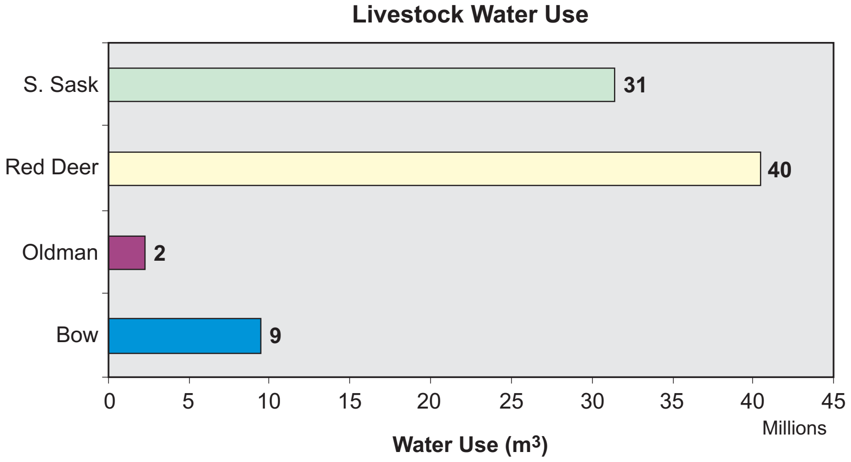


Figure 8.20 *Livestock water use (1996).*

8.4.3 Summary of Agricultural Water Use by Sub-basin

The proportion of water used for agriculture for each sub-basin is given in Figure 8.21 and the amount of water used within each sub-basin in Figure 8.22. The total amount of water used for agriculture within the SSRB is estimated at 2.6 million m^3. Agricultural water use is highest within the Oldman River Basin at 35% of the total (or an estimated 934 million m^3); this is due to the significant amount of water used for irrigation. The Bow River Basin accounts for about one quarter of the total agricultural water use at 24% (about 625 million m^3). The Red Deer and South Saskatchewan River basins use similar amounts of water for agricultural uses at 21% (539,000 m^3) and 20% (509,000 m^3), respectively.

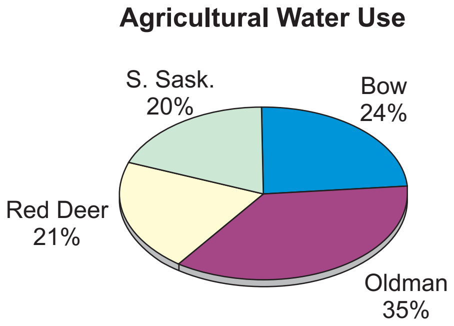


Figure 8.21 *Proportion of agricultural water use by sub-basin (1996).*

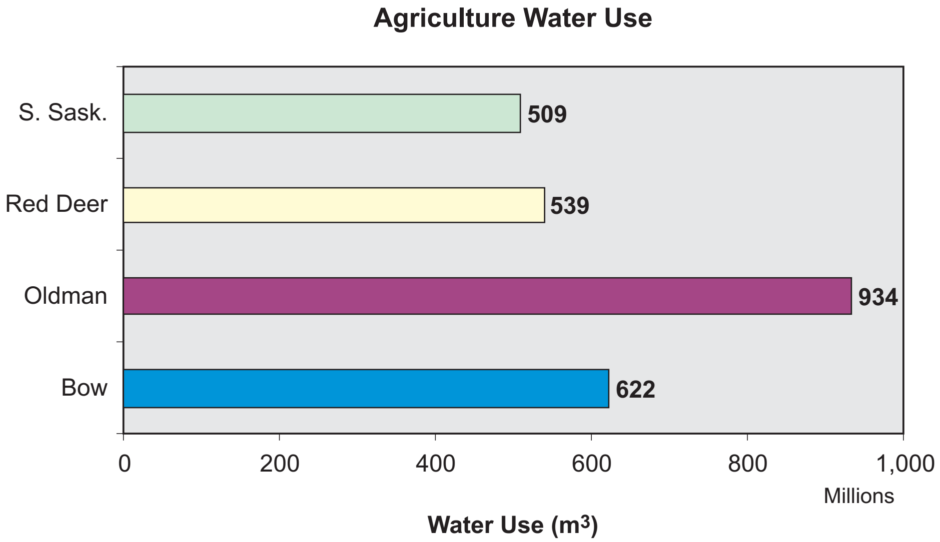


Figure 8.22 *Agriculture water use by sub-basin (1996).*

8.5 Industrial Water Use

Industrial water use data was obtained from Environment Canada's 1996 *Industrial Water Use Survey*. The survey included the mining and manufacturing sectors. The following sections include water use information for both the mining and manufacturing sectors, and industrial water use by major sub-basin.

8.5.1 Water Use for Mining

Mining operation types include petroleum and coal, non-metal minerals, coal mines, and metal and non-metal mines. The proportion of water intake for these sectors is given in Figure 8.23 and the amount of water intake by each mining sector in Figure 8.24. Metal and non-metal mines and non-metal minerals accounted for 99% of the total mining water intake (nearly 12 million m^3). Metal and non-metal mines used more water than all other types combined accounting for almost 66% of the total or an estimated 8 million m^3. Non-metal mineral mining water intake accounts for about 33% of the total (4 million m^3). Coal mines, and petroleum and coal mining used far less water by comparison, accounting for 0.8% (98,000 m^3) and 0.2% (18,000 m^3), respectively.

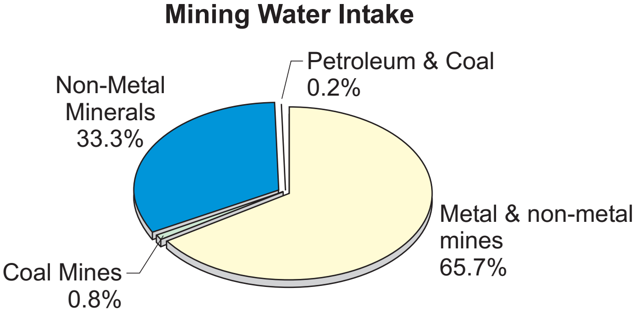


Figure 8.23 *Mining water intake (1996).*

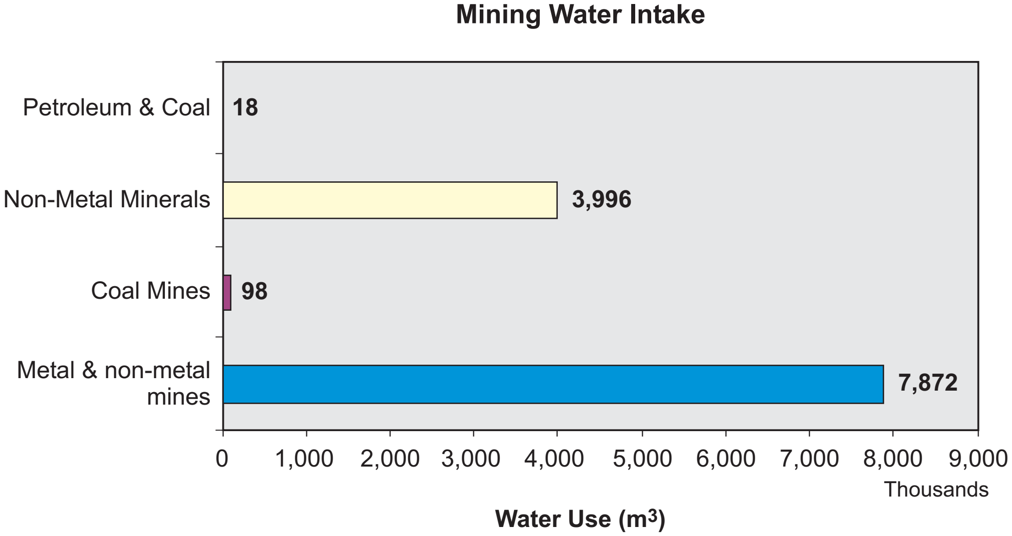


Figure 8.24 *Mining water intake (1996).*

8.5.2 Water Use for Manufacturing

Manufacturing industry types include: food and beverage, chemicals, primary metals (iron), rubber, plastics, transportation equipment, paper, wood, and metal fabrication. The proportion of water intake for these sectors is given in Figure 8.25 and the amount of water intake by each manufacturing industry in Figure 8.26. As with mining use, two industries account for the majority of the total water intake, at about 42 million m^3; the food and beverage, and chemical sectors account for 96% of the total water intake. The water intake by the food and beverage industry accounts for 59% (about 25 million m^3) of the total manufacturing water intake. Water intake by the chemical industry makes up 37% of the total or roughly 15 million m^3. Water intake by the primary metal (iron) industry was third highest at about 800,000 m^3, but this accounts for only 1.9% of the total. The rubber industry used similar amounts of water at about 600,000 m^3 or 1.4% of the total. The remaining 5 industries (plastics, transportation equipment, paper, wood, and metal fabrication) account only about 1% of the total water intake or about 375,000 m^3.

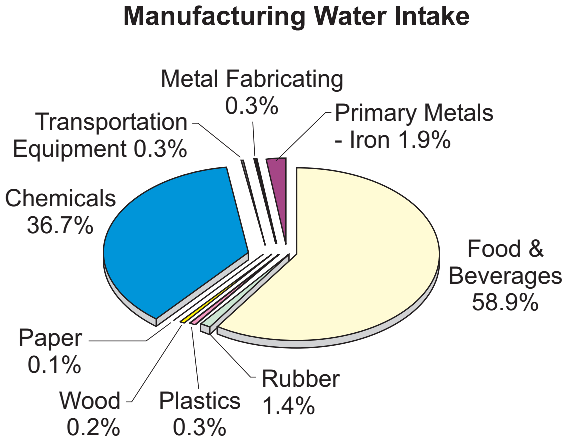


Figure 8.25 *Manufacturing water intake (1996).*

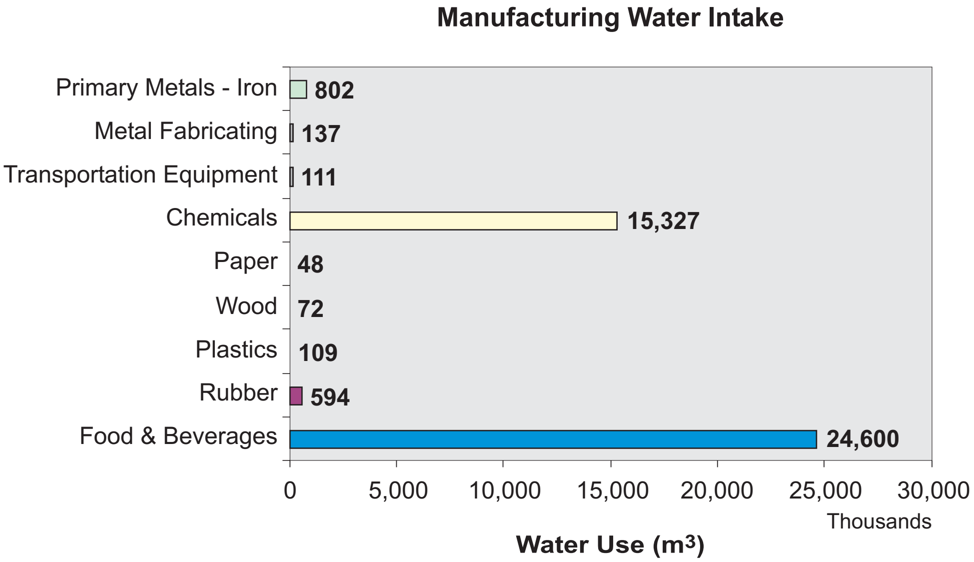


Figure 8.26 *Manufacturing water intake (1996).*

8.5.3 Summary of Industrial Water Use by Sub-basin

The industrial water use by sub-basin is given in Figure 8.27 Industrial water use is greatest within the SSR Basin at 36% with the Bow River Basin showing slightly less at 30%. Industrial water use within the Red Deer Basin accounts for 22% of the total, and the least amount of water used by industries is in the Oldman River Basin at 12% of the total.

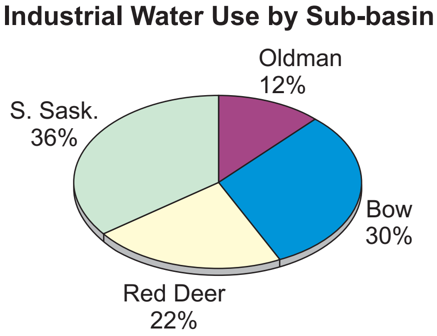


Figure 8.27 *Percentage of industrial water use by sub-basin (1996).*

A summary of the industrial water intake and percentage consumed by sub-basin is shown in Table 8.4. The total water intake by industries within the SSRB in 1996 is estimated at about 53 million m^3. The largest industrial water intake is shown to be in the SSR Basin at about 19 million m^3. The majority of the intake within the SSR occurs in three sectors: metal and non-metal mines (about 7.9 million m^3), food and beverage (about 6 million m^3), and chemicals (about 4.6 million m^3). Of these sectors, the metal and non-metal mines consume the most water at 90% of the total water intake. The food and beverage sector also consumes a large portion of the water intake, at 73%, while the chemicals sector uses less than 25% of the total water intake.

The second largest intake of water by industries occurs in the Bow River Basin at 16 million m^3. Two sectors account for the majority of the total intake here, at about 15 million m^3, namely the food and beverage (about 11 million m^3) and the non-metal minerals (about 3.7 million m^3) sectors. The primary metals (iron) sector is the third largest user within the Bow River Basin at almost 800,000 m^3. The food and beverage sector consumes 76% of the total water while non-metal minerals take about 50%.

Industrial water intake within the Red Deer Basin is estimated at almost 12 million m^3. The chemical sector accounts for the majority of this intake at about 10.5 million m^3 while the next largest intake is by the food and beverage sector at about 850,000 m^3. The non-metal minerals sector intake is third largest, estimated at about 200,000 m^3. The chemical sector consumes only a small proportion of the water intake, at 15%. The least amount of water used by industries is within the Oldman River Basin, at an estimated 6.6 million m^3. Nearly all of this (91%) is accounted for by the food and beverage industry at almost 6.5 million m^3.

Sector Name	Oldman		Bow		Red Deer		S. Sask	
	Intake (m^3)	Cons	Intake (m^3)	Cons	Intake (m^3)	Cons	Intake (m^3)	Cons
Non-Metal Minerals	69,381	32%	3,651,931	51%	185,977	41%	88,948	33%
Petroleum & Coal	-	-	-	-	18,235	96%	-	-
Metal & non-metal mines[1]	7,200	83%	-	-	-	-	7,865,091	90%
Coal Mines[1]	-	-	-	-	98,032	100%	-	-
Food & Beverages	6,461,075	91%	11,386,744	76%	844,068	82%	5,908,510	73%
Rubber	-	-	-	-	-	-	593,558	89%
Chemicals	202	66%	194,764	53%	10,512,268	15%	4,619,878	23%
Plastics	4,509	82%	84,238	60%	7,679	74%	12,165	91%
Wood	12,641	85%	25,357	96%	33,738	81%	-	-
Paper	-	-	24,630	10%	23,576	5%	-	-
Primary Metals - Iron	10,613	45%	780,838	62%	6,330	8%	4,200	100%
Metal Fabricating	2,241	91%	118,433	95%	4,835	92%	11,856	91%
Transportation Equipment	27,258	100%	79,788	98%	1,200	100%	2,820	100%
Total	**6,595,120**	**-**	**16,346,723**	**-**	**11,735,938**	**-**	**19,107,026**	**-**

Note: [1] Values from mineral extraction survey

Table 8.4 *Industrial water intake by sub-basin.*

8.7 *In Situ* Water Use

Various instream water uses include channel transportation and park or riparian zone enjoyment, some of which involve recreational use (i.e. boating/skiing, fishing and swimming) or wetlands direct or indirect use (i.e. for hunting versus waterfowl conservation).

8.7.1 Recreational Water Use

Information about the location of recreational areas and parks was obtained from the Government of Alberta and Saskatchewan Environment. Figure 8.28 shows the location of recreational areas and parks within the SSRB. The accurate measurement of recreational water use is a challenge.

The actual measure of water use itself is often not possible, not tracked or overlapping in terms of activities (i.e. scenic viewing while fishing or transporting goods). Typically, statistics focus on the number of people who visit recreational areas and parks for water-based activities, and water use may be estimated from that data.

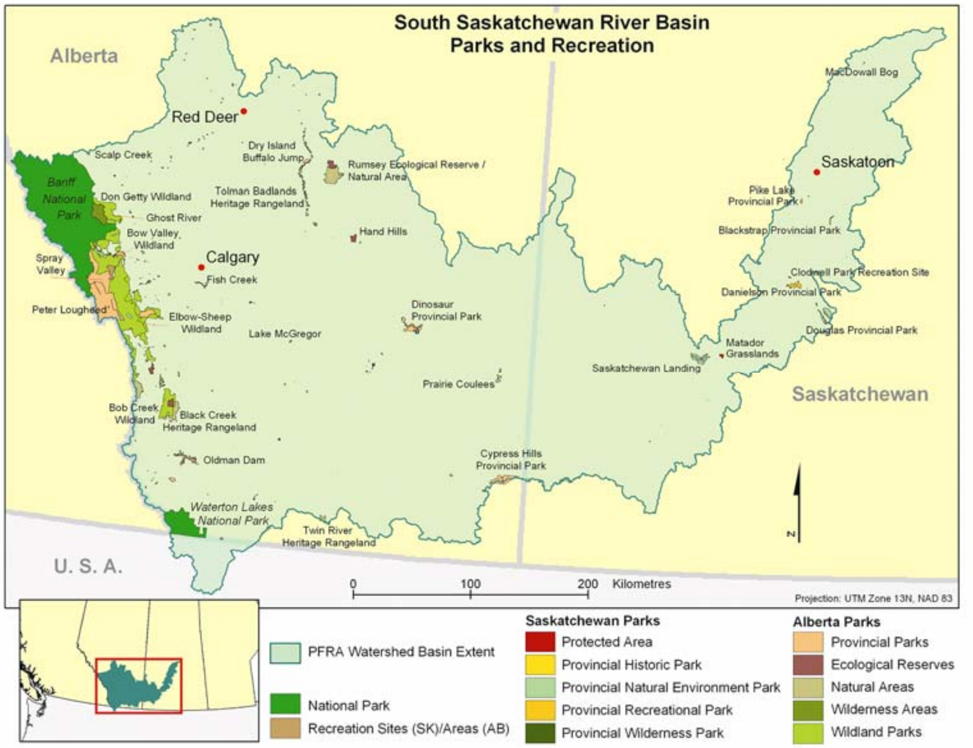


Figure 8.28 L*ocation of recreational areas and parks in the SSRB. Map produced by GIServices, University of Saskatchewan.*

8.7.2 Wetlands

Some basic information on wetlands was given previously in Section 7.16. An assessment of the current status of wetland research and inventories is ongoing. One challenge with mapping or doing an inventory of wetlands is the dry-wet cyclical nature of several categories of wetlands; hence, mapping may only capture wetland area at a given point in time.

9 Economic Value of Water in the South Saskatchewan River Basin

9.1 Introduction to the Economic Valuation of Water

Water has many alternative functions, some of which entail water losses, and some of which do not. For instance, households use water directly to provide utility enhancing services (food preparation, cleaning, sanitary services, recreation, etc) while businesses use water directly as a critical input into production (processing, cooling, cleaning, sanitation, etc). Households and businesses also benefit from water *in-situ* in terms of recreation possibilities (fishing, boating, and scenery), as productive inputs (hydro generation and transportation), or as a means of disposing of effluent. They also benefit from indirect services provided by a healthy watershed in terms of flood control, habitat preservation, water cleansing, etc.

In a world where water is unlimited, withdrawal and consumption in one activity will have negligible effects on other users in other spheres. We do not live in such a world. Rather, given the current demands for water in its alternative uses, activities by one affect others and we face tradeoffs between users and usages. For example, water used in irrigation may not be available for industries. Changes in water supply induced by global climate change, as well as continued population and economic growth, will tend to make these tradeoffs more acute as demand for water, in each of its uses, increases.
To assess the socio-economic effects of global climate change we need to gauge the impact on water users of changing supply, quality, and allocations. These impacts will differ across users and regions depending on the degree to which users rely on water, their access to alternative sources of water, and their ability to adapt to changing water conditions through changes in behaviour or changes in investments. A first step in this assessment process is to measure the benefit of water to current users as well as the effects changes in water supply would have on the welfare of current users.

The main objectives here are:

1. To identify data sources and methodologies used to measure the economic value of water in the SSRB.
2. To identify and measure the economic value of water in the SSRB in its alternative withdrawal uses.
3. To provide water values as an input to the measurement of the economic effects of climate change on water resources in the SSRB.

This section focuses solely on the value of withdrawn water in the SSRB. Our approach is to identify and quantify the economic impact of a *change* in water resources on i*ndividual users and user groups*. Depending on data availability we report both marginal values (the effect of a small reduction in water) and average values. Where possible we also report the total benefit of water to a user group. This approach is directly policy relevant as it allows us to identify the users or usages that are most affected by water shortages and to identify strategies that might minimize adverse impacts. To do this we need a common unit of measurement that permits direct comparisons between users and between usages. A common yardstick sheds light on the tradeoffs we face now and in the future. Our approach is to obtain a monetary value for water in its alternative uses though we recognize that it may not capture all policy relevant dimensions associated with water scarcity. Measurement of *in situ* values such as recreation, wetlands, and transportation is left to another report. Water quality, although of obvious importance, is not considered here.

This following section provides the underlying economic principles used to value water in its alternative uses. It also contains a brief summary of those uses. Section 9.3 then considers municipal water demands from households, commercial and institutional users, and industrial customers, Section 9.4 looks at the value of water in irrigations while Section 9.5 considers livestock producers. Sections 9.6 and 9.7 look at industrial and mining values followed by Sections 9.8 and 9.9 that consider hydro-electric generation and thermal generation respectively. Section 9.10 concludes.

9.2 Overview of Water Use and Valuation

9.2.1 Economic Premise

The basic premise for establishing a monetary value for water is that individuals (households as well as businesses) are willing to pay for the benefits they get from water whether or not these benefits are derived directly through the use of water or indirectly through services provided by water. For instance, individuals are willing to give up income or their own leisure time for greater access to water or for higher quality water. Businesses are willing to give up revenues that would otherwise accrue to workers or shareholders for access to, or preservation of, water resources. We can interpret an agent's *willingness to pay (WTP)* for water as the benefit (either direct or indirect) each perceives they receive from the watershed. The agent would not pay more than they receive in benefits regardless of whether those benefits accrue to themselves or, though altruistic motives, to others. As such, WTP can be interpreted as a direct measurement of the benefits received by agents. Since the WTP uses a money-metric to measure benefits, we can sum these up across agents to get a value of the benefits that accrue to the social group.

Further, the larger the observed WTP, the larger the perceived benefits to the user and to society. It is this change in benefits that we are trying to estimate when we consider changes in water resources. The common money-metric also allows us to consider reallocations of water resources from one user to another by comparing aggregate WTP measures across scenarios.

The *marginal willingness to pay* (mWTP) schedule is what agents would be willing to pay for one more unit of water. As with any other consumer item, the more water we have the less we are willing to pay for additional quantities: total benefits from water increase as the quantity (and/or quality and access) rises but the increase in benefits is diminishing. Hence, mWTP declines as quantity rises. Our task is to identify the mWTP schedule in the relevant range of reductions/increases to identify the change in welfare induced by changes in water resources. This change in welfare is sometimes referred to as a *penalty function* as it relates social costs of adjustment to restrictions in water use. Each category of use will generate its own penalty function.

The challenge we face is to identify agents' mWTP. If agents have to pay for each unit of water they use, as is the case for municipal water supplies, then the price they pay reflects their mWTP. The demand curve for water (the relationship between price and consumption) is observable and is identical to the mWTP schedule.

The problem we face, as with many other natural resource and environmental amenities, is that formal markets for water do not always exist: agents do not always pay an explicit price for additional water. This is either because water use is un-metered (as with irrigation and livestock), water use is un-meterable (such as with most recreation activities), or agents derive benefits without actually "using" the resource directly (as with the pleasure derived from knowing that an ecological area exists). This absence of formal markets means that direct observation of mWTP is often difficult. Our strategy in these cases is to simulate agent responses to hypothetical scenarios based on available production technologies and so impute the mWTP. For instance, livestock producers can respond to shortages in water by either reducing their herd size or finding alternative sources of water. We can estimate, using available data, what they would be willing to pay to avoid these changes. Similarly, irrigators can change the types of crops under irrigation, they can change irrigation techniques, or they can reduce the extent of irrigation. Each choice imposes additional costs in terms of lost net income or increased investment expenditures. Business enterprises can also reduce production, increase recycling of water, or alter the production process to reduce the intensity of water use. Prices that are not observed but imputed from the mWTP are called *shadow prices*. More details about techniques used for each type of water use are provided in each section below.

Important to these calculations is the timeframe considered for agents to adjust to changes in water availability. For instance, if there is an abrupt and unanticipated drought, agents will not have had much time to adjust. Consumers would give up watering lawns, firms may reduce the scale of production, and livestock producers may reduce herd sizes. If agents have some warning however, then they can institute changes to reduce their reliance on water or intensity of water use. For instance, firms can invest in more water recycling, livestock producers can build water collection ponds, and households can buy more water efficient appliances. In general, the more time agents have to adjust to water shortages, the lower their costs of adjustment, and so the smaller their mWTP for water. Where possible, we attempt to report values based on these different timeframes.

Also important is the degree to which current water use is restricted. For instance, some municipalities do not charge for water on a metered basis. Payments for water are independent of actual use. Hence the price of one unit of additional water is zero. Agents will rationally choose to consume until their mWTP is also zero. This implies that, at the margin, households are using water in ways that offer virtually no additional benefits. (For instance, they may use water to wash down their driveway). Therefore, small reductions in water use will have only a small impact on welfare. On the other hand, if the water is metered and the price is high, agents will rationally reduce their water consumption and eliminate low value uses. This implies that small reductions in water use will have large impacts on welfare. Where possible, we attempt to account for current efficiencies in estimating the implicit cost of water reductions.

9.2.2 Sources of Values

There are a number of different ways in which water can yield value to society. Figure 9.1 below shows alternatives sources of these values. Broadly, value derives either because we use the water, either directly or indirectly, or because we value the contribution water makes to welfare in some broader sense. We use water directly by withdrawing water from its source. This is the case with household municipal consumption as well as agricultural and industrial production. We also use water directly in the production of hydro-electricity even though that water is not withdrawn. This is also true for some recreation activities such as fishing, swimming, and boating.

We indirectly use water when we utilize amenities that are supported by water. For instance, hunting water birds depends on the services of water to support waterfowl populations. Hence hunters value water indirectly through the value they place on hunting. Similarly, we value a scenic view even though we do not “consume” the view in any conventional sense. This value can be directly confirmed by looking at property values and proximity to the river.

Water is also valued even if not used. For instance, though one may not regularly visit Lake Diefenbaker, the fact that one could has value. This option is valuable even if never realized. Similarly, one can value the lake as a bequest to the next generation as one recognizes that they would value the lake. A third alternative is that one may value the lake because it supports waterfowl populations even though that person may never intend to hunt, or never even intend to watch, waterfowl. It is the knowledge that the lake exists that provides the psychological payoff.

In this section only those values associated with direct use are estimated. These are the shaded boxes in Figure 9.1. This narrow focus is justified for three reasons. First, data on non-use and indirect use values is, by definition, difficult to find since no market exchanges need take place. Further, the extent of these

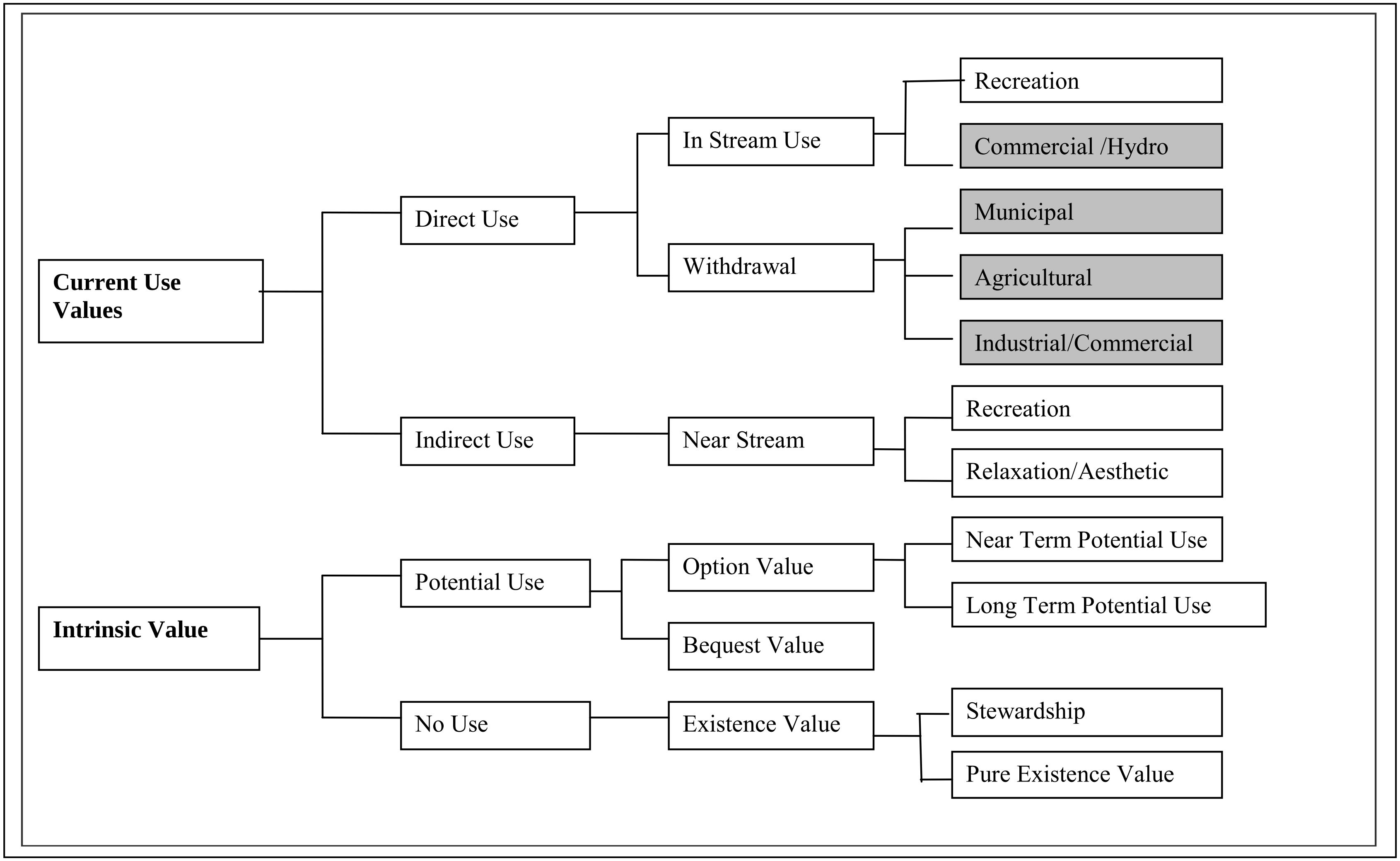


Figure 9.1 *Water Resource Values*
(*S*ource: Crane Management Consultants Ltd. *Net Economic Values of Recreationists for Outdoor Experiences in the Fraser River Basin*. Prepared for Environment Canada, Vancouver, B.C., 1992. Amended

"activities" is difficult to ascertain and so the scale is difficult to establish: it is not at all clear what constitutes the relevant "community" of interest. As indicated in the sections below, finding values for use sectors is not always easy, but it is generally more difficult for non-use sectors and likely less precise. Second, as long as climate-induced changes in water resources are not too severe, non-use values and some instream values may not have changed at all. Since we are interested in the impact of climate change on socioeconomic factors in the basin, it may be a safe first approximation to ignore non-use values. Third, climate-induced changes in the use value of water may in fact be a good proxy for climate-induced changes in the non-use value of water. Focus on the withdrawal uses would therefore offer insights into non-withdrawal uses.

A further consideration in valuation is whether we should consider the value of water at the point of withdrawal or whether we should consider the value of water used up in the process of production or consumption. That is, water withdrawn from a water source is returned to the environment in some form though not all water withdrawn is necessarily returned to the same water system. For instance, water used for washing in households and businesses is returned to the river system through the sewer system. Irrigation runoff is also returned. However, much of that irrigation water evaporates and is returned as precipitation; it may also find its way to another basin or into non-contributing areas (i.e. wetlands). Similarly, some of the water may enter the groundwater system and may or may not eventually replenish the basin in which it was taken from. To address some of these issues, we differentiate between *water withdrawal* and *water consumption*.

Water consumption refers to the fraction of water not returned to the river basin and so lost to other users. Different activities lead to different consumption intensities. Values associated with water withdrawal correspond more closely to *private values* – the value an individual places on access to water. Values associated with water consumption correspond more closely to *public or social values* – the opportunity cost of using water in one use as opposed to some other use. We are most directly concerned with the impact of water shortages on individual user so we use water withdrawal as a basis of analysis. However, where possible, we also provide information on water consumption for further analysis.

A third consideration is to value the raw untreated water from the river basin. This means we need to adjust values for municipal and industrial use to account for treatment and distribution. These value-added characteristics increase the benefits to users but make comparison across users more problematic. We make this adjustment by subtracting the incremental cost of delivery and treatment from the total value of water. The residual is the value of raw untreated water.

9.3 Value of Water in Municipal Residential, Commercial, Institutional and Industrial Enterprises

9.3.1 Demand and the Value of Water

Municipal water authorities supply treated water to residential, commercial, institutional and industrial users as well as to other municipalities. We can separate the value of water into residential, commercial/institutional and industrial water demand sectors since prices and consumption characteristics differ across these sectors.

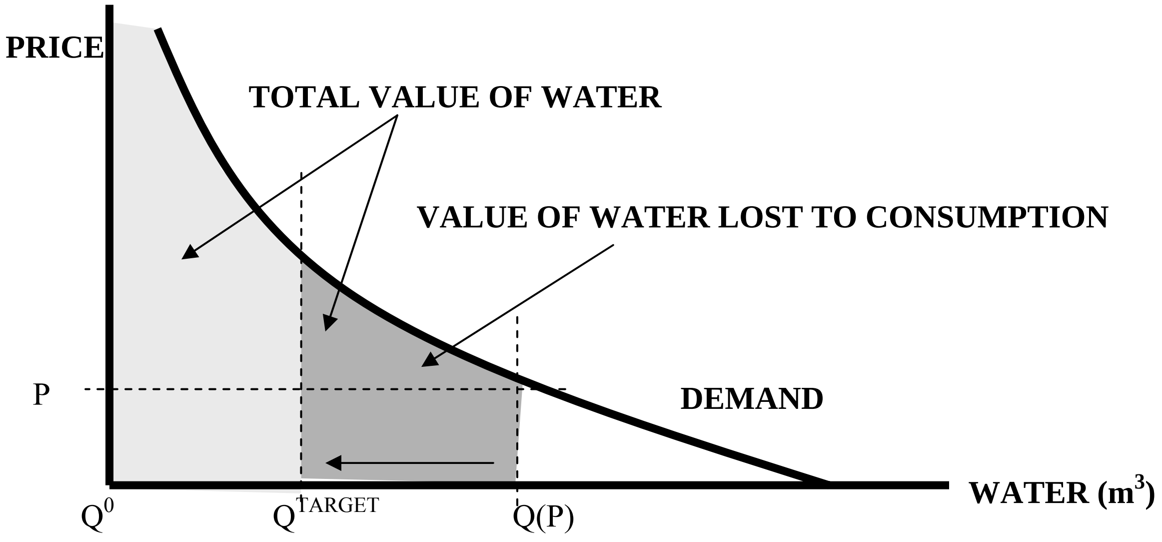


Figure 9.2 *Value of Water*

To determine the value of water consumed we must be able to identify the demand curve for water. The demand curve relates a household's or firm's actual consumption of water to a given price for water that they may face. It tells us how much the consumer would or does purchase at different prices. (It is therefore identical to the mWTP curve). We can interpret the demand curve in such a way as to impute the value of consumption a household receives even though we know that benefits may not be an observable phenomenon. See Figure 9.2 above. The demand curve for a particular municipality is plotted as the downward sloping curve. This reflects the fact that consumption increases as the price falls. If the actual price charged per cubic meter is P, and there are no quantitative restrictions on water use, then individuals would collectively consume water at the level Q(P) cubic meters per period. The total value of water to the community is the area under the demand curve from Q^0 to Q(P). The rationale for this interpretation follows from the assumption that households are free to choose their own consumption levels given their individual circumstances. For instance, if a person buys $100m^3$ of water at a price of $\$1m^3$, it must be the case that the person felt that the 100th unit of water was worth the $1 spent on it. Otherwise they would not have chosen to purchase that last cubic meter. Since the demand curve reveals actual willingness to pay for water at different prices, the area under the demand curve gives us a *revealed measure of benefits*. At low prices additional units of water are not as valuable since the household is already consuming a lot of water. At high prices, the low Q implies a high value of an additional unit of water.

There are three factors that determine the total and marginal value of water: the price paid for each additional unit of water (denoted as *marginal price*), actual consumption, and the shape of the demand curve. Price and consumption data are often directly available from water suppliers. The shape of the demand curve is identified by the *demand elasticity of water* (or simply *elasticity*). This demand elasticity measures the sensitivity of consumption to changes in prices. The higher the elasticity the more sensitive is demand to prices. Higher elasticity reflects an increased ability of users to reduce water consumption. Hence a higher elasticity implies that a given reduction in quantity imposes a smaller penalty. Elasticity is calculated as the proportionate change in consumption induced by a change in prices:

$$\Delta Q/Q \ / \ \Delta P/P = P/Q \ \Delta Q/\Delta P = \mathrm{dln}Q/\mathrm{dln}P.$$

If elasticity is perfectly elastic ($-\infty$) then there is no penalty to lower consumption since the user can find substitutes that provide equal value (perfect substitutes). This is not likely the case for water as perfect substitutes are not easily available.

We can estimate the residential elasticity of demand for water econometrically. We first specify the individual demand function for water as $Q=\alpha P^{\beta}$ where:

- Q is consumption of water in cubic meters per household or per capita,
- P is the price of water for one additional unit, and
- and $\alpha > 0$ and $\beta < 0$ are demand parameters to be estimated.

Taking natural logarithms gives us $\ln(Q) = \ln(\alpha) + \beta \ln(P)$. Hence $d\ln Q/d\ln P = \beta$. The log-linear form provides an intuitive interpretation: a 1% rise in the price of water will decrease the quantity of water per unit of output by β%. It is this value of β that we must first estimate.

Estimating the elasticity of demand for commercial water requires some additional assumptions. Following Renzetti (1987) industrial/commercial water demand can be considered a function of the price for water and the firm's output: $ln(Q) = \alpha + \beta\, ln(P) + \gamma ln(Y)$ where:

- Q is the quantity of water in cubic meters intake by the commercial sector,
- P is the marginal price of water per cubic meter,
- Y is output of the commercial sector, and
- $\alpha > 0, \beta < 0,$ and $\gamma > 0.$

If we assume that there is a fixed coefficient between Y and Q then $\gamma = 1$ since a 1% increase in Y will entail a 1% increase in water demand Q. Hence we can rewrite this as:

$$ln(Q/Y) = \alpha + \beta\, ln(P)$$

where Q/Y is the amount of water used per unit of output. This formulation tells us that water consumption per unit of output is solely a function of the price of water.

Commercial output on a community basis is not easily available so we assume that output is a linear function of the labour employed in commercial enterprises. We further assume that the labour employed in commercial enterprises is a fixed proportion of the local (census) population. Under these further assumptions, Q/POP varies one-for-one with Q/Y and yields the relationship:

$$ln(Q/POP) = a + b\, ln(P)$$

Here b is the elasticity of per capita commercial consumption use induced by a change in water prices and is identical to the elasticity of commercial consumption.

9.3.2 Calculation of Penalty Function

The most direct way to estimate value is to measure the area under the demand curve. However, we cannot estimate this value since the marginal value of water is infinite as consumption goes to zero. That is, the value of water currently consumed is, by definition, infinite: $\int_0^Q v(x)\, dx = \infty$.

Since the total value of water is immeasurable, the approach we will take is to estimate the lost value resulting from a restriction on water use. For instance, if we reduce water consumption by 10% we can estimate the reduction in benefits if we know what the relevant demand curve looks like. See Figure 9.3 below. This change in value is the area under the demand curve between current water use (Q^A) and target water use (Q^R). This has a finite value. We can calculate this value for any quantitative reduction. By estimating this penalty function we can measure the value of water by its opportunity cost. Further, how we reduce consumption, whether it be through higher prices or quantitative restrictions, is not important.

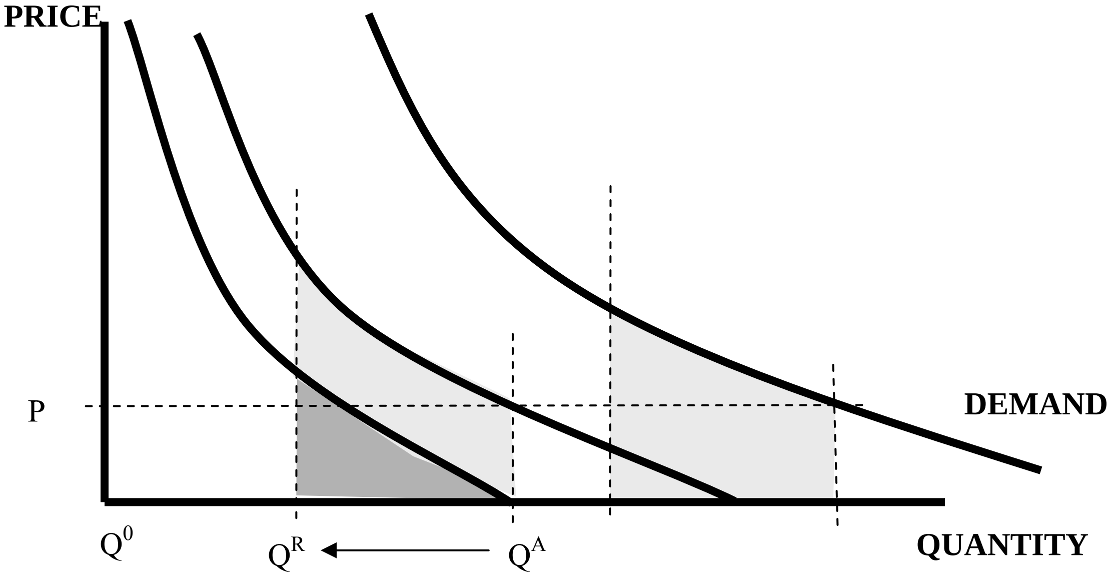


Figure 9.3 *Value of Water with Different Prices and Consumption*

To estimate the penalty function we need to be able to locate the demand curve in price and quantity space as well as determine the shape of the curve. The location is determined by actual observations of marginal price and quantity for each community. The higher the marginal price paid, the more difficult consumers find meeting the restriction, and therefore the higher the penalty (as depicted in Figure 9.3). Due to data limitations it is not possible to identify individual demand curves for each community. Our approach is to assume that the elasticity of demand is identical for each community but that the location, as determined by price and quantity, differ. Hence the penalty of a reduction is solely dependent on the marginal price paid since a given quantity reduction imposes the same penalty regardless of community size.

Given the estimate of elasticity (η) and current level of consumption (Q) and prices (P) we can easily estimate the value of lost consumption by integrating the area under the demand curve (taken from Jenkins, 2000).

$$\eta = \frac{d\ln Q}{d\ln P} \text{ or } d\ln P = \frac{d\ln Q}{\eta}$$

$$P_i = \exp[\frac{\ln Q_i}{\eta} + C]$$ where i refers to the observed price and quantity in community i

and C is the integrating constant

$$C = \ln P_i - \frac{\ln Q_i}{\eta}$$

The penalty function is $\int_{Q_r}^{Q} v(x)dx$ where Qr is the restricted quantity of water and Q is the actual quantity consumed. V(x) is the marginal value of water and is equal to P(x). Hence the penalty function is derived solely from the elasticity of demand, observed price and consumption, and the degree of restricted consumption.

$$P(r) = \int_{Q_r}^{Q} P(x)dx$$

$$P(r)= \int_{Q_r}^{Q} \exp(\frac{\ln x}{\eta} + C)dx$$

$$P(r)= \int_{Q_r}^{Q} \exp(\frac{\ln x}{\eta}) \exp Cdx$$

$$P(r)= \exp C\int_{Q_r}^{Q} \exp(\ln x^{\frac{1}{\eta}})dx$$

$$P(r)= \exp C\int_{Q_r}^{Q} (x^{\frac{1}{\eta}})dx$$

$$P(r)= \exp C[\frac{(x^{\frac{1}{\eta}+1})}{\frac{1}{\eta}+1}]|_{Qr}^{Q}$$

$$P(r)= \frac{\exp C}{1+ {}^{1}\!/_{\eta}}[Q^{1+1/\eta} - Q_r^{1+1/\eta}]$$

9.3.3 Calculating Community Penalty Functions

There are two approaches used to determine the penalty function: a uniform reduction and an efficient reduction. These two measures give us a bound on the value of water in the SSRB. Actual costs will depend on what extent restrictions are efficiently allocated within sub-basins and across sub-basins.

The first approach assumes that each community (in a particular basin or in the SSRB as a whole) must make an equal proportionate reduction in water. That is, each community must decrease water use by, say, 10% regardless of actual per capita use. This is termed a *uniform reduction*. The total imputed cost is the sum of individual community penalties. This total cost is then distributed over the total amount of water reduction to arrive at an average value of water for the basin.

The alternative approach, termed an *efficient reduction*, assumes that the costs of reductions are minimized for the relevant set of communities. Communities with initially lower water prices, for the same size reduction, will experience a smaller penalty (see Figure 9.3). The efficient reduction imposes reductions on these communities first. As their implicit shadow price of water rises, additional reductions are distributed across more communities. For large reductions, all communities are affected but by differing amounts.

To execute this procedure we use prices as the target and allow quantity to adjust rather than target quantities directly as above. We begin by sorting the communities in ascending order of marginal prices. The first *n* communities have marginal prices for water of zero (or 0.10 after adjusting). Using the MS EXCEL solver function we find a positive price that would induce a desired proportionate reduction in aggregate consumption across all communities: $Q_R = \alpha P^{\wedge\beta}$ where P^ is the simulated price and α is calibrated so that computed consumption is equal to actual consumption at the initial price: $\alpha = Q_0/P_0^{\beta}$. If $P^{\wedge} < P_0$ then no reduction takes place in that community. We then find successfully higher prices to achieve target reductions. For each set of prices we can determine the penalty. This is aggregated across communities and then averaged over water reductions.

9.3.4 Data Description

We estimate the value of municipal water using the Municipal Use Database (MUD) described in Environment Canada's Municipal Water Pricing, 1991-1999 (2001). This database reports consumption and prices for water for virtually every community in Canada with a population above 1000 people. The data set breaks down water supplies into residential, commercial and institutional, industrial, and other users (where other includes system losses and transfers to other municipalities). The data also contains information on population served, prices, and rate schemes. It identifies consumption and prices separately for residential and commercial/institutional/industrial customers. Data is reported for 1991, 1994, 1996, and 1999. Additional data on communities is taken from Statistics Canada.

Table 9.1 shows the population and water consumption in Alberta and Saskatchewan broken down into water use. In Saskatchewan, residential users consume 50% of municipal water supplies, Commercial and institutional enterprises consume 25%, industrial enterprise consumes approximately 13%, with the remaining 12% accounted for under other purposes including system losses. Alberta has almost identical patterns over the period; although, 1999 shows a greater proportion allocated to residential water. The large share of water allocated to enterprises means that any significant reductions in municipal water supplies will need to fall, at least partially, on commercial users in addition to residential consumers.

	SASKATCHEWAN					**ALBERTA**				
	1991	**1994**	**1996**	**1999**	**Average share 1991-1999**	**1991**	**1994**	**1996**	**1999**	**Average share 1991-1999**
Number of COMMUNITIES in MUD with data	65	70	66	65		125	128	125	127	
POPULATION (1000)	603	634	652	666		2028	2101	2165	2298	
	WITHDRAWALS (MCM)					**WITHDRAWALS (MCM)**				
RESIDENTIAL CONSUMPTION	59	56	55	57	**50%**	195	182	203	246	**51%**
COMMERCIAL AND INSTITUTIONAL	33	25	27	27	**25%**	106	82	87	95	**23%**
INDUSTRIAL	20	15	11	16	**13%**	57	68	68	44	**15%**
Sum of COMM, INST, IND	20	15	11	16	**38%**	57	68	68	44	**38%**
OTHER	14	15	13	13	**12%**	46	47	30	47	**11%**
TOTAL WATER WITHDRAWN	**125**	**110**	**105**	**113**		**403**	**379**	**387**	**432**	

Table 9.1 *Water Consumption by User Type, 1991-1999*
Source: Municipal Use Database (MUD) 2001

If we look at yearly per capita consumption (Table 9.2), we see that total municipal consumption fell over the period in Saskatchewan and to a lesser extent in Alberta. Per capita consumption for all components also fell in both provinces. Using 1999 as a comparison we see that Albertans consume 25% more water per year for residential purposes than Saskatchewanians. Commercial and institutional consumption was virtually identical across the two provinces but 20% less water was consumed for industrial purposes in Saskatchewan. Altogether Albertans use 6% more water per capita for commercial, institutional and industrial purposes. Note that this refers to municipal supply of water and may not reflect the total enterprise consumption of water as some of this may come from non-municipal supplies.

	SK				**AB**				**Ratio AB to SK**
	1991	**1994**	**1996**	**1999**	**1991**	**1994**	**1996**	**1999**	**1999**
RESIDENTIAL CONSUMPTION	97.0	87.8	83.6	85.7	96.0	86.6	93.6	107.0	**1.25**
COMMERCIAL AND INSTITUTIONAL	53.9	39.6	41.5	40.2	52.4	39.1	40.2	41.5	**1.03**
INDUSTRIAL	32.4	23.1	16.6	24.1	27.9	32.5	31.4	19.0	**0.79**
Sum of COMM, INST, and IND	86.3	62.8	58.1	64.3	80.3	71.6	71.6	60.5	**0.94**
OTHER	23.1	23.5	19.5	20.0	22.5	22.3	13.7	20.5	**1.02**
TOTAL WATER	**206**	**174**	**161**	**170**	**199**	**180**	**179**	**189**	**1.11**

Table 9.2 *Per Capita Consumption by User Type, 1991-1999*
Consumption is in cubic meters per person per year.
Source: Municipal Use Database (MUD) 2001

Table 9.3 shows the population and residential water consumption in the SSRB broken down into SSRB sub-basins. Data is taken from Statistics Canada and reported by the Prairie Farm Rehabilitation Administration. The table shows that per capita consumption per year for all uses averaged about 225m^3 in all years for those communities that have both population and water consumption data. Per capita consumption was lowest in the Red Deer River district at 180m^3 per year and highest in Alberta communities on the South Saskatchewan River system.

	1991			**1996**			**2001**		
BASIN	**Water Use 1000m^3**	**POP**	**per capita water use m^3**	**Water Use 1000m^3**	**POP**	**per capita water use m^3**	**Water Use 1000m^3**	**POP**	**per capita water use m^3**
SSR-sk	49,845	233,649	213.3	51,553	240,920	214.0	52,419	245,272	213.7
SSR-ab	17,858	54,860	325.5	18,463	56,446	327.1	20,048	61,136	327.9
RD	22,565	124,499	181.2	23,234	128,556	180.7	27,058	149,583	180.9
OR	32,248	112,993	285.4	33,377	117,176	284.8	35,296	124,033	284.6
BR	165,559	754,608	219.4	180,594	820,312	220.2	207,282	946,070	219.1
TOTAL [1]	**288,075**	**1,280,609**	**225.0**	**307,222**	**1,363,410**	**225.3**	**342,103**	**1,526,094**	**224.2**
TOTAL [2]	288,091	1,296,144	222.3	307,222	1,379,651	222.7	342,103	1,546,219	221.3

Note: [1] includes communities with both population and water data
Note: [2] includes communities with either population or water data

Table 9.3 *Water Consumption and Population in the SSRB, 1991-2001*

As a comparison, Table 9.4 compares total per capita consumption (residential, commercial and institutional, industrial, and other) using MUD data for 1996 for communities in both the SSRB and MUD datasets. Population covered is virtually identical but some differences emerge for consumption. In most cases per capita municipal water consumption in the MUD data set is smaller than the SSRB data. The source of the difference between the two data is unknown at this point.

	SSRB DATA			**MUD data (all users)**		
	Water Use $1000m^3$	**POP**	**per capita water use m^3**	**Municipal Water Use $1000m^3$**	**POP**	**per capita water use m^3**
SSR-sk	48,620	220,586	**220.4**	40,934	227,594	**179.9**
SSR-ab	17,138	51,207	**334.7**	15,603	52,709	**296.0**
RDR	21,094	115,122	**183.2**	20,073	115,502	**173.8**
OR	31,148	108,428	**287.3**	33,855	107,641	**314.5**
BR	179,880	818,776	**219.7**	156,125	803,808	**194.2**
TOTAL*	297,881	1,314,119	**226.7**	266,590	1,307,254	**203.9**

Table 9.4 *Residential Consumption: MUD versus SSRB data, 1996*
Source: Municipal Use Database (MUD) 2001

9.3.5 Marginal and Average Values

9.3.5.1 Residential Marginal and Average Prices

The first step in determining the penalty function is to determine the marginal price (cost per cubic meter of additional water consumed) for each community. The MUD data set does not report this directly. Rather, they report the marginal and average price for ranges of consumption: 0-10, 10-25, and 25-35m^3 per billing period.

To identify the relevant range for an average household in a community we first estimate the average household size, using data from Statistics Canada. Average household size is calculated as community population divided by number of dwellings. This typically has a value from 2.7 to 3.2 persons per dwelling. We also assume that the relevant billing period is one month. We inflate per capita consumption per month as calculated from the MUD data set by household size to get average consumption per dwelling per month (denoted as ADF_HOU).

To identify the price paid we need to account for the type of pricing scheme used (rate types). There are five primary rate schemes used (Burke et al., *Municipal Water Pricing, 1991-1999*). In each case there is generally an access fee charged that is independent of consumption. This affects the average price paid for water but not the marginal price. Also, many communities enforce a minimum metered amount. This quantity is reported in MUD. If monthly household consumption is below this cutoff, then each household simply makes the minimum payment. In these cases the marginal price is imputed as zero since a small rise in consumption would typically leave the household below the cutoff and therefore would not entail further charges. Some communities do not report a minimum metered amount so any metered level is presumed to be charged the marginal rate in the relevant range. The following are the rate types reported in the MUD data set.

Constant Unit Cost (CUC): Water is metered and billed at a constant price per unit consumed independent of the quantity. The price per unit (CUC) identifies the marginal cost of water and is independent of household size and does not change with volume.

Flat Rate (FLAT): Users are charged a flat rate and water is not metered. The price charged is independent of consumption *per se*. Typically the flat rate is assessed on property characteristics such as lot size, property value or size, and characteristics of the dwelling. Since charges are independent of actual consumption, the implicit marginal price of water is zero.

Decreasing Block Rate (DBR): Water is metered and the marginal price falls as consumption exceeds predetermined levels (blocks). The idea is that the cost of supplying water to large consumers does not increase proportionately as there are economies of scale in delivery. These savings in delivery are passed on to consumers as lower prices for higher quantities. Communities generally have more than one block price. Block sizes are generally designed so that the average residential user remains within the first two blocks. MUD does not directly report the cutoffs for each level but does report the price paid for an additional unit of water within the ranges of 0-10, 10-25, and 25-35m^3. The marginal price is imputed by locating ADF_HOU in the relevant range and using the reported marginal cost as the relevant marginal price. In most instances, there is little effective difference between CUC pricing and DBR pricing.

Increasing Block Rate (IBR): Like DBR, water is metered but the marginal price rises as consumption exceeds predetermined levels. This is also referred to as *incentive pricing* since households are encouraged, through pricing, to limit consumption so that it remains at the lower price. Like DBR, the marginal price is imputed by placing ADF_HOU in the relevant range and using the reported marginal cost as the relevant marginal price.

Complex Rate (COMP): Water rates are a complex combination of different rate types with different cutoffs. However, few communities use this method and those that do turn out to be close to CUC.

One aspect that complicates our analysis is that some communities use two rate types at the same time. For instance, the City of Calgary reports 46% of the population metered under CUC while the remainder is unmetered and pay an assessed fee (FLAT). We treat these as two distinct communities. Unfortunately, MUD does not deal with these communities effectively. The data allocates total water deliveries by population and does not account for differences in water use intensities across the two rate types. This likely underestimates consumption in the FLAT rate users (see below) and over-estimates it for CUC customers.

Table 9.5a and 9.5b show the breakdown by rate type in Saskatchewan and Alberta by number of communities and population. In general Alberta relies more on flat charges. Flat charges are also more common among smaller communities. The percentage of Saskatchewan communities in the MUD that used metering of some sort rose from 79% in 1991 to 91% in 1999. In Alberta, it rose from 73% to 83%. In terms of populations, by 1999, Saskatchewan metered 99% of residential households and Alberta about 82%.

	1991	%	1994	%	1996	%	1999	%
SASKATCHEWAN								
CUC	39	50	37	52	35	57	35	60
FLAT	16	21	10	14	7	11	5	9
DBR	14	18	15	21	13	21	14	24
IBR	8	10	8	11	5	8	4	7
COMB	1	1	1	1	1	2	0	0
TOTAL	**78**		**71**		**61**		**58**	
ALBERTA								
CUC	63	46	60	51	69	57	61	58
FLAT	37	27	22	19	21	17	18	17
DBR	30	22	26	22	19	16	15	14
IBR	8	6	9	8	13	11	11	10
COMB	0	0	0	0	0	0	1	1
TOTAL	**138**		**117**		**122**		**106**	

Table 9.5a *Rate Types by Number of Communities, 1991-1999*
Source: Municipal Use Database (MUD) 2001

	1991		1994		1996		1999	
SASKATCHEWAN								
	POP	**%**	**POP**	**%**	**POP**	**%**	**POP**	**%**
CUC	267,042	44	252,057	42	285,424	45	287,308	45
FLAT	6,456.24	1	8,674	1	7,830	1	8,009	1
DBR	298,033.8	49	320,434	53	315,997	50	337,932	53
IBR	30,250	5	24,682	4	22,050	3	7,750	1
COMB	1,229	0	1,129	0	1,150	0	0	0
TOTAL	**603,011**		**606,976**		**632,451**		**640,999**	
ALBERTA								
	POP	**%**	**POP**	**%**	**POP**	**%**	**POP**	**%**
CUC	509,287	25	534,151	27	770,654	36	906,687	43
FLAT	621,123	31	522,728	26	442,962	21	386,287	18
DBR	833,745	41	816,272	41	132,245	6	56,548	3
IBR	64,569	3	105,582	5	776,694	37	770,352	36
COMB	0	0	0	0	0	0	1,081	0
TOTAL	**2,028,724**		**1,978,733**		**2,122,555**		**2,120,955**	

Table 9.5b *Rate Types by Population, 1991-1999*
Source: Municipal Use Database (MUD) 2001

Table 9.6 shows the marginal price and average price paid by households by rate type. The average price includes access charges. These are average values using populations as weights. In general, CUC rates provided the highest marginal prices in Saskatchewan while IBR provided the highest rates in Alberta. CUC rates provided the highest average prices in both provinces. Flat rates have an implied marginal price of zero and also yielded the lowest average price for water. In each year, marginal and average prices paid by Saskatchewan residents exceed those of Alberta residents. In each year, marginal prices were less than average prices. This reflected the relative importance of access fees in residential consumption as well as the zero marginal under FLAT rate pricing.

	MARGINAL PRICE[1] ($/m^3)				**AVERAGE PRICE[1] ($/m^3)**			
	1991	**1994**	**1996**	**1999**	**1991**	**1994**	**1996**	**1999**
	SASKATCHEWAN				**SASKATCHEWAN**			
CUC	1.04	1.24	1.25	1.26	1.13	1.30	1.58	1.84
FLAT	0.00	0.00	0.00	0.00	0.60	0.99	0.80	0.88
DBR	0.81	0.76	1.02	1.03	1.21	1.14	1.43	1.44
IBR	0.95	1.00	1.05	0.80	1.30	1.72	1.74	1.29
COMB	0.00	0.55	0.66		2.13	1.35	1.13	
AVERAGE	**0.91**	**0.96**	**1.11**	**1.12**	**1.18**	**1.23**	**1.50**	**1.61**
	ALBERTA				**ALBERTA**			
CUC	0.86	1.08	1.12	1.21	1.41	1.67	1.70	1.73
FLAT	0.00	0.00	0.00	0.00	0.08	0.09	0.06	0.10
DBR	1.16	1.34	0.88	1.05	1.29	1.52	1.54	1.74
IBR	0.91	0.77	1.42	1.42	0.97	2.19	1.77	1.68
COMB				1.41				1.66
AVERAGE	0.72	0.88	0.98	1.06	0.94	1.22	1.37	1.42
Ratio SK/AB	**1.26**	**1.08**	**1.13**	**1.06**	**1.25**	**1.01**	**1.09**	**1.14**

Note: [1] Weighted average price using populations as weights.

Table 9.6 *Residential Pricing by Rate Types, 1991-1999*

Since flat rates imply a zero marginal price, we expect to see higher consumption per capita in those communities. Also, Saskatchewan residents face higher marginal prices on average and so should consume less than Albertans. The data confirm this. Table 9.7 shows the per capita consumption as a function of the rate type in each province as well as the overall average consumption. Consumption was much higher in communities that used flat rate pricing and lowest for those using IBR or CUC. Looking at 1996 and 1999 we see that, on average, Saskatchewan residents consumed slightly less than Alberta residents. This perhaps reflects the greater use of metering in Saskatchewan.

	1991	**1994**	**1996**	**1999**		**1991**	**1994**	**1996**	**1999**
SASKATCHEWAN					**ALBERTA**				
CUC[1]	86.9	83.4	77.1	81.5	**CUC**	105.4	99.3	109.6	124.4
FLAT	82.3	122.9	166.2	169.2	**FLAT**	104.8	89.6	114.6	126.8
DBR	107.4	88.2	84.9	86.4	**DBR**	84.5	75.0	116.2	104.1
IBR	89.1	76.9	85.8	119.1	**IBR**	87.3	86.2	60.3	74.6
COMB	75.6	141.3	84.4		**COMB**				120.6
AVG	**97.0**	**86.4**	**82.4**	**85.6**	**AVG**	**96.0**	**86.1**	**93.0**	**106.2**

Note: [1] Weighted by population

Table 9.7 *Residential Consumption per capita by Rate Types, 1991-1999*
Source: Municipal Use Database (MUD) 2001

9.3.5.2 Commercial Marginal and Average Prices

The MUD does not report individual firm level consumption. This poses difficulties given the heterogeneity among enterprises. Some are likely to be intensive water consumers (hotels and breweries) while others are not (banks and muffler shops). Establishments also differ by size from large hospitals to small corner stores. This heterogeneity is not the case with residential consumers as differences across households are much smaller. This creates the problem of getting a measure of demand elasticity for commercial, institutional and industrial consumers. Unlike residential consumption, there is no easy way to impute relevant consumption per firm per billing period since no data appears available to calculate the average size of firms. As a result, no attempt is made to impute the billing volume. Rather we rely directly on the MUD data and calculate commercial consumption per capita, using population served by water as a proxy for the relevant population.

We ran three scenarios using the reported marginal costs for 10, 35, and $100m^3$. Elasticities and penalties are calculated for each marginal price. Though not precisely estimated, we do find an elasticity of demand for enterprises that is small but non-zero. This implies that firms are capable of reducing water consumption and willing to do so at current water charges. The resulting value of water to firms exceeds that for residential consumption. As we are unable to estimate demand elasticities with much precision given the lack of firm level data in the MUD data set we reported values under different elasticity scenarios.

As in residential pricing, communities can choose different rate types to charge enterprises. Tables 9.8a and 9.8b breaks down communities into rate types. In Saskatchewan, about 54% of communities use constant unit charges (CUC), 3% use flat rates (FLAT), 28% use decreasing block rates (DBR), and 14% use increasing block rates (IBR). Alberta has a similar pattern but relies more heavily on flat rates.

	1991	**%**	**1994**	**%**	**1996**	**%**	**1999**	**%**
SASKATCHEWAN								
CUC	36	55	38	54	35	53	35	54
FLAT	1	2	1	1	2	3	2	3
DBR	19	29	20	29	18	27	18	28
IBR	8	12	10	14	9	14	9	14
COMB	1	2	1	1	2	3	1	2
TOTAL	**65**		**70**		**66**		**65**	
ALBERTA								
CUC	60	48	65	51	69	55	71	56
FLAT	16	13	14	11	11	9	10	8
DBR	35	28	36	28	32	26	30	24
IBR	10	8	11	9	12	10	14	11
COMB	4	3	2	2	1	1	2	2
TOTAL	**125**		**128**		**125**		**127**	

Table 9.8a *Commercial Rate Types by Number of Communities*
Source: Municipal Use Database (MUD) 2001

Table 9.8b shows the number and share of populations under each rate type. In terms of populations served, Saskatchewan is almost evenly split between CUC and DBR while in Alberta, over 70% use DBR and only 18% use CUC. Only 3% and 7% of the populations respectively are served with IBR.

	1991	**%**	**1994**	**%**	**1996**	**%**	**1999**	**%**
SASKATCHEWAN								
CUC	254,731	42	263,368	42	285,255	44	301,454	45
FLAT	1,526	0	1,401	0	4,172	1	4,328	1
DBR	315,241	52	336,437	53	329,219	50	342,040	51
IBR	30,284	5	31,951	5	31,436	5	16,973	3
COMB	1,229	0	1,129	0	2,279	0	1,300	0
TOTAL	**603,011**		**634,286**		**652,361**		**666,095**	
ALBERTA								
CUC	302,569	15	262,443	12	382,725	18	406,617	18
FLAT	50,252	2	51,189	2	39,019	2	25,451	1
DBR	1,581,446	77	1,614,539	76	1,591,393	73	1,659,307	73
IBR	71,924	3	151,352	7	159,989	7	168,114	7
COMB	54,856	3	54,175	3	10,800	0	12,138	1
TOTAL	**2,061,047**		**2,133,698**		**2,183,926**		**2,271,627**	

Table 9.8b *Commercial Rate Types by Population*
Source: Municipal Use Database (MUD) 2001

Table 9.9 reports the population weighted average prices broken down by rate type using 35m^3 as the benchmark case. For Saskatchewan in 1999, the highest average and marginal charges were under CUC followed by DBR. In Alberta the highest average and marginal prices were under DBR followed by CUC. Despite the fact that DBR are less conducive to conservation, Alberta accommodates this by choosing higher initial price levels. In general, average and marginal prices were much higher in Alberta than Saskatchewan.

	MARGINAL PRICE ($\$/\text{m}^3$)				**AVERAGE PRICE[1] ($\$/\text{m}^3$)**			
	1991	**1991**	**1994**	**1996**	**1999**	**1994**	**1996**	**1999**
	SASKATCHEWAN				**SASKATCHEWAN**			
CUC	1.07	1.22	1.25	1.27	1.13	1.29	1.77	1.65
FLAT	0.00	0.00	0.00	0.00	1.07	1.07	1.00	1.22
DBR	0.86	0.88	1.11	1.00	1.14	1.21	1.12	1.50
IBR	0.91	0.98	1.02	0.80	1.56	1.60	1.41	1.12
COMB	0.55	0.55	0.61	1.10	1.19	1.19	1.00	1.47
AVERAGE	**0.95**	**1.03**	**1.16**	**1.11**	**1.16**	**1.26**	**1.42**	**1.56**
	ALBERTA				**ALBERTA**			
CUC	0.84	1.03	1.05	1.13	1.38	1.57	1.65	1.72
FLAT	0.00	0.00	0.00	0.00	0.74	0.80	0.55	1.20
DBR	1.22	1.43	1.51	1.46	1.62	1.87	2.03	2.09
IBR	1.08	0.75	0.96	0.94	1.65	1.60	1.91	1.62
COMB	0.75	0.75	0.87	0.92	1.59	1.44	2.00	1.98
AVERAGE	1.13	1.29	1.37	1.34	1.57	1.79	1.93	1.97
Ratio SK/AB	**0.84**	**0.80**	**0.85**	**0.83**	**0.74**	**0.70**	**0.73**	**0.79**

Note: [1] Weighted average price using populations as weights.
Note: Values use 35m^3 as the relevant marginal and average billing quantity per

Table 9.9 *Commercial Pricing by Rate Types (All Enterprises)*
Source: Municipal Use Database (MUD) *2001*

Table 9.10 shows the yearly per capita consumption of water for enterprises. In 1999, the average consumption for enterprises was 64.3m^3 per person per year in Saskatchewan and 60m^3 per person per year in Alberta. This is consistent with the higher marginal prices in Alberta. Taking only 1999 data, we see that flat rates communities had the highest per capita consumption as expected. In Alberta, IBR communities had the second highest rate; in Saskatchewan DBR communities had the second highest rate.

	1991	1994	1996	1999		1991	1994	1996	1999
SASKATCHEWAN					ALBERTA				
CUC	67.4	52.8	49.2	48.5	**CUC**	80.4	75.4	67.5	49.4
FLAT	54.4	71.1	42.3	87.3	**FLAT**	123.5	135.7	134.8	99.4
DBR	105.8	72.4	68.9	79.9	**DBR**	82.7	73.4	71.4	59.9
IBR	46.9	43.7	30.0	27.3	**IBR**	53.4	61.0	77.8	79.7
COMB	18.9	35.2	22.7	5.3	**COMB**	37.6	13.0	58.1	69.1
AVG	**86.3**	**62.8**	**58.1**	**64.3**	**AVG**	**81.2**	**72.7**	**72.3**	**60.0**

Note: Includes commercial, institutional and industrial

Table 9.10 *Commercial Consumption per capita by Rate Types (All Enterprises)*
Source: Municipal Use Database (MUD) 2001

9.3.6 Elasticity of Water Demand

9.3.6.1 Elasticity of Residential Water Demand

Elasticity (η) is calculated as the proportionate change in consumption induced by a proportionate change in prices: $\eta = [dQ/Q] / [dP/P] = d\ln Q/d\ln P$. If we take the demand function to be $Q = aP^{\eta}$, then $\ln(q) = \ln(a) + \eta \ln(P)$ where η is the elasticity of water demand. This demand function can be directly estimated using the MUD data for Saskatchewan and Alberta. Three simple regressions of the (log of) domestic consumption and the (log of) prices are reported using 1999 data. Regression results for 1996 were very similar. The first regressions limit data to only those communities where marginal prices were strictly positive. Two measures of consumption were used. The first regression (Figure 9.11, column 1) uses domestic consumption per capita per month and the second (column 2) uses domestic consumption per household per month. Household size was estimated as total population divided by number of households using Census of Canada data. The next regressions (column 3 and column 4) use all the data. Since the marginal charge is zero for some communities we impose the assumption that actual marginal costs in these communities are \$0.01 per cubic meter so that ln(P) is well-defined. This assumption reflects non-monetary opportunity costs of using water for a household (primarily time). Regressions (5) and (6) then use average prices rather than marginal prices as a point of comparison. Additional regressions that included climate variables were also run but did not alter results to any significant degree.

Using marginal costs and restricting data to communities where marginal costs were strictly positive yielded an elasticity of -0.25 to -0.23. This means that a 1% rise in price lowered monthly water consumption by 0.23 to 0.25%. If we include data with flat rates, the elasticity falls to -0.16. This decrease in elasticity is puzzling as we expect the ability to reduce water use to be greater given the higher per capita consumption associated with flat rates. However, the extent that flat rates are typically used in small communities suggests that we may be missing factors specific to small communities. Alternately, how people react to changes in prices may be partially determined by whether they have ever faced metered water. If un-metered consumers are qualitatively different from metered consumers, then the difference in elasticities may reflect this.

	1	**2**	**3**	**4**	**5**	**6**
Dependent Variable (log of)	**per capita consumption per month**	**per household consumption per month**	**per capita consumption per month**	**per household consumption per month**	**per capita consumption per month**	**per household consumption per month**
Independent Variable (log of)	**MAR price ($ per m^3)**	**MAR price ($ per m^3)**	**MAR price ($ per m^3)**	**MAR price ($ per m^3)**	**AVG price ($ per m^3)**	**AVG price ($ per m^3)**
restriction	**MC > 0**	**MC > 0**	**MC > = 0**	**MC > = 0**	**MC > 0**	**MC > 0**
R^2 - adjusted	0.18	0.13	0.13	0.17	0.31	0.24
n	138	138	159	159	136	136
Intercept	-1.235	3.144	-1.239	3.139	-0.983	3.376
SE	0.025	0.027	0.028	0.030	0.037	0.041
t Stat	-50.234	116.461	-44.251	103.060	-26.876	82.298
ln(P)	**-0.253**	**-0.227**	**-0.158**	**-0.164**	**-0.507**	**-0.473**
SE	0.045	0.050	0.028	0.030	0.064	0.072
t Stat	-5.579	-4.559	-5.701	-5.445	-7.885	-6.552

Table 9.11 *Regression Results for Alberta and Saskatchewan, 1999*
Source: Municipal Use Database (MUD) 2001

As a check, one can use average costs as the relevant price that consumers perceive as their opportunity costs. The idea is that consumers may not necessarily understand the marginal relationship between more water and more charges since few peruse their monthly bills in detail. However, they would understand that in general more consumption means more charges and they may have a heuristic sense of the average cost. As it turns out, the fit of the regression improves (the adjusted r^2 doubles) and the elasticity rises to around -0.50. However, households paying flat rates would likely understand the relationship between consumption and charges and so would not use average prices. This means that elasticity of demand in terms of average prices may not be a better indicator of behaviour despite the better statistical fit.

The preceding results prompt further discussion:

1) The elasticity estimates fall in the range reported by other researchers (see Gibbons (1986, 10-11) for one such summary).

2) The data used above are based on average water use in 1999. The estimated elasticity indicates the ability of households to reduce water consumption over an entire year. However, water use is much higher during summer months and so too are the associated elasticities (Gibbons 1986, 10-11). The estimates above undoubtedly overestimate winter elasticities and underestimate summer elasticities. Hence the penalty function will depend on the timing of the water restrictions. If these restrictions take place during the summer, then the implied costs will be lower than if the restrictions take place in winter.

3) The estimated elasticities use cross-sectional data and are likely to overestimate the ability of actual consumers to react to rate changes. In most communities the price charged for water is close to the charges over the previous years. We expect consumers to have adjusted fully to this price. The ability of individuals to adjust to a move to higher prices is likely much lower. In effect, the cross-sectional data yields a long-run measure of elasticity. Hence the estimated elasticities are likely to overestimate the short-run ability to adjust to water shortages and so underestimate the cost of adjustment.

4) Most communities have been using the same sort of pricing regime for some time. Any changes that might occur over time are typically in terms of the level of charges rather than in terms of the type of rate scheme employed. The elasticity assumes that all communities can institute higher marginal charges for water. This applies to communities currently charging flat rates. However, the change in regime may induce changes in water use patterns that cannot be associated with prices alone. In this case, the actual elasticity in communities with flat rates would likely differ from those who employ metered pricing. Whether this implies a higher or lower elasticity is difficult to ascertain.

5) To account for these possibilities we take as the base case an elasticity of -0.3 but also consider elasticities of -0.1 to -0.6 in the loss calculations. As shown below, the calculated value of water is sensitive to the elasticity chosen.

9.3.6.2 Elasticity of Commercial Water Demand

Regressions were run for monthly per capita consumption for All Enterprises, Commercial and Institutional users, and Industrial users separately. For each type of user we ran regressions using each of the quantity categories identified in the MUD dataset and also with and without restrictions for communities with strictly positive marginal prices.

We first ran regressions using Saskatchewan and Alberta data (see Appendix Section 9.3.9). However, the fit of the regressions was quite poor and the elasticity estimates were generally not statistically significant. The fit was better using strictly positive marginal prices. To improve our point estimates we employ data for all of Canada for 1999. This raised the point estimates of the elasticities and their statistical significance. Tables 9.12a-c show the regression results between the (log of) per capita consumption and the (log of) price using Canadian data for 1999. Restricting data to those communities with strictly positive marginal prices yielded estimated elasticities of: -0.32, -0.28, and -0.27 for All Enterprises using quantities $10m^3$, $35m^3$, and $100m^3$ respectively. For Commercial and Institutional enterprises the elasticities were -0.15, -0.13, and -0.12 and for Industrial enterprises the elasticities were higher at -0.39, -0.41, -0.39.

An important result was that the elasticities were not sensitive to the price series used. This is encouraging. What did matter was whether communities with marginal prices of zero were included. When we do so, point estimates fall into the range 0 to -0.06 and are not always statistically significant.

As a check the same procedure was used on residential consumption data. The elasticity estimates from this procedure were very similar to those where average household size was estimated. This suggests that the procedure used here is probably not sensitive to firm size and so not sensitive to the quantity range used.

This data suggests that firms do have the ability and desire to reduce water consumption. The elasticities are surprisingly large given that water expenditures often make up only a very small share of total expenses for a firm. That any firm deems it worthwhile to economize on such a small input is consistent with residential customers also economizing on their water consumption. These elasticities are generally larger than identified in other research. In fact, Jenkins (2000), in her estimate of water values in California, applies an elasticity of zero in her calculations. This data does not support such a pessimistic approach.

	C10_MAR	**C35_MAR**	**C100_MAR**	**C10_MAR**	**C35_MAR**	**C100_MAR**
	MC > 0	MC > 0	MC > 0	MC > =0	MC > = 0	MC > = 0
R^2 - adj	0.047	0.037	0.035	-0.001	0.002	0.002
n	526	751	751	1368	1368	1368
Intercept	**1.314**	**1.255**	**1.253**	**1.394**	**1.318**	**1.324**
SE	0.05	0.04	0.04	0.05	0.04	0.04
t Stat	26.06	29.79	29.43	27.81	31.49	32.48
ln(P)	**-0.317**	**-0.283**	**-0.272**	**0.006**	**-0.025**	**-0.024**
SE	0.06	0.05	0.05	0.01	0.01	0.01
t Stat	-5.19	-5.43	-5.31	0.46	-1.88	-1.79

Table 9.12a *Demand Elasticities for All Enterprises in Canada, 1999*

	C10_MAR	**C35_MAR**	**C100_MAR**	**C10_MAR**	**C35_MAR**	**C100_MAR**
restriction	MC > 0	MC > 0	MC > 0	MC > =0	MC > = 0	MC > = 0
R^2 - adj	0.011	0.008	0.008	-0.001	0.000	0.000
n	521	745	745	1345	1345	1345
Intercept	**0.811**	**0.779**	**0.778**	**0.849**	**0.808**	**0.809**
SE	0.05	0.04	0.04	0.05	0.04	0.04
t Stat	16.79	19.69	19.47	18.75	21.36	21.96
ln(P)	**-0.151**	**-0.131**	**-0.124**	**0.004**	**-0.014**	**-0.014**
SE	0.06	0.05	0.05	0.01	0.01	0.01
t Stat	-2.58	-2.66	-2.59	0.29	-1.12	-1.15

Table 9.12b *Elasticities for Commercial and Institutional Users in Canada, 1999*

	C10_MAR	**C35_MAR**	**C100_MAR**	**C10_MAR**	**C35_MAR**	**C100_MAR**
restriction	MC > 0	MC > 0	MC > 0	MC > =0	MC > = 0	MC > = 0
R^2 - adj	0.041	0.046	0.043	0.000	0.006	0.003
n	397	551	551	999	999	999
Intercept	**0.415**	**0.376**	**0.374**	**0.530**	**0.477**	**0.510**
SE	0.08	0.06	0.06	0.07	0.06	0.06
t Stat	5.34	5.90	5.79	7.16	7.64	8.37
ln(P)	**-0.394**	**-0.409**	**-0.389**	**-0.023**	**-0.052**	**-0.041**
SE	0.09	0.08	0.08	0.02	0.02	0.02
t Stat	-4.25	-5.27	-5.04	-1.10	-2.63	-2.02

Table 9.12c *Elasticities for Industrial Users in Canada, 1999*

9.3.7 Penalty Estimates

9.3.7.1 Residential Demand

We begin by assuming reductions are uniformly applied across Alberta and Saskatchewan for those communities in the MUD data set. Table 9.13 shows costs of reductions for 1% to 50% using the base elasticity of -0.30. Interpretation is straight forward. If we want to reduce residential water use by 1% then the total imputed cost to residents in both provinces is $231,790 per month. This reduces aggregate consumption by 196,561m^3 per month. On a per capita basis it means that each person must reduce consumption by 0.08m^3 per month at a cost to each of $0.10 per month. On a per cubic meter basis, the average cost of the reduction is $1.18. Note that this is very close to the average marginal price of water in 1999. If we want consumption to fall by 10% the average cost per cubic meter rises to $1.39 and a 50% reduction costs $4.02 per cubic meter.

Marginal costs are higher. If we go from a 1% to a 2% reduction, the average cost rises from $1.18 to $1.20. The cost of going from 1% to 2% implies a marginal cost of $1.22.

COST of REDUCTION in WATER USE for ALBERTA and SASKATCHEWAN: elasticity = -0.3

% reduction	TOTAL COST ($ per month)	TOTAL REDUCTION (m^3 per month)	per capita reductions per month (m^3)	per capita costs per month	AVERAGE COST ($/m^3)	MARGINAL COST ($/m^3)
1%	231,790	196,561	0.08	0.10	1.18	
2%	471,518	393,122	0.16	0.20	1.20	1.22
3%	719,541	589,683	0.25	0.30	1.22	1.26
4%	976,235	786,244	0.33	0.41	1.24	1.31
5%	1,241,999	982,805	0.41	0.52	1.26	1.35
10%	**2,722,495**	**1,965,610**	**0.82**	**1.13**	**1.39**	**1.51**
15%	4,504,639	2,948,414	1.23	1.87	1.53	1.81
20%	6,673,490	3,931,219	1.64	2.78	1.70	2.21
25%	9,345,667	4,914,024	2.04	3.89	1.90	2.72
30%	12,684,282	5,896,829	2.45	5.28	2.15	3.40
35%	16,922,712	6,879,633	2.86	7.04	2.46	4.31
40%	22,403,670	7,862,438	3.27	9.32	2.85	5.58
45%	29,645,825	8,845,243	3.68	12.33	3.35	7.37
50%	39,462,359	9,828,048	4.09	16.42	4.02	9.99

Table 9.13 *Losses Calculations Alberta and Saskatchewan, 1999: Uniform Reductions*

Table 9.14 shows the associated average and marginal costs under different assumptions about the elasticity of water demand. As expected, the higher the elasticity the lower the cost of implementing a particular reduction. For small reductions the differences in costs are small, less than 5% difference as we raise elasticity from -0.1 to -0.6; however, as the degree to which restrictions increase, the difference in costs increases dramatically. For instance, a 20% reduction implies an average cost per cubic meter of $4.16 if elasticity is -0.1. That cost is only $1.39 per cubic meter if the elasticity is -0.6. Marginal costs of the restrictions are $8.07 and $1.60, respectively. This tells us that the imputed value of water is probably not sensitive to the assumed elasticity for small restrictions. For larger restrictions, however, the imputed values become quite sensitive to assumed elasticities.

Elasticity	**-0.1**		**-0.2**		**-0.3**		**-0.4**		**-0.5**		**-0.6**	
% reduction	**AC**	**MC**	**AC**	**MC**	**AC**	**MC**	**AC**	**MC**	**AC**	**MC**	**AC**	**MC**
1%	**1.22**		**1.19**		**1.18**		**1.17**		**1.17**		**1.17**	
2%	**1.28**	1.35	**1.22**	1.25	**1.20**	1.22	**1.19**	1.20	**1.18**	1.20	**1.18**	1.19
3%	**1.35**	1.49	**1.25**	1.32	**1.22**	1.26	**1.20**	1.24	**1.20**	1.22	**1.19**	1.21
4%	**1.43**	1.66	**1.29**	1.39	**1.24**	1.31	**1.22**	1.27	**1.21**	1.25	**1.20**	1.23
5%	**1.51**	1.84	**1.32**	1.46	**1.26**	1.35	**1.24**	1.30	**1.22**	1.27	**1.21**	1.25
10%	**2.04**	2.56	**1.52**	1.72	**1.39**	1.51	**1.32**	1.41	**1.29**	1.36	**1.27**	1.32
15%	**2.85**	4.47	**1.77**	2.27	**1.53**	1.81	**1.42**	1.62	**1.36**	1.52	**1.33**	1.45
20%	**4.16**	8.07	**2.09**	3.05	**1.70**	2.21	**1.54**	1.88	**1.45**	1.71	**1.39**	1.60
25%	**6.35**	15.12	**2.51**	4.17	**1.90**	2.72	**1.67**	2.20	**1.55**	1.93	**1.47**	1.77
30%	**10.21**	29.54	**3.06**	5.82	**2.15**	3.40	**1.82**	2.60	**1.66**	2.21	**1.56**	1.98
35%	**17.41**	60.56	**3.81**	8.33	**2.46**	4.31	**2.01**	3.10	**1.78**	2.55	**1.65**	2.23
40%	**31.64**	131.3	**4.87**	12.26	**2.85**	5.58	**2.23**	3.76	**1.93**	2.97	**1.76**	2.54
45%	**61.89**	303.8	**6.40**	18.62	**3.35**	7.37	**2.49**	4.64	**2.11**	3.51	**1.89**	2.92
50%	**131.7**	759.8	**8.70**	29.41	**4.02**	9.99	**2.83**	5.83	**2.32**	4.22	**2.04**	3.40

Table 9.14 *Losses Calculations Alberta and Saskatchewan, 1999: Various Elasticities*

Table 9.15 shows the costs of applying the efficient allocation of restrictions across communities. If we want to impose a 1% restriction over both provinces then the cost is $4,339. The price that would implement this is a charge of 0.05 per cubic meter in all communities (25 in total) that were previously non-metered. The average and marginal cost per cubic meter of water is very low at $0.02 per cubic meter.

% reduction	**Total Cost ($ per month)**	**Total Reduction (m^3 per month)**	**per capita costs per month ($)**	**per capita reductions per month (m^3)**	**Implicit Price ($/m^3$)**	**Average Cost ($/m^3$)**	**Marginal Cost ($/m^3$)**
1%	4,339	196,561	0.08	0.00	0.05	0.02	0.02
2%	37,730	393,122	0.16	0.02	0.36	0.10	0.17
3%	122,938	589,683	0.25	0.05	0.51	0.21	0.43
4%	240,450	786,244	0.33	0.10	0.69	0.31	0.60
5%	395,653	982,805	0.41	0.16	0.89	0.40	0.79
10%	**1,585,899**	**1,965,610**	**0.82**	**0.66**	**1.45**	**0.81**	**1.21**
15%	3,186,587	2,948,414	1.23	1.33	1.80	1.08	1.63
20%	5,148,376	3,931,219	1.64	2.14	2.21	1.31	2.00
25%	7,568,778	4,914,024	2.04	3.15	2.74	1.54	2.46
30%	10,593,394	5,896,829	2.45	4.41	3.45	1.80	3.08
35%	14,433,197	6,879,634	2.86	6.00	4.42	2.10	3.91
40%	19,398,667	7,862,438	3.27	8.07	5.77	2.47	5.05
45%	25,959,693	8,845,243	3.68	10.80	7.71	2.93	6.68
50%	34,852,975	9,828,048	4.09	14.50	10.59	3.55	9.05

Table 9.15 *Losses Calculations Alberta and Saskatchewan, 1999: Efficient Reductions*

For a 10% reduction, total costs rise $1,585,899. The implicit price that would implement this change is a charge of $1.45 per cubic meter. This alters the charges in 140 of the 161 communities in the dataset. The average cost rises to $0.81 and the marginal cost to $1.21. The maximum observed unit charge in 1999 was $2.61 in Mackenzie. Once we get to a 25% reduction or over, all communities must raise their prices to the same level. From this point forward, all new reductions are proportionately distributed across the communities.

As we can see, the costs are much smaller under the efficient reduction scheme than under the uniform reductions shown in Table 9.16. Note that the percentage difference in costs diminishes as the restrictions rise. For instance, a 1% reduction implies a cost of only $4,337 using the efficient reduction but a cost of $231,790 using uniform reductions. At a 20% reduction, the costs are $5,148,376 and $6,673,490 per month. The savings are significant at over 1.5 million dollars per month but the percentage difference is about 23%. For a 50% reduction the percentage difference is only 12%. This is reflected in the average costs of $1.31 and $1.70.

If we consider alternative elasticities, we get the same pattern as with uniform reductions: with average and marginal costs fall as elasticities rise. The average and marginal costs are always higher under uniform reductions but the differences are smaller as the elasticity rises and the level of restrictions rise.

Elasticity	-0.1		-0.2		-0.3		-0.4		-0.5		-0.6	
% reduction	**AC**	**MC**	**AC**	**MC**	**AC**	**MC**	**AC**	**MC**	**AC**	**MC**	**AC**	**MC**
1%	**0.13**	0.13	**0.04**	0.04	**0.02**	0.02	**0.02**	0.02	**0.02**	0.02	**0.01**	0.01
2%	**0.38**	0.62	**0.17**	0.31	**0.10**	0.17	**0.06**	0.09	**0.04**	0.06	**0.03**	0.04
3%	**0.60**	1.05	**0.31**	0.57	**0.21**	0.43	**0.16**	0.37	**0.13**	0.31	**0.11**	0.26
4%	**0.79**	1.36	**0.44**	0.84	**0.31**	0.60	**0.24**	0.50	**0.21**	0.45	**0.18**	0.42
5%	**0.94**	1.56	**0.56**	1.05	**0.40**	0.79	**0.32**	0.64	**0.28**	0.55	**0.25**	0.51
10%	**1.57**	2.20	**1.02**	1.47	**0.81**	1.21	**0.68**	1.04	**0.60**	0.92	**0.54**	0.83
15%	**2.33**	3.85	**1.35**	2.01	**1.08**	1.63	**0.94**	1.45	**0.85**	1.34	**0.78**	1.25
20%	**3.48**	6.94	**1.68**	2.70	**1.31**	2.00	**1.14**	1.73	**1.03**	1.59	**0.96**	1.49
25%	**5.38**	12.99	**2.08**	3.69	**1.54**	2.46	**1.31**	2.03	**1.19**	1.81	**1.10**	1.69
30%	**8.72**	25.38	**2.60**	5.15	**1.80**	3.08	**1.50**	2.40	**1.33**	2.07	**1.23**	1.89
35%	**14.91**	52.04	**3.28**	7.37	**2.10**	3.91	**1.69**	2.87	**1.49**	2.40	**1.36**	2.13
40%	**27.15**	113	**4.22**	10.84	**2.47**	5.05	**1.91**	3.48	**1.65**	2.80	**1.49**	2.42
45%	**53.14**	261	**5.59**	16.48	**2.93**	6.68	**2.18**	4.29	**1.83**	3.30	**1.64**	2.79
50%	**113**	653	**7.63**	26.01	**3.55**	9.05	**2.50**	5.38	**2.05**	3.96	**1.80**	3.24

Table 9.16 *Losses Calculations Alberta and Saskatchewan, 1999: Various Elasticities, Efficient Reductions*

Table 9.17 shows the ratio of average costs under uniform reductions to average costs under efficient reductions. For instance, for a 1% reduction the uniform reduction approach imposes costs that are over 8 times as much as the efficient reduction scheme. This assumes an elasticity of -0.1. Note that the biggest differences are at the smallest restrictions.

Elasticity	**-0.1**	**-0.2**	**-0.3**	**-0.4**	**-0.5**	**-06**
% reduction	**AC**	**AC**	**AC**	**AC**	**AC**	**AC**
1%	838%	2875%	5800%	5750%	5750%	11600%
2%	237%	618%	1100%	1883%	2850%	3833%
3%	125%	303%	481%	650%	823%	982%
4%	81%	193%	300%	408%	476%	567%
5%	61%	136%	215%	288%	336%	384%
10%	30%	49%	72%	94%	115%	135%
15%	22%	31%	42%	51%	60%	71%
20%	20%	24%	30%	35%	41%	45%
25%	18%	21%	23%	27%	30%	34%
30%	17%	18%	19%	21%	25%	27%
35%	17%	16%	17%	19%	19%	21%
40%	17%	15%	15%	17%	17%	18%
45%	16%	14%	14%	14%	15%	15%
50%	17%	14%	13%	13%	13%	13%

Table 9.17 *Ratio of Average Costs: Uniform to Efficient Reductions*

9.3.7.2 Commercial Demand

We calculate the value of water for All Enterprises using the same approach as residential water but apply a smaller range of elasticity measures (-0.10, -0.20, -0.30, and -0.40), taking an elasticity of -0.30 as the benchmark. Prices are for communities in the MUD data set. We report prices based on a billing quantity of $35m^3$ using both uniform reductions and efficient reductions.

Table 9.18 shows the costs of reducing water allocated to All Enterprises in Alberta and Saskatchewan. Restrictions range from 1% to 50% and are applied uniformly to each community.

A 10% reduction costs $2.2 million with an average imputed value for water of $1.47 per cubic meter. The marginal price to reduce consumption further is higher at $1.60. Note that these values are slightly higher but very comparable to the corresponding cost of reductions in residential usage.

Table 9.19 shows the imputed values under different elasticity assumptions. We see the same pattern that developed under residential usage: the lower the elasticity, the higher the value of water. The estimated values across elasticities are not dissimilar for small reductions. However, if reductions are significant, then the differences across assumed elasticities are important. For example, the value of water under a 10% reduction varies from $2.17 to $1.41. For a 30% reduction they vary from $10.87 to $1.94.

COST of REDUCTION in WATER USE for ALBERTA and SASKATCHEWAN
elasticity = -0.30 Price series: C35_MAR

% reduction	TOTAL COST (1000 $ per month)	TOTAL REDUCTION (1000m^3 per month)	per capita reductions per month (m^3)	per capita costs per month ($)	AVERAGE COST ($/m^3)	MARGINAL COST ($/m^3)
1%	192	153	0.05	0.06	1.25	
2%	391	307	0.10	0.13	1.28	1.30
3%	597	460	0.15	0.20	1.30	1.34
4%	810	613	0.21	0.27	1.32	1.39
5%	1,030	766	0.26	0.35	1.34	1.44
10%	**2,259**	**1,533**	**0.51**	**0.76**	**1.47**	**1.60**
15%	3,737	2,299	0.77	1.25	1.63	1.93
20%	5,537	3,066	1.03	1.86	1.81	2.35
25%	7,753	3,832	1.29	2.60	2.02	2.89
30%	10,523	4,598	1.54	3.53	2.29	3.61
35%	14,040	5,365	1.80	4.71	2.62	4.59
40%	18,587	6,131	2.06	6.24	3.03	5.93
45%	24,595	6,898	2.32	8.26	3.57	7.84
50%	32,739	7,664	2.57	10.99	4.27	10.63

Table 9.18 *Losses Calculations 1999: Uniform Reductions, All Enterprises*

COST of REDUCTION in WATER USE for ALBERTA SASKATCHEWAN
Price series: C35_MAR

Elasticity	-0.1		-0.2		-0.3		-0.4	
% reduction	**AC**	**MC**	**AC**	**MC**	**AC**	**MC**	**AC**	**MC**
1%	**1.30**		**1.27**		**1.25**		**1.25**	
2%	**1.37**	1.44	**1.30**	1.33	**1.28**	1.30	**1.27**	1.28
3%	**1.44**	1.59	**1.33**	1.40	**1.30**	1.34	**1.28**	1.31
4%	**1.52**	1.76	**1.37**	1.47	**1.32**	1.39	**1.30**	1.35
5%	**1.61**	1.96	**1.40**	1.55	**1.34**	1.44	**1.32**	1.38
10%	**2.17**	2.73	**1.62**	1.83	**1.47**	1.60	**1.41**	1.50
15%	**3.03**	4.76	**1.88**	2.42	**1.63**	1.93	**1.51**	1.72
20%	**4.42**	8.59	**2.22**	3.24	**1.81**	2.35	**1.63**	2.00
25%	**6.75**	16.09	**2.67**	4.44	**2.02**	2.89	**1.78**	2.34
30%	**10.87**	31.43	**3.25**	6.20	**2.29**	3.61	**1.94**	2.76
35%	**18.52**	64.43	**4.06**	8.86	**2.62**	4.59	**2.13**	3.30
40%	**33.66**	139.67	**5.18**	13.04	**3.03**	5.93	**2.37**	4.00
45%	**65.84**	323.25	**6.80**	19.81	**3.57**	7.84	**2.65**	4.93
50%	**140.09**	808.37	**9.25**	31.28	**4.27**	10.63	**3.01**	6.20

Table 9.19 *Losses Calculations Alberta and Saskatchewan 1999: Various Elasticities, All Enterprises*

The above values were determined under the assumption that all communities reduced consumption by the same proportion. If we make the alternative assumption that reductions are allocated efficiently then the costs of restricting water use falls. See Tables 9.20 and 9.21. A 10% reduction will entail costs of about $1.5 million with a minimum price for water of $1.61 per cubic meter. Uniform reductions cost 53% or $784,000 per month more than efficient reductions. This is a significant amount. In general, the differences between the uniform and efficient reductions are more pronounced at the lower reductions. For instance, under uniform reductions the average value of a 1% decrease in water is $1.25 per cubic meter. Under an efficient allocation, the average value is $0.02 per cubic meter. The difference is that we are only forcing those who previously paid a marginal price of zero to reduce consumption. Presumably it is easier for firms in these communities to reduce consumption than it is for firms who pay much higher marginal prices in other communities.

The biggest difference in values between the efficient and uniform reductions is found at lower restrictions. For small reductions the percentage savings are very large even if the dollar savings are small. The difference become less pronounced (although the dollar figures are significant) at larger reductions.

COST of REDUCTION in WATER USE for ALBERTA and SASKATCHEWAN
Elasticity = -0.30 Price Series C35_MAR

% reduction	**TOTAL COST (1000 $ per month)**	**TOTAL REDUCTION (1000m^3 per month)**	**per capita reductions per month (m^3)**	**per capita costs per month ($)**	**AVG COST (\$/m^3)**	**MARGINAL COST (\$/m^3)**	**IMPLICIT PRICE (\$/m^3)**
1%	3	153	0.05	0.00	0.02	0.02	0.04
2%	21	307	0.10	0.01	0.07	0.12	0.31
3%	109	460	0.15	0.04	0.24	0.57	0.77
4%	245	613	0.21	0.08	0.40	0.89	0.97
5%	405	766	0.26	0.14	0.53	1.04	1.11
10%	**1,474**	**1,533**	**0.51**	**0.49**	**0.96**	**1.39**	**1.61**
15%	2,834	2,299	0.77	0.95	1.23	1.78	1.95
20%	4,495	3,066	1.03	1.51	1.47	2.17	2.40
25%	6,542	3,832	1.29	2.20	1.71	2.67	2.97
30%	9,101	4,598	1.54	3.06	1.98	3.34	3.74
35%	12,348	5,365	1.80	4.15	2.30	4.24	4.79
40%	16,548	6,131	2.06	5.56	2.70	5.48	6.25
45%	22,098	6,898	2.32	7.42	3.20	7.24	8.36
50%	29,620	7,664	2.57	9.95	3.86	9.81	11.49

Table 9.20 *Losses Calculations Alberta and Saskatchewan 1999: Efficient Reductions, All Enterprises*

COST of REDUCTION in WATER USE for ALBERTA and SASKATCHEWAN
Price Series C35_MAR Efficient Allocations

Elasticity	-0.1		-0.2		-0.3		-0.4	
% reduction	AC	MC	AC	MC	AC	MC	AC	MC
1%	0.11	0.11	0.03	0.03	0.02	0.02	0.02	0.02
2%	0.47	0.83	0.17	0.30	0.07	0.12	0.04	0.06
3%	0.73	1.26	0.39	0.83	0.24	0.57	0.16	0.39
4%	0.93	1.52	0.56	1.07	0.40	0.89	0.31	0.76
5%	1.09	1.71	0.70	1.27	0.53	1.04	0.43	0.94
10%	1.74	2.40	1.17	1.63	0.96	1.39	0.84	1.25
15%	2.56	4.19	1.50	2.18	1.23	1.78	1.10	1.60
20%	3.81	7.55	1.86	2.93	1.47	2.17	1.29	1.87
25%	5.87	14.15	2.29	4.01	1.71	2.67	1.47	2.19
30%	9.50	27.64	2.84	5.60	1.98	3.34	1.66	2.60
35%	16.24	56.66	3.58	8.01	2.30	4.24	1.87	3.10
40%	30	123	4.61	11.79	2.70	5.48	2.10	3.76
45%	58	284	6.08	17.91	3.20	7.24	2.38	4.64
50%	123	711	8.30	28.28	3.86	9.81	2.73	5.83

Table 9.21 *Losses Calculations Alberta and Saskatchewan 1999: Various Elasticities, Efficient Reductions, All Enterprises*

Elasticity	-0.1	-0.2	-0.3	-0.4
% reduction	AC	AC	AC	AC
1%	1082	4133	6150	6150
2%	191	665	1729	3075
3%	97	241	442	700
4%	63	145	230	319
5%	48	100	153	207
10%	25	38	53	68
15%	18	25	33	37
20%	16	19	23	26
25%	15	17	18	21
30%	15	14	16	17
35%	14	13	14	14
40%	14	12	12	13
45%	14	12	12	11
50%	14	11	11	10

Table 9.22 *Ratio of Average Costs: Uniform to Efficient Reductions, All Enterprises*

9.3.8 Discussion

To estimate the total cost of adjusting to a water shortage in the SSRB, we can take the average value of water reported above and apply it to a given scenario. For instance, suppose we wanted to impose a 10% reduction in total water withdrawals for some or all of the SSRB. First, consider the cost to residential consumers in each sub-basin (see Table 9.23). For Saskatchewan residents of the SSRB, a 10% reduction results in a 2.58 MCM fall in withdrawals per year based on a total withdrawal of 25.8 MCM. (This is calculated as 50% of total withdrawals in the Saskatchewan portion of the SSRB by all users). If we assume the baseline elasticity of -0.3, the average cost per cubic meter is $1.39 (taken from Table 9.14). This results in a total imputed adjustment cost of $3.59M per year. If this reduction is applied to all sub-basins, a 10% reduction results in a 16.5 MCM fall in consumption and a total cost of $21.71M per year.

We can do the same for Commercial and Institutional enterprises. Here we assume the elasticity is smaller at -0.1 (consistent with Table 9.12). A 10% reduction reduces consumption in the Saskatchewan part of the SSRB by 1.29 MCM and a cost of $2.80M per year given the average cost of $2.17 per cubic meter. For industrial users we apply an elasticity of -0.4 and get a cost of $0.95M to achieve a fall in withdrawals of 0.67 MCM. In aggregate, a 10% reduction, applied to each sub-basin and to each user group, decreases withdrawals by 30.7 MCM per year and costs $43.63M per year. The average cost is $1.42 per cubic meter. If the efficient reduction scheme is applied across the sub-basins, but the allocated reductions are equally applied across users within the basin, then the total cost would be $28.92M. This is a savings of $14.71M per year. This is a substantial sum.

	WITHDRAWLS per year (MCM)				**COSTS (10% reduction) Uniform Reductions ($M)**			**COSTS (10% reduction) Efficient Reductions ($M)**		
	Total	**RES[1]**	**COMM & INST[1]**	**IND[1]**	**RES**	**COMM & INST**	**IND**	**RES**	**COMM & INST**	**IND**
ELASTICITY					-0.30	-0.10	-0.40	-0.30	-0.10	-0.40
PRICE					**1.39**	**2.17**	**1.41**	**0.81**	**1.74**	**0.84**
BASIN:										
SSR-SK	51.6	25.8	12.9	6.7	3.59	2.80	0.95	2.09	2.24	0.56
SSR-AB	18.5	9.4	4.3	2.8	1.31	0.92	0.39	0.76	0.74	0.23
RD	23.2	11.8	5.3	3.5	1.64	1.16	0.49	0.96	0.93	0.29
OR	33.4	17.0	7.7	5.0	2.37	1.67	0.71	1.38	1.34	0.42
BR	180.6	92.1	41.5	27.1	12.80	9.01	3.82	7.46	7.23	2.28
TOTAL	**307.2**	**156.2**	**71.7**	**45.1**	**21.71**	**15.56**	**6.35**	**12.65**	**12.48**	**3.79**
							43.63			**28.92**

Note: [1] Total withdrawals by basin are taken from Kassem (2004). Residential, Commercial and Institutional, and Industrial withdrawals are calculated by taking the share allocated to each sector in the MUD data set and applying it to the total withdrawals.

Table 9.23 *Total Costs per 10% Reduction for All Municipal Users*

Of course we could achieve the entire reduction by forcing one group to achieve the entire reduction. For instance, if we imposed the entire reduction on residential customers then the 30.7 MCM reduction is equivalent to about a 20% reduction in residential withdrawals (as they absorb about one half of all municipal deliveries). However, the average cost for this magnitude reduction is about $1.70 per cubic meter. Hence, forcing only households to absorb all reductions would be more costly then distributing them across user types. The optimal allocation of reductions would ensure that each of the user groups faced the same shadow price at all times.

9.3.8.1 Treated Versus Raw Water

Note that the value of water calculated above is based on treated and delivered water to the household or enterprise rather than raw water directly from the watershed. In many other instances, such as livestock-watering and irrigation, water values are calculated for raw untreated water. To convert residential and commercial water values to a common basis we need to subtract the marginal costs of treating and delivering water to customers. That is, the value of water to households is the sum of the value of raw water, treatment, and delivery together. When we reduce water availability, some of the lost value is offset by reductions in delivery and treatment costs. To identify raw water values separately we need to subtract cost savings from the benefit reductions calculated above.

Environment Canada's *Industrial Water Use 1996* reports water intake quantities and treatment costs for manufacturing sectors in Canada. These are reported below and in Section 9.6. We can identify two costs. The first is the average cost of treating intake water on a per cubic meter basis. These range in value from \$0.013 to a high of \$0.098. However, not all water is used for processing; some is used for cooling and condensing or sanitary purposes. If we assume all costs of treatment are intended to produce clean water for processing, the average cost for treated water basically doubles. These costs ignore capital costs required to treat water and only include variable costs (labour, energy inputs, maintenance, and repair). However, since we are considering changes in water availability from current levels, we can ignore infrastructure costs since these are unlikely to change in the relevant timeframe or relevant quantity range.

	Intake Water	**Processing Water**	**Treatment costs**		
			Total	**Intake Water**	**Processing Water**
	MCM	**MCM**	**\$M**	**\$ per m^3**	**\$ per m^3**
Food	269.5	128.6	8.4	0.031	0.065
Beverages	73.1	38.4	4.9	0.067	0.128
Rubber Products	12.3	3.6	0.7	0.057	0.194
Plastic Products	13.3	5.9	1.3	0.098	0.220
Primary Textiles	86.7	15.5	1.4	0.016	0.090
Textile Products	15	12.8	0.7	0.047	0.055
Wood Products	45.1	9.7	1.4	0.031	0.144
Paper and Allied Products	2421.3	1847.5	45.8	0.019	0.025
Primary Metals	1423	557.6	29.2	0.021	0.052
Fabricated Metals	19.4	11.3	0.8	0.041	0.071
Transportation Equipment	65.4	28.5	6	0.092	0.211
Non-Metallic Mineral Products	102.3	21.6	1.3	0.013	0.060
Petroleum and Coal Products	370.5	34.4	14.1	0.038	0.410
Chemicals and Chemical Products	1121.3	220.9	23.7	0.021	0.107
Total	**6038.2**	**2936.3**	**139.7**	**0.023**	**0.048**

Table 9.24 *Water Treatment Costs*
Source: Industrial Water Use 1996, 2002

For our purposes the beverage industry is the relevant industry for direct comparison to municipal water treatment since both use water for consumption purposes. This gives us a range of costs between $0.067 and $0.128 per cubic meter. This corresponds to 5% to 9% of the average shadow price for a 10% reduction in water made available to residential customers.

An alternative calculation assumes that all current municipal water charges are based on a pure cost recovery basis. Since municipalities do not pay for water, but do pay for treatment and delivery, the marginal value of untreated water is zero given current consumption levels. Reductions in water from current levels would entail an implicit charge for raw, untreated water. Hence we can use actual payments to identify the implicit charge for untreated water that would generate the desired reduction in withdrawals. Note that since we are interested in changes in water use, the actual reduction in costs would only include the reductions associated with variable costs and not include capital costs. Using all charges gives us a long-run cost estimate since infrastructure costs are included.

Data from MUD shows that the average marginal cost charged to consumers is $1.12 in Saskatchewan and $1.06 in Alberta. The average charge is higher at $1.61 and $1.42 respectively. For commercial enterprises the average marginal cost is $1.11 and $1.34 respectively. Taking the implicit price associated with a reduction in consumption of 10% (this is $1.39 taken from Table 3.14) indicates a net rise in marginal prices for consumers of $0.28 and $0.33 per cubic meter in Saskatchewan and Alberta respectively. That is, if current water charges just pay for water treatment, then a 10% reduction in water withdrawals implies an increase in the price paid for untreated water of $0.27 in Saskatchewan.

We can use this value to consider allocations of raw, untreated water across different users. Of course, there is likely some cross-subsidy between commercial and residential consumers since the average charges differ depending on the type of customer. Second, the marginal cost of treatment is likely much smaller than the average cost since capital investments need not be changed. The value for beverage manufacturing was in the $0.06 to $0.12 range. Hence the value of $0.27 per cubic meter is likely an understatement of the true value of raw water and is perhaps closer to a long run marginal value.

9.3.9 Appendix

	C10_MAR	**C35_MAR**	**C100_MAR**	**C10_MAR**	**C35_MAR**	**C100_MAR**
	MC > 0	MC > 0	MC > 0	MC > =0	MC > = 0	MC > = 0
R^2 - adj	0.030	-0.001	-0.004	-0.005	0.004	0.008
n	110	175	177	192	192	192
Intercept	**1.120**	**1.061**	**1.056**	**1.096**	**1.059**	**1.057**
SE	0.09	0.07	0.07	0.09	0.07	0.07
t Stat	11.99	14.42	14.42	11.80	14.35	14.48
ln(P)	**-0.300**	**-0.125**	**-0.081**	**0.004**	**-0.067**	**-0.089**
SE	0.14	0.14	0.14	0.03	0.05	0.06
t Stat	-2.09	-0.88	-0.59	0.12	-1.32	-1.59

Table 9.25a *Elasticities for Alberta and Saskatchewan 1999: All Enterprises*

	C10_MAR	**C35_MAR**	**C100_MAR**	**C10_MAR**	**C35_MAR**	**C100_MAR**
restriction	MC > 0	MC > 0	MC > 0	MC > =0	MC > = 0	MC > = 0
R^2 - adj	0.013	0.000	-0.002	-0.005	-0.002	0.005
n	109	173	173	190	190	190
Intercept	**0.779**	**0.710**	**0.710**	**0.762**	**0.791**	**1.622**
SE	0.09	0.07	0.07	0.09	0.09	0.62
t Stat	8.60	10.33	10.30	8.71	8.37	2.60
ln(P)	**-0.213**	**-0.132**	**-0.105**	**0.011**	**-0.139**	**-0.188**
SE	0.14	0.13	0.13	0.03	0.18	0.13
t Stat	-1.54	-1.00	-0.82	0.39	-0.77	-1.42

Table 9.25b *Elasticities for Alberta and Saskatchewan 1999: Commercial and Institutional*

	C10_MAR	**C35_MAR**	**C100_MAR**	**C10_MAR**	**C35_MAR**	**C100_MAR**
restriction	MC > 0	MC > 0	MC > 0	MC > =0	MC > = 0	MC > = 0
R^2 - adj	0.012	-0.008	-0.009	-0.005	-0.007	-0.008
n	70	110	110	120	120	120
Intercept	**-3.317**	**-3.290**	**-3.286**	**-3.337**	**-3.291**	**-3.273**
SE	0.14	0.11	0.11	0.14	0.11	0.11
t Stat	-23.49	-28.98	-28.90	-23.75	-29.12	-29.17
ln(P)	**-0.260**	**-0.081**	**-0.002**	**-0.032**	**-0.036**	**0.007**
SE	0.19	0.21	0.21	0.05	0.08	0.09
t Stat	-1.35	-0.38	-0.01	-0.68	-0.46	0.08

Table 9.25c *Elasticities Alberta and Saskatchewan 1999: Industrial*

9.4 Irrigation Water Use

9.4.1 Water Use

Water withdrawal for irrigation is the largest component of water withdrawals in the SSRB. For 1996, total diversions in the SSRB were 2,864 MCM with 580,613 hectares under irrigation (see Table 9.26). Most irrigation in the SSRB is in Alberta with about 96% of the irrigated land and just under 98% of the irrigation diversions. Private irrigators in Alberta account for a significant component of all irrigation. Data for 1996 are not available but data for 1986 show that 14% of total irrigation withdrawals in Alberta are attributable to private irrigation. On average, Alberta irrigators use water more intensively applying an average of 500 mm of water per hectare. Saskatchewan irrigators apply only 250 mm per hectare on average.

		Irrigated area (ha)	**Diversions (1000m^3)**	**Irrigated return flows (1000m^3)**	**average use (1000m^3/ha)**
ALBERTA	AID	868	4,975	2,801	5.729
	BRID	79,374	404,648	119,776	5.098
	EID	109,747	758,884	245,120	6.915
	LID	1,732	6,032	3,396	3.483
	LNID	57,954	258,437	37,990	4.459
	MID	5,806	19,160	2,989	3.300
	MVID	1,358	3,280	1,847	2.415
	RCID	297	1,338	803	4.502
	RID	16,057	56,135	8,757	3.496
	SMRID	137,287	614,630	95,882	4.477
	TID	30,270	157,129	24,512	5.191
	UID	5,723	24,453	14,305	4.273
	WID	27,818	144,341	90,069	5.189
	PRIVATE [1]	85,219	342,356	90,457	4.017
	TOTAL	**559,511**	**2,795,796**	**738,703**	**4.997**
SASKATCHEWAN	CWUD	280	645		2.304
	FFWUD	0	0		
	GWUD	1,047	2,226		2.126
	HWUD	1,291	2,970		2.301
	LLWUD	3,307	7,607		2.300
	MWUD	847	1,947		2.299
	MCP	0	0		
	MCF	0	0		
	MCWUD	675	3,083		4.567
	MLWUD	616	1,417		2.300
	RWUD	2,912	6,756		2.320
	SSRID	15,272	38,638		2.530
	WWUD	667	2,033		3.048
	SK TOTAL	**26,914**	**67,322**		**2.501**
	SSRB TOTAL	**580,613**	**2,864,194**		**4.933**

Note: [1] Private irrigation calculated by inflating 1996 District data by share of water withdrawals of private irrigators in 1986. Inflating factor is 0.1797 for irrigated area and 0.1395 for water diversions.

Table 9.26 S*SRB Irrigation Water Withdrawal Areas, 1996*
Source: Prairie Farm Rehabilitation Administration *Socio-Economic Database 2003*

9.4.2 Crop Production

9.4.2.1 Major Crops

Alberta Agriculture identifies over sixty crops grown under irrigation. However, only ten main crops make up about two-thirds of all irrigated sectors. These crops are: Alfalfa, Barley, Barley Silage, Canola, Dry Beans, Grass Hay, HRS Wheat, SWS Wheat, Potatoes, and Sugar Beets. Table 9.27 shows the total area under irrigation by crop. The most common irrigated crop is Alfalfa, followed by Barley and Barley Silage. Saskatchewan differs from Alberta in that a greater share of irrigated area is allocated to HRS Wheat and Potatoes and less to Sugar Beets and Barley.

	TOTAL IRRIGATED AREA (ha)		
	AB SSRB	**SK SSRB**	**Total SSRB**
Total Area	**545,994**	**62,363**	**608,357**
In %	90%	10%	
Alfalfa	**158,834**	**19,589**	**178,422**
	29.1%	31.4%	29.3%
Barley	**133,638**	**0**	**133,638**
	24.5%	0.0%	22.0%
Barley Silage	**68,408**	**5,186**	**73,594**
	12.5%	8.3%	12.1%
Canola	**54,714**	**4,681**	**59,395**
	10.0%	7.5%	9.8%
Pea	**29,578**	**4,461**	**34,039**
	5.4%	7.2%	5.6%
Grass	**0**	**5,186**	**5,186**
	0.0%	8.3%	0.9%
HRS Wheat	**0**	**21,180**	**21,180**
	0.0%	34.0%	3.5%
SWS Wheat	**59,408**	**0**	**59,408**
	10.9%	0.0%	9.8%
Potato	**0**	**2,081**	**2,081**
	0.0%	3.3%	0.3%
Sugar Beet	**41,440**	**0**	**41,440**
	7.6%	0.0%	6.8%

Table 9.27 *Major Irrigated Crops by Area, 1996*
Source: Kassem (2004)

9.4.2.2 Crop Prices

Alberta Agriculture also reports prices for these crops over the period 1970 to 1998 in both nominal and real terms. See the following Table 9.28 for a year by year summary of the crops grown.

Year	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1989-98**
Alfalfa	109.27	109.32	90.00	85.86	107.74	106.37	104.15	127.35	114.19	120.80	**107.51**
Barley Silage	22.55	19.54	17.40	19.41	17.85	23.26	31.65	26.53	25.57	22.06	**22.58**
Tame Grass	58.22	59.87	48.75	57.79	58.09	60.80	72.65	84.93	77.29	68.83	**64.72**
HRS Wheat	134.26	95.45	103.40	122.23	187.71	216.07	215.85	180.66	201.25	127.33	**158.42**
SWS Wheat	138.61	92.71	104.97	129.23	106.79	151.97	204.66	155.90	129.05	113.28	**132.72**
Barley	112.78	97.75	87.04	97.08	89.27	116.32	158.32	132.68	127.86	110.36	**112.95**
Canola	277.96	257.31	237.25	287.15	344.94	359.96	370.84	391.84	371.39	327.31	**322.60**
Sugar Beets	45.54	41.28	32.52	38.79	39.54	43.93	44.74	43.25	49.72	34.91	**41.42**
Dry Beans	33.92	16.89	14.58	18.86	32.60	18.31	21.00	24.21	24.17	21.21	**22.58**
Potato	120.0	120.0	120.0	120.0	130.0	130.0	130.0	130.0	130.0	130.0	**126.00**
Corn Silage[1]	20.35	20.93	17.04	20.20	20.31	21.26	25.40	29.69	27.02	24.06	**22.63**

Note: [1] Corn Silage price was not reported by Alberta Agriculture. The price was determined by the long run average of the price of Fodder Corn to Tame Hay for 1974-84 (taken from Statistics Canada *Table 001-0010 - Estimated areas, yield, production and average farm price of principal field crops, in metric units, annual.* Tame Hay was worth 2.8605 times more than Fodder Corn.

Table 9.28 *Crop Prices 1989-1998, ($ per 1000kg in real prices)*
Source: *South Saskatchewan River Basin: Irrigation in the 21st Century.*
Volume 5: Economic Opportunities and Impacts,
Irrigation Water Management Study Committee,
Alberta Irrigation Projects Association, 2002, Table 7, page 14

9.4.2.3 Irrigation Costs

Alberta Agriculture reports on-farm irrigation costs for different irrigation technologies. In general, the more efficient the technique in terms of water usage, the more labour intensive it is. The least expensive technique is the developed gravity system which costs $0.099 per millimeter of water applied per hectare. This works out to $9.90 per $1000m^3$ per hectare.

System Type	Labour costs	R & M costs	Energy Costs	Total Costs	Capital Costs	App Eff[2]
	($/mm/ha)				(ha)	(%)
Gravity – flood	0.101	0.0065	0.000	0.108	310	20
Gravity-developed	0.079	0.020	0.000	0.099	990	54
Gravity – controlled	0.045	0.049	0.037	0.131	1665	70
Sprinkler-Hand move, Solid Set or Wheel-Roll	0.067	0.057	0.195	0.319	1360	65
Sprinkler- Pivot/Linear - High Pressure w/ or w/o Corner Systems	0.022	0.109	0.220	0.351	1665	71
Sprinkler- Pivot/Linear - Low Pressure w/ or w/o Corner Systems	0.022	0.111	0.160	0.293	1600	75
Sprinkler - Volume Gun, Traveller	0.045	0.084	0.350	0.479	1550	63
Micro	0.027	0.185	0.067	0.279	2720	82

Note: [1]Application Efficiency based on standard techniques and refers to the percentage of water that reaches the root zone.

Table 9.29 *On-Farm Irrigation Costs and Efficiencies*
Source: *South Saskatchewan River Basin: Irrigation in the 21st Century. Volume 5: Economic Opportunities and Impacts,* Irrigation Water Management Study Committee, Alberta Irrigation Projects Association, 2002, Table 9, page 17, and Table 3 page 6.

9.4.3 Marginal and Average Value of Water in Irrigation

For irrigators, water is a productive input that raises yields and farm revenues. Like other inputs, water application involves additional costs. In general, water is charged on an assessed basis using irrigated acreage as the base for charges although some irrigation districts also charge a fee for pipelines based on acreage and/or water pressure. Irrigators are allocated an amount of water based on supply criteria and specified legal rights (first user rights). However, water is seldom directly metered. This implies that the actual marginal cost of purchasing water for irrigators is zero, although irrigators would be willing to pay a positive price for water if they were forced to. It is this shadow price of water that we aim to identify.

We impute the shadow price of water by assessing the increase in net revenues of additional applications of water for each crop type. We take a crop production approach where we calculate crop yields as a function of water application. Data for crop production functions come from the Irrigation Branch of Alberta Agriculture, Food and Rural Development. We adjust the shadow price for the additional costs of pumping water associated with energy and labour inputs.

The shadow price of water depends on the crop type, irrigation technique, irrigation delivery efficiency, crop prices, and weather during the crop year. For instance, Table 9.30 shows the value of water in alfalfa production. Data are for 1983 which was considered an average year for water demand. The scenario assumes a low pressure pivot system with a water delivery efficiency of 75%. This is the fraction of delivered water that reaches the root system and so contributes to plant growth. Alfalfa, in this particular location, has a theoretical evapotranspiration (ETp) of 906 mm for the entire growing season. This is the theoretical maximum amount of water that can be processed by the plant. In general, ETp rises as the growing season expands or temperatures rise and hence is year, crop, and location specific. However, due to management practices, the actual amount of water applied to fields is typically less; irrigators seldom

Water Delivery Efficiency	75.0%
ETp (mm)	906
ETc (mm)	822
MAX Theoretical Yield (kg/ha)	23,641
MAX Potential Yield (kg/ha)	20,406
Actual Rainfall (mm)	378
Irrigation Management Factor	75.0%
Average real Price 1989-1998 ($/tonne)	$107.51
Irrigation Costs ($/mm/ha)	$0.293

Application (mm)	**ETa (mm)**	**Yield kg/ha**	**Revenue ($/ha)**	**Irrigation costs ($/ha)**	**Net Revenue ($/ha)**	**Water Diversion (m^3)**	**Marginal Value ($\$/m^3$)**
0	378.0	6,101	655.94	0.00	655.90	0	
25	396.8	6,809	732.01	7.33	724.70	250	**0.275**
50	415.5	7,507	807.10	14.65	792.50	500	**0.271**
75	434.3	8,197	881.21	21.98	859.20	750	**0.267**
100	453.0	8,877	954.34	29.30	925.00	1000	**0.263**
125	471.8	9,548	1026.5	36.63	989.90	1250	**0.259**
150	490.5	10,210	1097.70	43.95	1053.70	1500	**0.255**
175	509.3	10,863	1167.80	51.28	1116.60	1750	**0.251**
200	528.0	11,506	1237.00	58.60	1178.40	2000	**0.248**
225	546.8	12,141	1305.30	65.93	1239.30	2250	**0.244**
250	565.5	12,766	1372.50	73.25	1299.30	2500	**0.240**
275	584.3	13,383	1438.80	80.58	1358.20	2750	**0.236**
300	603.0	13,990	1504.10	87.90	1416.20	3000	**0.232**
318	616.5	14,421	1550.40	93.17	1457.30	3180	**0.228**

Table 9.30 *Value of Water in Alfalfa*
Source: Irrigation Branch of Alberta Agriculture, Food and Rural Development.

apply water to the maximum theoretical level. This potential crop water use (ETc) when water is not a limiting factor is 822 mm. Again, this is crop, year, and location specific. Applying these amounts of water, and assuming 75% of the water reaches the root system, generates a maximum theoretical and a practical maximum yield of 23,641 and 20,406 kg per hectare, respectively. An irrigation management factor of 75% accounts for the fact that on-farm irrigators typically do not fully apply the maximum potential water. Hence, if unconstrained, the maximum water applied to the root system including rain, denoted as ETa, is 616.5 mm of which 378 mm was from precipitation during the growing season (all precipitation is assumed to reach the roots). This generates a yield of 14,421 kg per hectare.

As we increase water applications the water applied to the root system also rises. Given the system efficiency of 75%, each 25 mm in applied water increases water at the root system by 18.75 mm. This raises yields. At the ten-year average real price of $107 per ton, this rise in yields also raises revenues. However, increasing water applications also raises irrigation costs such as repair and maintenance, labour, and energy by $0.293 per mm per hectare or $0.0293 per cubic meter. If we take an initial application of water of 25 mm per hectare (in addition to precipitation), revenues rise by \$76, pumping costs by \$7.33, and water diversions rise by 250m^3. This implies a net gain of \$0.275 per cubic meter of water. That is, the first 25 mm of irrigation water generates, on average, \$0.275 of additional net revenues per cubic meter. This gives us a measure of the shadow price of water: the maximum an irrigator would be willing to pay for an additional cubic meter of water. As we apply more water, the shadow price falls, since the contribution to additional growth also falls. The last 18 mm of water applied generates an average benefit of \$0.228 per cubic meter. These calculations assume that other inputs, such as fertilizer and pesticides, do not change with water applications. This is not unreasonable as long as we consider relatively small changes in water. The total contribution of water is about \$801.4 per hectare (increased revenues less increased on farm irrigation costs) but uses 3180m^3 for an average value of \$0.252 per cubic meter. Note that a small change in price will tend to raise water use a lot. This implies that water use is sensitive to prices (elastic demand) at least for a single crop.

Table 9.31 illustrates how delivery efficiencies, prices, precipitation, and management practices affect the shadow price of water. Six new experiments were run looking at the sensitivity of these values to changes in growing conditions, practices, and prices.

Experiment [1]: This is the base case laid out in the Table 9.30 above.

Experiment [2]: Rather than low pressure pivot system we move to a high pressure system. This increases the delivery costs of water since pumping at high pressure increases energy costs. The high pressure also reduces delivery efficiency since more water evaporates before reaching the root zone. The effect of this delivery mechanism is to lower the value of water by about 8% but also forces the irrigator to use more water to achieve maximum yield.

Experiment [3]: Here we move to a wheel roll system. Delivery efficiency falls and irrigation costs rises due to additional labour as well as energy costs. The value of water falls below [1] by about 16% and again forces the irrigator to use more water to achieve maximum yield.

Experiment [4]: Here we move to a developed gravity system. Delivery efficiency falls but so do irrigation costs since energy costs are lower. The value of water falls below [1] by about 23% and again forces the irrigator to use more water to achieve maximum yield.

Experiment [5]: Here we move back to the base scenario but double the market price. The value of water rises by about 112%. That is, revenues double but costs and water applications stay the same so the net revenues rise by more than 100%.

Experiment [6]: Here we maintain the base scenario but reduce precipitation to zero. This forces the irrigator to apply all the water for growth. The value of water rises by about 16%. The idea here is that the most valuable water is the first few millimeters that reach the root zone. This was previously provided by rainfall. With less rainfall, irrigation water becomes more valuable to the irrigator. Total applications of course also rise.

Experiment [7]: Here we maintain the base scenario but increase the management factor from 75% to 85%. This means that the farm operator will increase the target water application closer to the optimum. The value of water, however, does not change. The only difference is that the irrigator applies more water to achieve a higher target application rate. Since the underlying efficiency of the delivery system does not change, the value of water does not change for the initial applications of water.

	[1]	[2]	[3]	[4]	[5]	[6]	[7]
	Base Pivot Low	**Pivot High**	**Wheel Turn**	**Gravity dev'd**	**Double Price**	**No Precip**	**Management**
Water Delivery Efficiency	75%	71%	65%	54%	75%	75%	75%
ETp (mm)	906	906	906	906	906	906	906
ETc (mm)	822	822	822	822	822	822	822
MAX Theoretical Yield (kg/ha)	23,641	23,641	23,641	23,641	23,641	23,641	23,641
MAX Potential Yield (kg/ha)	20,406	20,406	20,406	20,406	20,406	20,406	20,406
Actual Rain (mm)	378	378	378	378	378	0	0
Irrigation Management Factor:	75.0%	75.0%	75.0%	75%	75.0%	75.0%	85.0%
Average real Price 1989-1998 ($/tonne)	$107.51	$107.51	$107.51	$107.51	$215.02	$107.51	$107.51
Irrigation Costs ($/mm/ha)	0.293	0.351	0.319	0.099	0.293	0.293	0.293
Average Value for full application ($/m3)	**0.252**	**0.231**	**0.212**	**0.193**	**0.533**	**0.292**	**0.244**
% difference		-8%	-16%	-23%	+112%	+16%	-3%
Applied water	**Marginal Value ($/m3)**						
0							
25	0.275	0.253	0.232		0.579	0.354	0.275
50	0.271	0.250	0.229	0.210	0.571	0.350	0.271
75	0.267	0.246	0.226	0.208	0.564	0.346	0.267
100	0.263	0.243	0.223	0.206	0.556	0.342	0.263
125	0.259	0.239	0.220	0.203	0.548	0.338	0.259
150	0.255	0.235	0.217	0.201	0.540	0.335	0.255
175	0.251	0.232	0.214	0.199	0.532	0.331	0.251
200	0.248	0.228	0.211	0.197	0.524	0.327	0.248
225	0.244	0.225	0.208	0.195	0.516	0.323	0.244
250	0.240	0.221	0.206	0.193	0.509	0.319	0.240
275	0.236	0.218	0.203	0.191	0.501	0.315	0.236
300	0.232	0.214	0.200	0.189	0.493	0.311	0.232
325	0.228	0.211	0.197	0.187	0.485	0.307	0.228
350		0.207	0.194	0.185		0.303	0.224
375			0.191	0.183		0.299	0.220
400				0.181		0.295	0.216
425				0.179		0.291	0.212
450				0.177		0.287	
475				0.175		0.283	
500						0.280	
525						0.276	
550						0.272	
575						0.268	
600						0.264	
625						0.260	
650						0.256	
675						0.252	
700						0.248	
725						0.244	
750						0.240	
775						0.236	
800						0.232	
825						0.229	

Table 9.31 *Value of Water in Alfalfa: Scenarios*
Source: Irrigation Branch of Alberta Agriculture, Food and Rural Development.

	Alfalfa	Grass Hay	Barley	Barley Silage	Corn Silage	Canola	HRS Wheat	SWS Wheat	Dry Beans	Potatoes	Sugar Beets
Irrigation factor	75%	75%	83%	83%	83%	83%	83%	83%	90%	90%	90%
ETp (mm)	906	973	644	570	831	690	690	690	641	912	771
ETc (mm)	822	427	445	414	508	475	520	520	347	620	567
ETa (mm)	617	320	369	344	422	394	432	432	312	558	510
Actual Precipitation (mm)	378	232	204	191	226	204	205	210	207	211	212
MAX Theoretical yield (tonnes/ha)	23.64	20.71	10.79	16.83	108.8	4.673	6.52	9.44	6.30	59.14	75.65
MAX Unconstrained yield (tonnes/ha)	20.41	7.77	7.20	33.31	88.58	3.55	4.85	7.01	3.06	41.56	66.57
MAX Actual yield (tonnes/ha)	14.42	4.38	27.33	74.59	3.10	5.88	3.99	5.77	2.46	36.02	60.41
Price (1989-98) ($/tonne)	107.5	64.72	113	22.58	22.63	322.6	158.4	132.7	22.58	126.0	41.42
Irrigation Costs ($/mm/ha)	0.293	0.293	0.293	0.293	0.293	0.293	0.293	0.293	0.293	0.293	0.293
Average Value for full application ($/m3)	**0.252**	**0.143**	**0.159**	**0.120**	**0.362**	**0.132**	**0.125**	**0.154**	**0.004**	**1.139**	**0.498**
Applied water (mm)	**Marginal Values ($/m^3)**										
0											
25	0.275	0.148	0.183	0.124	0.434	0.150	0.143	0.179	0.007	1.412	0.649
50	0.271	0.145	0.177	0.123	0.419	0.146	0.139	0.174	0.006	1.382	0.629
75	0.267	0.142	0.171	0.122	0.403	0.142	0.135	0.169	0.005	1.352	0.609
100	0.263	0.138	0.164	0.121	0.388	0.139	0.131	0.164	0.003	1.321	0.589
125	0.259	0.136	0.158	0.120	0.373	0.135	0.127	0.159	0.002	1.291	0.569
150	0.255		0.152	0.119	0.357	0.131	0.123	0.154	0.001	1.260	0.549
175	0.251		0.146	0.118	0.342	0.127	0.119	0.149		1.230	0.528
200	0.248		0.139	0.117	0.326	0.123	0.115	0.144		1.199	0.508
225	0.244		0.133	0.116	0.311	0.119	0.111	0.139		1.169	0.488
250	0.240				0.296	0.115	0.107	0.134		1.139	0.468
275	0.236					0.113		0.129		1.108	0.448
300	0.232							0.124		1.078	0.427
325	0.228									1.047	0.407
350										1.017	0.387
375										0.987	0.367
400										0.956	0.347
425										0.926	
450										0.895	
475										0.865	

Table 9.32 *Value of Water in Major Crops*
Source: Irrigation Branch of Alberta Agriculture, Food and Rural Development.

Prior Table 9.31 considers the value of water in alfalfa production. Table 9.32 shows the shadow prices for all the ten major crops grown. We can assume a low-pressure pivot system as this appears to be the direction taken with new irrigation investments. Note that the irrigation factors differ amongst the crops due to differences in actual farm practices. Precipitation also differs due to differences in the length of the growing season for each crop. The table shows that the average value of water if applied to achieve maximum ETa varies from a low of $0.004 per cubic meter for dry beans to a high of $1.139 per cubic meter for potatoes. Marginal values vary from $0.001 to $1.412 per cubic meter. Not surprising is that water is more valuable in specialty crops and less valuable in grains. As above, changing prices, delivery systems, and precipitation will all be factors that alter these values.

9.4.4 On-Farm Efficiency

Table 9.32 shows the average and marginal value of water for each major crop. Water diversions are, however, allocated on a farm enterprise basis. Hence the marginal value of water to an enterprise is the price they would pay to avoid a shortage given their cropping decisions. Profit maximization principles tell us that the farm operator will allocate available water to minimize their opportunity costs. As long as a farm enterprise has low value crops, such as wheat in their rotation, the shadow price will reflect the minimum marginal value. That is, the irrigator will reduce water to those crops that contribute least to net revenues. This implies a shadow price of water of approximately $0.04 to $0.12 per cubic meter depending on irrigation technique and the crop mix employed. This effective marginal value is for raw water.

A more detailed optimization calculation can be performed at the farm level to determine the optimal response to water shortages. However, such a calculation is currently beyond the scope of this study. Furthermore, it need not shed additional light on basin-wide responses.

9.4.5 Total Value of Water in Irrigation

Calculating the total value of water used in irrigation is difficult since we have to factor in the crop mix, the type of irrigation equipment, and on-farm management factors as well as actual climatic conditions at each site. As a ballpark figure, however, we can calculate the value of production associated with irrigation per cubic meter of water. Kulshreshtha and Thompson (2004) report total value of production from irrigation of $1,013M in 1996. The withdrawal of 3,191 MCM yields an average value of production $0.317 per cubic meter of water diversions. This value also includes expenditures on all inputs so the net contribution of water alone is much smaller. This value forms an upper bound.

We can use a different calculation of the value of water using the average values of water for each crop (taken from Table 9.32) and weighting it by the distribution of crops (identified in Table 9.27) across the SSRB. Table 9.33 shows these calculations. These calculations give us a weighted average value of water of $0.193 per cubic meter for the entire SSRB. For Saskatchewan it is higher at $0.202 since Potatoes made up a greater share of irrigated acreage in 1996. Inflating this average value of water by the amount withdrawn in the SSRB yields a total value of approximately $551 million. This value is the contribution to total revenues afforded by irrigation net of direct on farm irrigation costs and assumes that each crop gets its full application of water.

	AVERAGE VALUE ($/m^3)	**IRRIGATED AREA (ha)**		
		AB SSRB	**SK SSRB**	**Total SSRB**
Alfalfa	0.252	158,834	19,589	178,422
Barley	0.159	133,638	0	133,638
Barley Silage	0.120	68,408	5,186	73,594
Canola	0.132	54,714	4,681	59,395
Pea	0.004	29,578	4,461	34,039
Grass	0.143	0	5,186	5,186
HRS Wheat	0.154	0	21,180	21,180
SWS Wheat	0.125	59,408	0	59,408
Potato	1.139	0	2,081	2,081
Sugar Beet	0.498	41,440	0	41,440
Weighted Average Value[1] ($/m^3)		**0.192**	**0.202**	**0.193**
Withdrawals (MCM)		**2,796**	**67.3**	**2,864**
Total Value ($1000)		**537,081**	**13,786**	**550,867**

Note: [1] weighted average of average water value using irrigated area as weights.

Table 9.33 *Total Value of Water, 1996*

9.4.6 Discussion

We need to account for a number of factors when using the values reported above. The following should be kept in mind.

- The average value of water of $0.193 per cubic meter is the shadow price of water delivered to the farm and is not the value of raw water. In general, however, the marginal delivery costs will be very low since the majority of costs are tied to infrastructure and would not change with delivery. As such, the value of $0.193 per cubic meter is likely very close to the average value of raw water drawn from the watershed.

- The marginal value of water, for a small reduction, is much lower and likely in the range of $0.10 to $0.12 since irrigators typically have some lower value crops in rotation and would chose to impose restrictions on these crops first. Hence, for small reductions in water delivery, the value of water in irrigation is much lower than that water in municipal use.

- Changes in water availability induced by global climate change would likely have widespread impacts that extend beyond the SSRB. This is likely to alter crop prices at the same time it alters water supplies. As shown above, the higher the crop price, the higher the value of water. Also, the lower the precipitation, the higher the value. Therefore, if climate change leads to deeper droughts, here and elsewhere, the value of water in these periods would rise since both scarcity and higher crop prices will work in the same direction. This clearly suggests that the demand for irrigation is likely going to rise and so demands for access to water will also rise.

9.5 Livestock Water Use

9.5.1 Water Use

Water used for livestock is an important, and growing, component of water use in the SSRB. Data from the Canadian Agricultural Census was used to identify herd sizes in each of the SSRB sub-basins. The types of livestock accounted for are listed in Table 9.34. Using estimated water use coefficients for each type of animal (see Table 9.36 for these values), we can estimate the volume of water used for livestock in each sub-basin and by type of animal. Total water used in livestock is estimated at about 58 MCM with the Red Deer sub-basin absorbing 34% of the total. The largest single use of water is for raising beef cows. The data also show that about 85% of the water consumed is for raising calves, bulls, steers and beef cows. Dairy cows draw another 6%. The remaining 9% is primarily allocated to horses and pigs.

	RED DEER RIVER	BOW RIVER	OLDMAN RIVER	SOUTH SASK RIVER - AB	SOUTH SASK RIVER - SK	TOTAL	SHARE Of WATER
BULLS	855	325	564	246	401	**2,391**	4%
CALVES	3,445	1,313	2,514	946	1,583	**9,802**	17%
STEERS	2,927	1,195	4,835	1,512	797	**11,265**	19%
BEEF COWS	9,372	3,294	6,137	2,538	4,498	**25,838**	45%
MILK COWS	1,267	320	960	275	496	**3,319**	6%
HENS AND CHICKENS	127	95	172	45	75	**513**	1%
OTHER POULTRY	7	3	11	5	4	**29**	0.1%
SHEEP	52	26	78	16	22	**196**	0.3%
HORSES	709	322	612	91	212	**1,946**	3%
PIGS	925	186	696	242	431	**2,479**	4%
TOTAL	**19,685**	**7,081**	**16,578**	**5,915**	**8,519**	**57,778**	**100%**
SHARE	34%	12%	29%	10%	15%	100%	

Table 9.34 *Livestock Water Use in the SSRB, 1996 (1000m^3 per year)*
Source: Kassem, 2004.

9.5.2 Value of Water

To estimate the value of water used in livestock we calculate the value-added in the production of the different livestock raised in Saskatchewan and Alberta and attribute this entirely to water. This is called the *residual imputation method.* The idea is that any decrease in water availability will lower stock populations and decrease net operating profits. The converse holds for any increase in water. The critical assumption is that one cannot reduce total water consumption without also reducing herd sizes. There is no substitute for water nor can one increase the efficiency of water use. A further assumption is that reductions in water availability lead to a one-for-one decrease in water available for livestock. Livestock operators are assumed to have no alternative source for water nor can they divert water from other activities. This is a strong assumption as water can often be trucked in to overcome shortfalls in water. However, as long as the value of water is small, trucking in water is not a long-term, viable option. In the long-run, one can switch to alternative livestock or crops. Therefore, the values presented here will tend to overestimate the long-run opportunity cost to livestock owners but underestimate their willingness to cover short-term water deficiencies.

The data for the value of livestock per head come from *Value of Farm Capital* (Statistics Canada, 2003). This document reports the value per head of livestock as of July 1 of each year from 1986 to 2002. To see how these are calculated we can use Alberta data from dairy producers (see Section 9.5.4 Appendix). Gross income from all sources (sales, subsidies, inventory sales, etc.) was $5732 per head per year for 2002. Total operating costs (feed, veterinary, hauling, fuels, labour, repairs to machinery, etc.) was $4142. Hence operating profits (excluding capital costs) was about $1590 per head per year. If we include capital costs ($944 per year) then profit per head falls to $646 (or about 40% of operating profits).

Livestock populations are derived from the *Census of Agriculture*. Adjustments were made to account for the fact that only portions of some census divisions are contained in the SSRB. Water use coefficients per head of livestock are reported by Kassem 2004.

Table 9.35 shows the concordance between the Statistics Canada Census categories for livestock and the water use categories for livestock. Also presented are the livestock values per head for 1996 as well as the ten year average for 1991-2000 using constant 1996 prices. Considering only 1996 data we can see that the value of livestock per head is very similar for the two provinces. However, if we take a ten year average for 1991-2000, using 1996 as the base year, the value per head in Saskatchewan is quite a bit larger than in Alberta. This is partially due to the systematically higher inflation rates in Alberta that reduce the real value of livestock.

SSRB CATEGORY	**STATISTICS CANADA CATEGORY**	**SK[1] 1996**	**AB[1] 1996**	**SK[2] 1991-2001**	**AB[2] 1991-2001**	**Diff[3]**
BULLS	Bulls	1600.00	1550.00	2013.76	1885.51	6.4%
CALVES	Includes all calves (from 0-6 mo and 6-12 mo)	263.00	291.00	431.48	452.35	-4.8%
STEERS	Slaughter Steers	779.00	764.00	835.31	800.09	4.2%
BEEF COWS	Beef cows	750.00	750.00	1156.23	949.00	17.9%
MILK COWS	Dairy cows	1300.00	1300.00	1481.91	1445.57	2.5%
HENS AND CHICKENS	Total Chickens (broilers, layers, pullets, and cockerels)	3.00	3.00	2.83	2.57	9.1%
OTHER POULTRY	Total Turkeys	10.00	9.00	9.94	8.47	14.8%
SHEEP	Total Sheep (rams and ewes)	128.00	127.00	136.46	101.42	25.7%
HORSES	[4]	781.00	777.00	1114.06	929.99	16.5%
PIGS	Sows and bred gilts	300.00	300.00	299.54	267.82	10.6%

Notes: [1] Value per head in 1996 using 1996 dollars.

[2] Average value per head in the period 1991-2000 using constant 1996 dollars.

[3] Percentage difference in ten year averages between Saskatchewan and Alberta.

[4] Not Listed. We use the same price series as Total Cattle (excluding Calves).

Table 9.35 *Value per Head of Livestock, 1996*

Sources: Value per head in Statistics Canada, 2003, Table 003-0025:

Value per head of livestock at July 1, annual (Dollars).

Documentation in *"Value of Farm Capital"* Catalogue No. 21-013-XIE, VOL. 2, NO. 1 (ISSN: 1705-0987).

CPI data: Statistics Canada, Table 384-0036: Implicit price indexes, Gross Domestic Product (GDP), Provincial Economic Accounts, annual (Index, 1997=100).

Table 9.36 takes the value per head and the consumption of water per head to calculate the value of water used in livestock on a per cubic meter basis. The interpretation is that a reduction in water of, say $1000m^3$, forces livestock owners to reduce their herd size. This reduces the net value of their herds. The imputed lost net value due to the reduction in water is equal to their willingness to pay for additional water (their shadow price of water). The imputed value of water is likely an upper estimate as the entire net value is attributed to water. In reality, other unmeasured inputs are also critical to livestock production but are excluded. Given this caveat, the imputed value of water on a per cubic meter basis varies from a low of $25.72 for Dairy Cows as well as Hens and Chickens to a high of $136.78 for Pigs. There is a difference in the value across provinces due to the differences in value per head.

	Water use coefficient (m^3 per head per year)[1]	**Value per head ($) SK 1991-2000**	**Value per head ($) AB 1991-2000**	**Value of water ($/$m^3$) SK**	**Value of water ($/$m^3$) AB**
BULLS	35.41	2,014	1,886	56.87	**53.25**
CALVES	9.31	431	452	46.35	**48.59**
STEERS	18.62	835	800	44.86	**42.97**
BEEF COWS	23.36	1,156	949	49.50	**40.63**
MILK COWS	56.21	1,482	1,446	26.36	**25.72**
HENS AND CHICKENS	0.10	3	3	28.30	**25.72**
OTHER POULTRY	0.18	10	8	55.23	**47.07**
SHEEP	1.28	136	101	106.61	**79.24**
HORSES	24.82	1,114	930	44.89	**37.47**
PIGS	2.19	300	268	136.78	**122.29**

Table 9.36 *Value of Water Used in Livestock (SSRB 1996)*
Source: Water use coefficients are from Kassem 2004

9.5.3 Total Value of Water in Livestock Watering

We can now use the values above to impute the total amount and value of water used in livestock for each sub-basins in the SSRB (see Table 9.37). The sub-basin with the most livestock is the Red Deer River followed by the Old Man River. The smallest is the Alberta portion of the South Saskatchewan River.

Using the values per head from above, we can also find the value of livestock in the SSRB. This amounted to over $2.6 billion with, again, just over one third in the Red Deer basin. Again, cattle operations account for about 81% of the total value. Pigs, on the other hand, make up 11% of the livestock value but consume only 4.3% of the water.

This data also allows us to compute the weighted average value of water in each basin. For the SSRB as a whole, the average value of water is $46.33 per cubic meter. Water is more valuable in Saskatchewan primarily due to the higher average value of livestock rather than a different herd composition. The values differ across basins since there are differences between provinces and also because of differences in livestock type used in each basin. However, these differences turn out to be less than 10%.

	HERD SIZE (000's)					**TOTALS for HERD TYPE**		
	RD	**BR**	**OR**	**SSR AB**	**SSR SK**	**WATER USE (1000m^3)**	**HERD VALUE ($M)**	**WATER VALUE ($/m^3)**
BULLS	24	9	16	7	11	**2.39**	**129**	**53.86**
CALVES	370	141	270	102	170	**9.80**	**473**	**48.23**
STEERS	157	64	260	81	43	**11.27**	**486**	**43.10**
BEEF COWS	401	141	263	109	193	**25.84**	**1,090**	**42.17**
MILK COWS	23	6	17	5	9	**3.32**	**86**	**25.81**
HENS AND CHICKENS	1,268	953	1,719	447	747	**0.51**	**13**	**26.09**
OTHER POULTRY	36	19	59	30	20	**0.03**	**1**	**48.05**
SHEEP	41	21	61	13	17	**0.20**	**16**	**82.34**
HORSES	29	13	25	4	9	**1.95**	**74**	**38.28**
PIGS	422	85	318	110	197	**2.48**	**309**	**124.81**
WATER USE (1000m^3)	**19.69**	**7.08**	**16.58**	**5.92**	**8.52**	**57.79**		
HERD VALUE ($M)	**899**	**314**	**753**	**270**	**441**		**2,677**	
WATER VALUE ($/m^3)	**45.69**	**44.35**	**45.42**	**45.62**	**51.74**			**46.32**

Table 9.37 *Herd Size, Value, and Water Use by Sub-Basin, 1996*

9.5.4 Discussion

In interpreting the values above we need to consider the following:

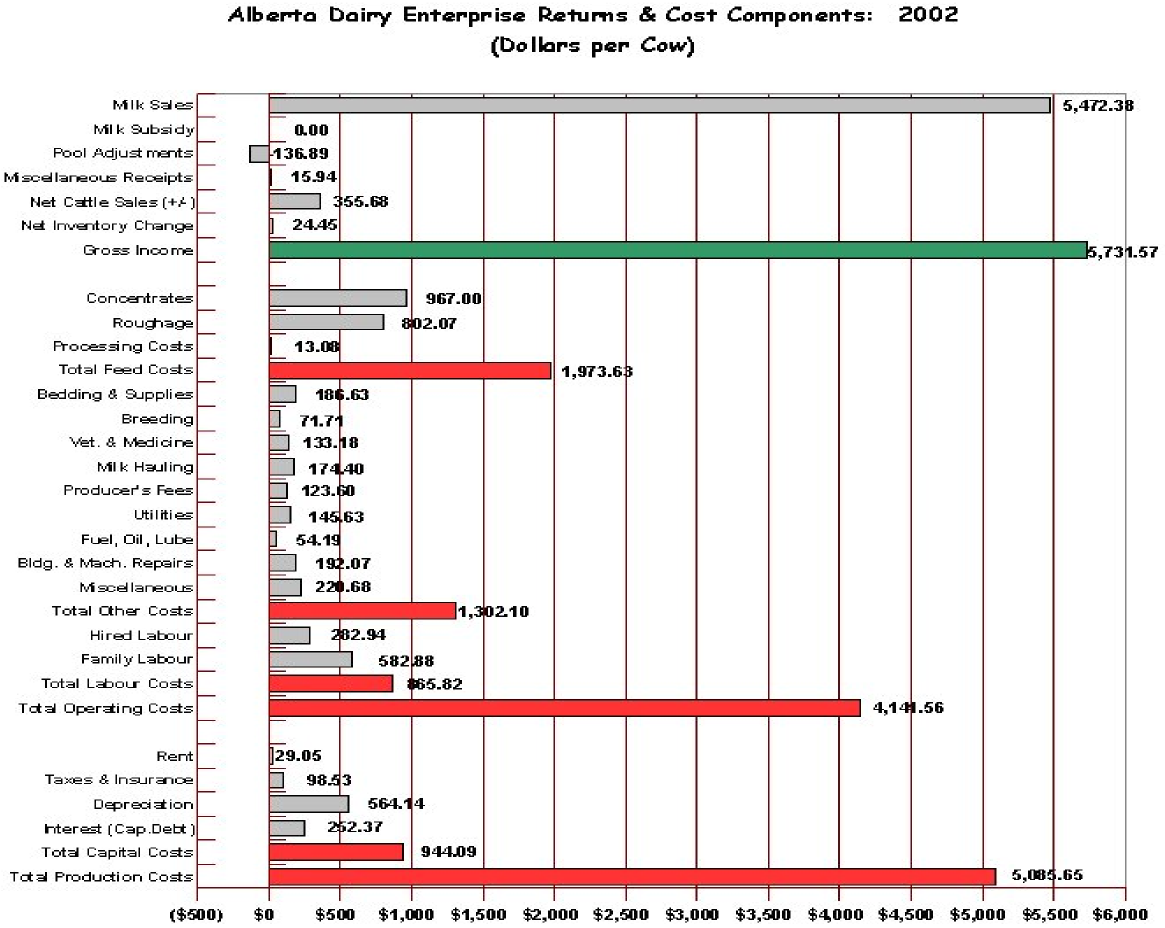
- The values presented in Table 9.37 show the value-added per unit of water used in livestock under the assumption that livestock owners, faced with a water shortage, will be forced to reduce their herds. We can interpret these values as the maximum that the owners would be willing to pay to obtain water. Compared to municipal consumers, the imputed WTP by livestock owners is anywhere from 20 to 100 times more than the average household pays for a cubic meter of water. Also, in most cases, livestock water is untreated and delivery costs are small.

- The high WTP also suggests owners will want to invest in alternative water sources (such as groundwater, rain water retention ponds, or storage ponds) in the event of reductions in surface water. Hence, the impact of a reduction in surface water will likely be made up by purchasing water from other users or investing in water replacement activities rather than in herd reductions. Alternatively, livestock producers may find it advantageous to move herds to where the water is rather than bring the water to the animals. This is possible for Cattle but not Chickens, Pigs, or Dairy Cows since production is reliant on built facilities. This suggests that, if given sufficient warning, livestock producers can accommodate water shortages in the future. Hence, the costs reported here over-estimate the long-run WTP for raw water from the watershed.

- The more likely problem will be the effect water shortages will have on owners' ability to feed their herds. For example, feed costs for dairy herds make up about 50% of the operating expenses for 2002 (see section 9.5.4 Appendix below). A doubling of feed costs will result in operating losses. One of the possible scenarios from climate change is for more frequent and severe droughts. In the past, this has resulted in feed shortages as well as big increases in feed prices. Hence, the greatest impact will likely be through these feed costs rather than an inability to directly water stocks. In this case, the value of water to livestock operators is the direct benefit derived from watering and the indirect benefits of water embodied in feed crops. This indirect value is probably the larger component. More research is required to identify these indirect benefits.

9.5.5 Appendix

The following Table is for Dairy Cows in Alberta and is taken from:
http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/econ5191?opendocument



Alberta Dairy Enterprise Returns & Cost Components: 2002
(Dollars per Cow)

Purpose: to indicate the relative importance of each income & expense item as they accumulate to their respective totals.
Applications: this layout is valuable as a "benchmark" to farm businesses. It is useful to individual operators as a "diagnostic tool" to compare their performance to provincial averages.

9.6 Industrial Water Use

9.6.1 Water Withdrawals by Industry

Table 9.38 shows water use in manufacturing in each region of Canada taken from Table 16 of Environment Canada's *Industrial Water Use, 1996*. Saskatchewan industries take in about 47 MCM of water and consume 3.9 MCM (or 8.3% of intake). Alberta is a much larger user taking in 282 MCM and consuming 76.9 MCM (or 27% of intake). Together, the three Prairie Provinces take in 367 MCM per year for manufacturing and consume 87.8 MCM. Together, water intake for manufacturing on the prairies is about of the same order of magnitude as for residential consumption. Residential consumption from the MUD for the Prairie Provinces is 322 MCM and inflating to account for communities not covered in MUD brings that amount to 486 MCM. Hence water intake in manufacturing is about 75% of that used by households. Final consumption by households is higher by 112% due to the lower discharge rates (84% versus 91%). Note also the relatively high degree of water recycling in each industry with an average recycling rate of 115%.

	INTAKE	**RECYCLE**	**GROSS**	**DISCHARGE**	**CONSUMED**
NEWFOUNDLAND & LAB.	106.6	75.1	181.7	90.2	16.4
PRINCE EDWARD ISLAND	10.4	1.7	12.1	9.8	0.7
NOVA SCOTIA	194.9	66	260.8	183.1	11.8
NEW BRUNSWICK	167.9	161.1	329	153.6	14.4
QUEBEC	1,172.5	1,066.3	2,238.8	1,046.3	126.2
ONTARIO	3,010.6	3,077.7	6,088.3	2,812.1	198.5
MANITOBA	38.3	10.3	48.6	31.4	7
SASKATCHEWAN	47.1	129.9	177.1	43.3	3.9
ALBERTA	282.1	896.6	1,178.7	205.1	76.9
BRITISH COLUMBIA	1,007.5	1473	2,480.5	911.6	95.8
TERRITORIES**	0.4	0	0.4	0.3	0
TOTAL	**6038.3**	**6,957.7**	**12,996**	**5,486.8**	**551.6**
RATES*		**115%**		**91%**	**9.1%**

Notes: * Recycled water as% of water intake, similarly for discharge and consumption
** Territories are combined due to privacy concerns

Table 9.38 *Manufacturing Water Use (MCM/year) by Province or Region, 1996*
Source: *Industrial Water Use 1996*, 2002, Table 16

Table 9.39 shows the water use characteristics by industry classification for Canada in 1996. The largest water users were food manufactures, paper and allied products, primary metals, and chemicals and chemical products. Most of the water was used either in processing (49%) or in cooling, condensing, and steam (47%); the remainder was used for sanitation and other purposes. The share allocated to the different uses depends on the industry. For instance, in paper and allied products 76% is allocated to processing whereas in chemicals and chemical products only 20% is for processing while 78% is for cooling and condensing. Table 9.39 also shows the recycling rates and discharges as well for each sector.

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	WATER SOURCE		**Gross Water use**	**Discharged Water**	**Consumed Water**	**WATER USE**			
	Intake Water	**Recycled Water**				**Processing**	**Cooling, Condensing, and Steam**	**Sanitary Services**	**Other**
	MCM	MCM	MCM	MCM	MCM	**MCM**	**MCM**	**MCM**	**MCM**
Food	269.5	145.3	414.9	240.0	29.5	128.6	107.3	27.8	5.9
Beverages	73.1	18.3	91.4	56.2	16.9	38.4	29.0	4.6	1.1
Rubber Products	12.3	12.9	25.2	11.3	1.0	3.6	7.7	0.9	0.1
Plastic Products	13.3	38.7	52.0	12.0	1.3	5.9	5.9	1.3	0.2
Primary Textiles	86.7	68.2	154.9	84.6	2.1	15.5	64.6	6.5	0.0
Textile Products	15.0	7.9	23.0	12.9	2.1	12.8	1.8	0.4	0.1
Wood Products	45.1	10.2	55.3	33.0	12.1	9.7	24.4	2.2	8.8
Paper and Allied Products	2,421.3	3,105.9	5,527.3	2,207.0	214.3	1,847.5	508.3	49.1	16.4
Primary Metals	1,423.0	1,447.9	2870.9	1,303.0	120.0	557.6	830.1	21.5	13.8
Fabricated Metals	19.4	8.1	27.5	18.4	1.1	11.3	6.4	1.6	0.1
Transportation Equipment	65.4	107.3	172.7	46.4	19.0	28.5	25.0	11.1	0.4
Non-Metallic Mineral Products	102.3	91.8	194.1	83.1	19.2	21.6	44.9	3.5	32.1
Petroleum and Coal Products	370.5	541.4	911.9	348.0	22.5	34.4	324.6	4.9	6.6
Chemicals and Chemical Products	1,121.3	1,353.7	2,475.0	1,030.6	90.7	220.9	879.8	10.9	9.7
Total	**6,038.2**	**6,957.6**	**12,996.1**	**5,486.5**	**551.8**	**2,936.3**	**2,859.8**	**146.3**	**95.3**
Rates		115%		90.9%	9.1%	49%	47%	2.4%	1.6%

Table 9.39 *Manufacturing Water Use (MCM/year), by Industry Group, Canada, 1996*
Source: *Industrial Water Use 1996*, 2002, Table 3 and Table 6.

9.6.2 Value of Water

We use two approaches to valuing a reduction in water availability. The first method estimates the value of reduced economic activity that could occur due to a scarcity of water. The second approach uses actual reported cost data to impute what firms would be willing to pay to avoid a reduction in water supply.

9.6.2.1 Method 1: Contribution of Water to Production and Value-Added

Each of the sectors uses water as a necessary input into their production process. In general, water use can be reduced through conservation methods but, ultimately, cannot be entirely replaced. This fact provides a basis for valuing the contribution of water in industrial production. *Water value coefficients* tell us the contribution to economic activity ultimately derived from the water used in production. Reductions in available water, if no alternative techniques can be found, will result in a reduction in economic activity, at least in that sector. *Water use coefficients* tell us how much water is required to produce a given amount of activity. This is the inverse of the water value coefficient. Water use coefficients are used in the input-output analysis to gauge the effect of an increase in economic activity on water demands or to estimate the reduction in activity of a reduction in water.

Industries use water to differing degrees of intensity and contribute to economic well-being to different degrees as well. This implies a difference in the value of water across industries. We can identify industry specific water value coefficients by calculating either gross production or value-added (GDP) in each sector per unit of water used in that sector. *Gross production* is the total market value of output generated within a sector. Output may be sold to households, to other firms, or exported. Inputs are derived from other sectors or directly produced within the sector. *Value-added* (or sectoral GDP) is the difference between the market value of output and the market value of purchased inputs from other industries. Value-added reflects the contribution to national output generated solely by that sector. Gross production always exceeds value-added since purchased input costs are not accounted for in the value-added approach. Typically gross output is two to three times value-added. The larger the water value coefficient the greater the contribution to economic activity a given quantity of water contributes to.

We want to interpret water value coefficients in a meaningful manner. The problem is which value to use. For our purposes we take the value-added approach. This gives us the lost net revenues suffered by a sector if water access is reduced. The underlying assumption is that factors of production used in that sector (such as labour and capital) will lie idle if water access is curtailed. The value-added that could have been generated by these idle inputs is permanently lost. Since firms and workers would want to avoid this loss, the value-added approach gives us a measure of the shadow-price of water: what they are willing to pay to avoid the loss. This is essentially the same approach as we used for irrigation and livestock. Note that the input–output approach uses gross production since linkages between sectors is a key focus of analysis.

An implicit assumption in this valuation process is that inputs used in the affected sector cannot flow to other sectors. If they could, then a water shortage (say in the pulp and paper sector) would induce factors of production (workers, machines, etc) to flow into other sectors (such as mineral processing). The net effect on value-added would be negligible since the value-added has shifted to some other sector. In the long run the value-added approach will over-estimate the shadow price of water since idle factors will migrate to other sectors. A further assumption is that non-affected sectors that require inputs, or indeed consumers, will need to look elsewhere for their purchases. As long as substitutes are readily available, these customers are unaffected by a reduction in any one sector. In a long-run timeframe, this is probably a reasonable assumption. However, in a short time frame, factors are unlikely to flow between sectors and so a shortage of water will induce a fall in economic activity in that sector.

	Intake Water[1](1000m^3)	Real Value-Added[2] ($M)	VA per m^3 of Intake Water
RESOURCE INDUSTRIES	**5,009,502**	**55,336**	**11.05**
Agricultural and related services industries	4,098,191	14,446	3.52
Fishing and trapping industries	0	1,102	-
Logging and forestry industries	6,295	6,281	998
Mining industries	905,016	33,507	37.0
MANUFACTURING INDUSTRIES	**6,397,024**	**134,996**	**21.10**
Food industries	302,966	13,122	43.3
Beverage industries	77,766	3,216	41.4
Tobacco products industries	1,679	1,405	837
Rubber products industries	13,417	2,055	153
Plastic products industries	15,152	3,562	235
Leather and allied products industries	1,973	358	181
Primary textile industries	88,881	1,399	15.7
Textile products industries	24,039	1,201	50.0
Clothing industries	7,816	2,918	373
Wood industries	62,172	8,412	135
Furniture and fixtures industries	5,768	2,432	422
Paper and allied products industries	2,504,799	12,075	4.8
Printing, publishing and allied industries	12,292	8,158	664
Primary metal industries	1,428,234	8,301	5.8
Fabricated metal products industries	54,528	9,531	175
Machinery industries (except electrical machinery)	26,849	6,691	249
Transportation equipment industries	76,108	21,839	287
Electrical and electronic products industries	24,122	8,377	347
Non-metallic mineral products industries	108,621	3,327	30.6
Refined petroleum and coal products industries	371,160	949	2.6
Chemical industries	1,181,790	11,528	9.8
Other manufacturing industries	6,891	4,140	601
SERVICES	**30,096,141**	**485,465**	**14.51**
Construction industries	37,580	36,523	972
Transportation industries	20,642	27,031	1310
Pipeline transport industries	403	3,626	8989
Storage and warehousing industries	5,857	966	165
Communication industries	11,591	22,368	1930
Other utility industries	28,665,761	26,104	0.9
Wholesale trade industries	41,366	38,849	939
Retail trade industries	163,164	38,442	236
Finance, insurance and real estate industries	30,943	57,942	1873
Insurance industries	4,139	10,728	2592
Business service industries	42,444	37,087	874
Government and social organizations	1,072,251	185,799	173
RESIDENTIAL WATER USE	**3,370,838**		
TOTAL	**44,873,504**	**675,797**	**15.10**

Notes: [1] Source: *Statistics Canada: Environmental Accounts and Statistics Division;* [2] Source: *Statistics Canada: Table 379-0001 - Gross Domestic Product (GDP) at factor cost, system of national accounts benchmark values, by industry, annual (Dollars).*

Table 9.40 *Intake Water, Real Value-Added, and Water Values, 1996, Canada*

We can also measure water access by withdrawals or by consumption. Each provides a different interpretation for the value of water. Value per unit of water intake provides a measure of the impact a reduction in water a sector is permitted to extract from the water source. This provides an opportunity cost measure to that sector of a water restriction. This is analogous to the value determined for residential consumption. Value per unit of water consumed, on the other hand, provides a social opportunity cost estimate and can be used to compare water use across sectors. For instance, suppose 1,000m^3 is fully consumed by an industry (it does not return to the watershed). The activity that is supported by this water can be compared to the contribution to welfare if this water were used for other purposes (such as hydro-electric generation). This would allow us to more efficiently allocate scarce water resources to maximize the benefits. As we are most interested, at this point, in identifying costs to individual users, we consider only value-added per unit of withdrawn (intake) water.

Statistics Canada identifies sectoral value-added (sectoral GDP) and water use using the L-level of aggregation for Canada as a whole. They identify 167 separate industries. From this data we can calculate value-added per cubic meter withdrawn. Table 9.40 shows these values for industrial sub-aggregates. See the Appendix Section 9.6.5 for data on real value-added and intake water use in 1981, 1986, and 1991. Table 9.40 differs from 9.39 in that all productive sectors, including electrical utilities, services and agriculture, are accounted for.

Table 9.40 shows a great deal of variation between sectors. For 1996, the agricultural sector generated about \$3.52 of value-added per cubic meter of intake water. (Note that this is an average of irrigated and non-irrigated sectors). The resource sector overall (Agriculture, Fishing and Trapping, Logging, and Mining) generates \$11.05, while Manufactures \$21.10 and Services \$14.51 in value-added. For the economy as a whole, value-added per cubic meter is \$15.10.

9.6.2.2 Method 2: Cost Savings in Water Use

Environment Canada reports expenditures on water by cost components for the manufacturing sectors. These are reported in Table 9.41. Although water is important to the production process, actual expenditures on water (as a fraction of industry value-added) are very small. Water acquisition costs for water in manufacturing sectors (amounts paid to utilities, plant operation and maintenance, and provincial license fees) in 1996 amounted to only \$337M in Canada, whereas value-added is estimated at over \$135B (see Table 9.40). Intake treatment was \$140M. Together, the cost of fully treated water, ready for use in processing, was \$477M. These account for about 47% of the costs associated with water intake, treatment, and use.

Water acquisition and intake treatment costs as a share of value-added is about 0.56% and ranges from a low of 0.14% (Transportation Equipment) to a high of 1.70% (Textile Products). The low cost of water partially reflects high labour but also a low marginal productivity of water. For instance, the average employee produces \$108,000 of value-added per year while 1,000m^3 of water taken in produces only \$15,100.

	Acquisition	**Intake Treatment**	**Recirculation**	**Discharge treatment**	**Total**	**Costs as share of production**	**Costs as share of value-added**	**Acquisition, intake treatment & recirculation**
	$M	$M	$M	$M	$M	%	%	$M
Food	68.1	8.4	5.2	27.8	109.5	0.18	0.58	81.7
Beverages	24.1	4.9	1.3	2.8	33.1	0.59	1.09	30.3
Rubber Products	3.8	0.7	0.8	0.3	5.6	0.08	0.23	5.3
Plastic Products	7.9	1.3	3.4	0.2	12.8	0.13	0.30	12.6
Primary Textiles	4.7	1.4	0.7	1.4	8.2	0.34	0.77	6.8
Textile Products	4.5	0.7	22.4	0.8	28.4	0.78	1.70	27.6
Wood Products	12.1	1.4	0.3	6.2	20	0.11	0.30	13.8
Paper +Allied Products	52	45.8	46.4	227.8	372	0.54	1.24	144.2
Primary Metals	70.4	29.2	36	56.7	192.3	0.45	1.20	135.6
Fabricated Metals	7.5	0.8	0.7	8.1	17.1	0.14	0.30	9
Transportation Equipment	29.4	6	4.2	15.4	55	0.03	0.14	39.6
Non-Metallic Mineral Products	12.1	1.3	1.6	0.6	15.6	0.20	0.40	15
Petroleum+Coal Products	4.7	14.1	9.1	23.1	51	0.14	1.69	27.9
Chemicals+Chemical Products	36.4	23.7	13	30.6	103.7	0.25	0.57	73.1
Total	**337.7**	**139.7**	**145.1**	**401.8**	**1024.3**	**0.17**	**0.56**	**622.5**
								61%

Table 9.41 *Total Water Costs in Manufacturing ($M), Canada, 1996*
Source: *Industry Water Use, 1996*, 2002, Table 11.

The basis of valuing water withdrawn from a basin and used as an input to a production process is that this raw water replaces alternatives (recycling, investments in new capital) and reduces costs for the firm. The firm's WTP for a unit of water is the cost savings that unit of water affords the firm. If water markets are formally established, then the market price paid for water tells us the firm's marginal WTP. Such a market for water does not exist for industrial production so we must use a different method to identify the willingness to pay. To do so, we first note that firms simultaneously take in new water but also recycle their own water. If we assume firms can freely choose between taking in new water and recycling water, then it must be the case that, at the margin, the net benefit of new water would be equal to the net benefit of recycled water.

The lack of detailed information forces us to assume that marginal costs are constant. This implies that the average cost per unit of new water (associated with intake fees, treatment costs, and operating and maintenance of intake equipment) is equal to the average costs of a unit of recycled water (associated with treatment costs and operating and maintenance costs of recycling plant and equipment). To estimate

	Water Use				Average WTP (Shadow Price)		
	Intake	**Gross**	**Consumption**	**Total expenditures on water for processing**	**Process Water**	**Raw Intake Water**	**Consumed water**
	MCM	MCM	MCM	$M	$\$/1000\text{m}^3$	$\$/1000\text{m}^3$	$\$/1000\text{m}^3$
Food	269.5	414.9	29.5	81.7	303	**272**	2,485
Beverages	73.1	91.4	16.9	30.3	415	**347**	1,503
Rubber Products	12.3	25.2	1.0	5.3	431	**374**	4,600
Plastic Products	13.3	52.0	1.3	12.6	947	**850**	8,692
Primary Textiles	86.7	154.9	2.1	6.8	78	**62**	2,571
Textile Products	15.0	23.0	2.1	27.6	1,840	**1,793**	12,810
Wood Products	45.1	55.3	12.1	13.8	306	**275**	1,025
Paper +Allied Products	2,421.3	5,527.3	214.3	144.2	60	**41**	459
Primary Metals	1,423.0	2,870.9	120.0	135.6	95	**75**	887
Fabricated Metals	19.4	27.5	1.1	9	464	**423**	7,455
Transportation Equipment	65.4	172.7	19.0	39.6	606	**514**	1,768
NonMetallic Mineral Products	102.3	194.1	19.2	15	147	**134**	714
Petroleum + Coal Products	370.5	911.9	22.5	27.9	75	**37**	613
Chemicals + Chemical Products	1,121.3	2,475.0	90.7	73.1	65	**44**	545
Total	**6,038.2**	**12,996.1**	**551.8**	**622.5**	**103**	**80**	**875**

Table 9.42 *Water Acquisition and Intake Treatment Costs per 1000m^3, Canada, 1996*
Source: *Industry Water Use, 1996*, 2002, Tables 6 and 13 and own calculations.

this average value we calculate the average cost as total water costs (acquisition, intake treatment, and recycling) divided by gross water use. These values are reported in Table 9.42.

We can now impute the value of water for each industry for Table 9.43. Consider the Food Manufactures. The total cost of intake water for processing is $81.7M ($68.1 million for acquisition, $8.4 for intake treatment, and $5.2 for recirculation). The average cost is $303 per 1,000m^3. If there is a reduction in the quantity that firms can take in, then they can simply meet their water demands by increased recirculation of water. They need not reduce production at all. They can do this as long as the restriction is not too severe or too prolonged. The average imputed cost of recycled water is $303 per 1,000m^3. Hence the firm would be willing to pay $303 for 1,000m^3 of fully treated water ready to be used in processing. We can do this for each sector. On average, firms are willing to pay $103 per 1,000m^3 of treated (recirculated) water. This compares to households average willingness to pay $1,390 for 1,000m^3 (assuming a 10% reduction in water and an elasticity of -0.3).

Of course, what the firm would be willing to pay for untreated, raw water directly from the watershed is somewhat less than this. We calculate this by subtracting the intake treatment costs per unit of intake water to find the net willingness to pay for intake water. For instance, from Table 9.39 we saw that Food Manufactures pay $8.4M to treat 269.3 MCM of intake water. The average intake treatment cost is $31 per 1,000m^3. Hence, the Food Manufactures would be willing to pay an average of $272 per 1,000m^3 for untreated water ($303 – $31). Anything more than this and they will resort to recirculation of existing water which costs $303. This $272 is a measure of the benefit to the firm of raw water since it saves them a net additional cost of $272 of resorting to recirculation. On average, industry is willing to pay $80 per 1,000m^3 for raw intake water.

To find the willingness to pay for consumed water, we simply take the total value of raw intake water and divide by actual water consumed. For instance, only 10.9% of total intake water is consumed by the Food Manufactures. Hence the value per unit consumed is about 9 times that per unit taken in. On average, only 9.1% of water is consumed so the average willingness to pay for consumption is about 11 times larger than the willingness to pay for raw intake water.

9.6.3 Total Value of Water in Industry

9.6.3.1 Value-Added in the SSRB

The data in Table 9.40 are for Canada as a whole. The value of water in the SSRB must reflect the differences in the type and scale of production. To identify SSRB value-added we need to first identify the size of each sector in the SSRB. Due to confidentiality constraints this information cannot be released directly by Statistics Canada. Statistics Canada, however, does report value-added by sector for each province (though some information is still censured). Our approach is to approximate the scale of production in the SSRB using labour force surveys from the Census of Canada that allows us to identify workers, their industry classification, and their location. We then scale the value-added in each province by the share of labour located in the SSRB for each sector. This is the same approach used in the input-output analysis. This provides the value-added in production located in the SSRB. We then take the water use coefficients implied in Table 9.42 to estimate the water used by each sector in the SSRB. From this we can estimate the weighted average value of water using sectoral GDP as weights. The results are reported in Table 9.43.

From Table 9.43 we see that the total GDP of Alberta is just over $92B in 1996. The SSRB holds about 52% of the total Alberta labour force so the total GDP of the Alberta portion of the SSRB is about $49B (aggregated from sectoral distribution). Saskatchewan has a smaller GDP of $25B and a smaller share of its workforce resides in the SSRB. The Saskatchewan portion of the SSRB has a GDP of $11B. In total, the SSRB has a GDP of around $60B. Using the water use coefficients from Table 9.40 and applying them to each sector generates a series of intake quantities. Summing this shows that SSRB industries take in 2,240 MCM in 1996. A full third of this was for power generation (hydro and thermal). Another third was for agricultural production (primarily irrigation). The remaining third was distributed across the remaining manufacturing and services industries. In total, water intake in the SSRB supports approximately $60B in GDP.

We can now calculate the value of water per sector and per aggregate. The value-added per unit of intake water is taken to be the same for each individual sector as it was for Canada as a whole. However, when we account for the difference in the sectoral composition of production in SSRB, relative to Canada as a whole, the average value of water used for production in the SSRB is $27.03 per cubic meter. This is much higher than that for Canada in general. For Manufacturing, the average SSRB value of 21.40 is very close to the national average of 21.10. For services, however, the SSRB average is much higher than the national average (46.14 versus 16.13). This partially reflects the reliance of water in power generation that is more prominent in Canada as a whole but is a relatively small sector in the SSRB. For the resource sector, the value of water in the SSRB is above the national average ($13.61 versus $11.05). This may reflect a relatively large mining sector in the SSRB.

	Value-Added ($M)					**Intake (1000m^3)**	**Value ($/$m^3$)**
	AB	**SSRB share**	**SK**	**SSRB share**	**SSRB TOTAL**	**SSRB TOTAL**	**SSRB TOTAL**
RESOURCE SECTORS	**24,293**		**6,839**		**14,560**	**1,070,155**	**13.61**
Agricultural and related services	3,372	0.50	3,426	0.28	2,643	749,818	3.52
Fishing and trapping industries	224	0.15	87	0.24	55	0	
Logging and forestry industries	3	0.47	4	0.11	2	2	998
Mining industries	20,694	0.52	3,322	0.32	11,860	320,335	37.0
MANUFACTURING INDUSTRIES	**9221**		**1,250**		**5,444**	**254,151**	**21.43**
Food industries	1,211	0.71	235	0.61	**1,001**	**23,101**	43.3
Beverage industries	71	0.56	0	0.42	**40**	**957**	41.4
Tobacco products industries	0	0.00	0	0.00	**0**	**0**	
Rubber products industries[1]	193	0.39	17	0.44	**82**	**416**	197
Plastic products industries[1]							
Leather and allied products industries	9	0.39	2	0.71	**5**	**26**	181
Primary textile industries	0	0.64	0	0.50	**0**	**0**	
Textile products industries	22	0.58	0	0.81	**13**	**258**	50.0
Clothing industries	79	0.39	15	0.78	**43**	**115**	373
Wood industries	830	0.36	116	0.27	**330**	**2,439**	135
Furniture and fixtures industries	236	0.78	14	0.71	**194**	**460**	422
Paper and allied products industries	555	0.23	13	0.75	**137**	**28,317**	4.82
Printing, publishing & allied industries	239	0.53	61	0.70	**169**	**254**	664
Primary metal industries	0	0.52	0	0.07	**0**	**0**	
Fabricated metal products industries	1,153	0.43	239	0.49	**617**	**3,531**	175
Machinery industries (except electrical)	731	0.53	224	0.58	**515**	**2,066**	249
Transportation equipment industries	247	0.51	38	0.61	**150**	**521**	287
Electrical and electronic products	474	0.76	79	0.71	**416**	**1,199**	347
Non-metallic mineral products industries	221	0.57	7	0.47	**130**	**4,245**	30.6
Refined petroleum and coal products	244	0.40	0	0.25	**98**	**38,164**	2.56
Chemical industries	2,598	0.52	175	0.57	**1,443**	**147,976**	9.75
Other manufacturing industries	107	0.52	14	0.56	**64**	**107**	601
SERVICES	**58,772**		**17,184**		**38,116**	**826,079**	**46.14**
Construction industries	5,494	0.51	1,401	0.44	**3,412**	**3,511**	972
Transportation industries	4,683	0.53	1,467	0.46	**3,167**	**2,694**	1175
Pipeline transport industries[2]							
Storage and warehousing industries[2]							
Communication industries[2]							
Other utility industries[2]	2,210	0.49	780	0.28	**1,307**	**773,020**	1.69
Wholesale trade industries	4,592	0.52	1,394	0.47	**3,030**	**3,227**	939
Retail trade industries	4,143	0.52	1,257	0.45	**2,715**	**11,522**	236
Finance, insurance and real estate	14,856	0.56	4,230	0.39	**9,956**	**5,086**	1957
Insurance industries[3]							
Business service industries	18,335	0.54	5,282	0.47	**12,283**	**14,058**	874
Government and social organizations	4,459	0.38	1,372	0.40	**2,246**	**12,961**	173
STATISTICAL DISCREPANCY[4]	3228	0.52	1909	0.40	**2,444**	**90,412**	27
TOTAL	**92,285**	**0.52**	**25,273**	**0.43**	**60,564**	**2,240,796**	**27.03**

Notes: [1]Rubber and Plastic Products combined; [2]Other Utilities include pipeline, storage and warehousing communications, and utilities; [3]Finance includes insurance; [4]Statistical discrepancy is the difference between total provincial GDP and the sum of the sub-aggregates. This difference is due to sector-level data censuring. The discrepancy is about 4% for Alberta and 7% for Saskatchewan.

Table 9.43 *Value-Added, Water Intake, and Water Values, 1996, SSRB*

9.6.3.2 Shadow Price of Raw Water

Valuing water under the assumption that firms can increase recycling rather than reducing employment yields much lower cost estimates. We use the imputed intake of water for manufacturing (Table 9.43) and use the national average WTP (Table 9.42) to impute the SSRB WTP for raw water, shown in Table 9.44.

	Water Intake	$/m^3 intake	Value $M
MANUFACTURING INDUSTRIES	**254,151**	**80**	**20.32**
Food industries	23,101	272	6.28
Beverage industries	957	347	0.33
Tobacco products industries	0		0.00
Rubber products industries[1]	416	621	0.26
Plastic products industries[1]			0.00
Leather and allied products industries	26	62	0.00
Primary textile industries	0	62	0.00
Textile products industries	258	1793	0.46
Clothing industries	115	1793	0.21
Wood industries	2,439	275	0.67
Furniture and fixtures industries	460	275	0.13
Paper and allied products industries	28,317	41	1.15
Printing, publishing and allied industries	254	41	0.01
Primary metal industries	0	75	0.00
Fabricated metal products industries	3,531	423	1.49
Machinery industries (except electrical machinery)	2,066	423	0.87
Transportation equipment industries	521	514	0.27
Electrical and electronic products industries	1,199	514	0.62
Non-metallic mineral products industries	4,245	134	0.57
Refined petroleum and coal products industries	38,164	80	1.42
Chemical industries	147,976	272	6.52
Other manufacturing industries	107	347	0.01

Notes: [1]Rubber and Plastic Products are combined; [2]Other Utilities includes pipeline, storage and warehousing, communications, and utilities; and, [3]Finance includes insurance

Table 9.44 *Shadow-Price of Intake Water, 1996, SSRB Manufacturing*

To calculate the values in Table 9.44 we impose the shadow prices for raw intake water from Table 9.42 on the intake water imputed for industries in Table 9.43. For instance, the Food Industries in the SSRB use an estimated 23,101 MCM of intake water. The shadow price of water in the Food Industries is $272 per 1,000m^3. The Food Industry would be willing to pay a total of $6.28M to avoid replacing all intake water with recycled water (if such a scale were possible). In total, manufacturing industries in the SSRB save $20.32M by having access to raw water since this is the imputed cost of reverting to recycled water.

9.6.4 Discussion

One way to interpret these different values is to consider the timeframe for adjusting to a water shortage.

1. This $20.3M is significantly less than the total GDP of $5,444M produced by these industries in the SSRB. Hence, access to recycling reduces the shadow price of water by over 99% compared to the value-added approach. Of course, it is highly unlikely that firms could totally replace intake water with recycled water. Further, the extent of recycling would likely raise the average costs of recycling particularly if new capital expenditures are required. Hence, costs in Table 9.44 are likely to be a lower bound.
2. The relevant question is to what extent firms can squeeze their production processes to reduce water requirements without resorting to production shutdowns. There is no available data that can tell us this.

However, one can reasonably expect that firms can increase recycling, or reduce water usage, for a small, unanticipated water shortage. For a small water shock, the values in Table 9.44 represent a reasonably close estimate of actual firm costs. As the degree to which water shortages increase, firms will need to adopt more efficient processes or increase water recycling. If they cannot, then output suffers, and the values in Table 9.43 tell us the impact to individual industries. The net effect on the entire economy will be less since inputs can move to less affected sectors and so recoup some lost value-added.

3. If the water shortage occurs abruptly and firms cannot immediately increase recirculation, the firms will need to reduce production, at least temporarily. As with livestock operators, there is an incentive to find alternatives sources (i.e. trucking water) or stock-piling water in tanks or in ponds. The average value of water of about $27 per cubic meter suggests this incentive is very high. Firms are unlikely to risk production shutdowns due to short-term water shortages, but problems would arise if shortages extended beyond the storage capacity of firms.

4. As noted in Table 9.42, the cost of treating water for recirculation is less than 2% of value-added in each industry, suggesting firms have leeway to increase expenditures on water without significant financial risk.

5. The analysis of water in irrigation shows that firms would allocate scarce water away from those crops that offered low value-added per unit of water. This lowers the shadow price of water. This substitution effect is also possible within manufacturing firms. However, these firms tend to specialize much more than irrigators and so the scope for water redistributions within enterprises is smaller. The scope to decrease costs by reallocations of water across industries is also limited since water markets do not formally exist. Firms cannot buy and sell water at this point so redistributions of water would have to be mandated by government.

6. If water shortages are anticipated, then firms can increase their capacity to recirculate water and so reduce intake water demands. The average cost of raw water, when recycling capacity exists, is quite low at $0.27 per cubic meter. If the capacity is not there, then some additional investments must be taken. Unfortunately, information on infrastructure costs is not always available.

9.6.5 Appendix

	EMPLOYMENT	**PRODUCTION**	**VALUE-ADDED**	**PROD per EMP**	**VALUE-ADDED/ EMP**
INDUSTRY GROUP	**thousands**	**millions of dollars**	**millions of dollars**	**Thousands per employee**	**Thousands per employee**
Food	198.9	56,918	17,602	286	89
Beverages	24.8	8,002	4,322	323	175
Rubber Products	23.9	7,716	2,592	323	109
Plastic Products	61.5	10,067	4,405	164	72
Primary Textiles	57.7	7,059	3,094	122	54
Textile Products	79.3	7,485	3,413	94	43
Wood Products	113.0	24,593	9,194	218	81
Paper +Allied Products	183.6	42,923	18,671	234	102
Primary Metals	91.8	27,849	10,357	303	113
Fabricated Metals	130.6	18,874	8,760	145	67
Transportation Equipment	140.3	88,104	17,842	628	127
NonMetallic Mineral Products	48.0	9,580	4,814	200	100
Petroleum + Coal Products	11.2	20,583	1,683	1841	150
Chemicals + Chemical Products	90.7	37,162	16,551	410	183
Total	**1,255**	**366,915**	**123,300**	**292**	**98**

Table 9.45 *Employment, Production, and Value-Added by Industry, Canada, 1996*
Source: OECD

	Intake thousand cubic meters				Real Value-added 1996 millions			
	1981	1986	1991	1996	1981	1986	1991	1996
RESOURCES	**4,000,798**	**4,283,376**	**4,663,094**	**5,009,502**	**54,257**	**51,713**	**46,691**	**55,336**
Agricultural and related services industries	3,125,000	3,559,000	3,991,000	4,098,191	14,922	16,136	13,691	14,446
Fishing and trapping industries	0	0	0	0	835	1,245	1,210	1,102
Logging and forestry industries	4,762	4,156	4,200	6,295	3,803	4,189	4,402	6,281
Mining industries	871,036	720,220	667,894	905,016	34,697	30,143	27,388	33,507
MANUFACTURING INDUSTRIES	**10,152,570**	**8,381,540**	**7,447,553**	**6,397,024**	**86,507**	**115,758**	**117,307**	**134,996**
Food industries	301,342	345,058	370,689	302,966	8,875	12,358	14,843	13,122
Beverage industries	104,923	63,694	68,281	77,766	2,444	3,138	3,695	3,216
Tobacco products industries	3,314	2,649	1,823	1,679	680	873	1,155	1,405
Rubber products industries	33,739	24,059	22,426	13,417	1,136	1,369	1,379	2,055
Plastic products industries	25,088	34,935	57,274	15,152	1,358	2,197	2,756	3,562
Leather and allied products industries	4,812	4,174	2,304	1,973	781	756	467	358
Primary textile industries	116,117	95,401	118,081	88,881	1,353	1,607	1,306	1,399
Textile products industries	16,740	25,261	16,028	24,039	1,132	1,400	1,333	1,201
Clothing industries	11,346	11,365	9,346	7,816	2,989	3,480	3,232	2,918
Wood industries	169,750	90,056	73,724	62,172	4,289	6,186	4,939	8,412
Furniture and fixtures industries	6,054	6,495	5,930	5,768	1,670	2,273	1,993	2,432
Paper and allied products industries	3,169,575	3,082,123	2,942,580	2,504,799	8,229	9,831	7,737	12,075
Printing, publishing and allied industries	10,749	12,321	13,353	12,292	4,946	7,453	8,798	8,158
Primary metal industries	2,074,096	2,057,443	1,609,663	1,428,234	6,939	8,036	6,630	8,301
Fabricated metal products industries	69,365	59,557	58,964	54,528	7,264	8,240	8,297	9,531
Machinery industries (except electrical machinery)	27,711	23,461	23,123	26,849	4,809	4,800	4,661	6,691
Transportation equipment industries	126,678	127,117	111,897	76,108	8,422	14,979	15,508	21,839
Electrical and electronic products industries	32,312	29,642	28,206	24,122	6,924	8,608	8,703	8,377
Non-metallic mineral products industries	90,851	97,603	134,919	108,621	2,821	3,916	3,222	3,327
Refined petroleum and coal products industries	563,462	487,682	445,864	371,160	747	2,330	2,947	949
Chemical industries	3,187,502	1,694,303	1,325,759	1,181,790	5,966	8,941	10,053	11,528
Other manufacturing industries	7,043	7,141	7,318	6,891	2,734	2,989	3,656	4,140
SERVICES	**19,530,889**	**26,521,589**	**29,645,213**	**30,096,141**	**307,661**	**416,699**	**511,934**	**485,465**
Construction industries	36,896	35,784	40,590	37,580	37,113	38,272	46,352	36,523
Transportation industries	17,320	17,848	19,521	20,642	21,201	26,852	27,278	27,031
Pipeline transport industries	376	352	322	403	1,923	2,924	3,061	3,626
Storage and warehousing industries	5,123	5,678	5,493	5,857	803	989	971	966
Communication industries	9,677	10,218	11,368	11,591	13,929	19,254	22,734	22,368
Other utility industries	18,166,315	24,964,076	28,289,265	28,665,761	13,746	22,158	25,922	26,104
Wholesale trade industries	34,395	34,683	38,812	41,366	21,775	32,212	38,594	38,849
Retail trade industries	134,418	154,586	157,941	163,164	28,574	39,230	43,886	38,442
Finance, insurance and real estate industries	22,573	25,316	29,586	30,943	32,938	46,643	58,035	57,942
Insurance industries	3,723	3,461	3,899	4,139	4,704	7,872	9,798	10,728
Business service industries	22,912	26,961	33,630	42,444	15,855	23,265	34,042	37,087
Government and social organizations	1,077,161	1,242,626	1,014,786	1,072,251	115,100	157,028	201,261	185,799
Residential water use	**3,033,000**	**2,896,111**	**3,262,698**	**3,370,838**				
TOTAL	**36,717,258**	**42,082,618**	**45,018,558**	**44,873,504**	**448,423**	**584,170**	**675,935**	**675,797**

Notes: [1] Sectoral GDP using 1996 dollars (*Table 379-0001 - Gross Domestic Product (GDP) at factor cost, system of national accounts benchmark values, by industry, annual*), [2] Water Intake by Sector: Statistics Canada: Environmental Accounts and Statistics Division

Table 9.46 *Intake and Real Value-Added for Canada*

9.7 Mining Water Use

Mining activities in the SSRB are relatively small. As a result, detailed data focused solely on the SSRB are not available due to confidentiality concerns. The following calculations for the value of water are based on national data obtained from Statistics Canada and Environment Canada. Some of this data is reported on a regional basis. Attempts have been made to use this regional data as much as possible.

9.7.1 Water Intake in Mining

Statistics Canada reports water consumption by mining sector at the L-level industrial classification on a national basis. Table 9.47 reports water intake, sources, recirculation, and consumption for 1996. The biggest water intake sectors are Iron Mines and Other Metal Mines. Crude Petroleum and Natural Gas also has a large water intake. In general, most water comes from fresh surface sources with groundwater contributing less than 8% of total intake water nationally. The largest user of water (intake plus recirculation) is the Crude Petroleum and Natural Gas sector. However, this sector has a high recycling rate so is not the largest intake user. Actual consumption of water in all sectors is relatively small as most water is discharged at some point. Crude Petroleum and Natural Gas is the exception with a consumption rate of approximately 52% compared to the average of 3.5% for the other sectors. As such, it is the largest net consumer of water of all sectors.

	Municipal Water	**Surface-fresh**	**Ground[1]**	**Other**	**Total Intake**	**Recirculation**	**Total Water Used**	**Consumption**
Gold Mines	3,281	34,534	5,052	8,128	50,995	34,224	85,219	0
Other Metal Mines	1,429	254,015	31,005	9,096	295,545	215,788	511,333	0
Iron Mines	869	226,053	145	0	227,067	864,117	1,091,184	0
Asbestos Mines	1,623	2,904	2,318	0	6,845	14	6,858	0
Other Non-Metal Mines	7,325	18,836	10,675	1,577	38,413	38,369	76,782	0
Salt Mines	141	16,919	2,761	7,768	27,590	1,925	29,515	459
Coal Mines	331	5,774	10,343	17,775	34,223	42,493	76,716	8,349
Crude Petroleum and Natural Gas	0	137,478	7,236	0	144,714	1,012,998	1,157,712	74,760
Quarries and Sand Pits	0	74,095	0	0	74,095	0	74,095	14,819
Services related to extraction	0	5,530	0	0	5,530	0	5,530	2,765
TOTAL	**15,000**	**776,139**	**69,534**	**44,344**	**905,016**	**2,209,928**	**3,114,944**	**101,152**

Note: [1] Includes water pumped from mine sites (mine water).

Table 9.47 *Water Intake by Source per* $1000m^3$*, Canada, 1996*
Source: Statistics Canada, Environment Accounts and Statistics Division.

9.7.2 Value of Water in Mining

As with valuing water for manufacturing, we use two approaches in valuing water in mining industries. The first is to identify the contribution to value-added under the assumption that firms react to reductions in water by reducing production levels. This reduces the value of output and constitutes an opportunity cost to firms and society. The second approach is to assume firms can replace reductions in intake water with increased recycling and recirculation of water.

9.7.2.1 Contribution of Water to Production and Value-Added

Using data from Statistics Canada Input-Output Tables we can identify the value-added for each of the sectors identified above for 1996 (see Table 9.48). The total value of production in mining and related services (but not including manufactured products from mining) for all of Canada in 1996 exceeded $53B with total value-added around $44B. The largest sector was Crude Petroleum and Natural Gas with total production in excess of $31B.

Water intake and gross water use is from Statistics Canada, Environment Accounts and Statistics Division. Looking at gross output per total cubic meter of water used yields an average value of $17.30 ranging from a low of $1.34 for Iron Mines and a high of $1138 for Services Related to Mineral Extraction. In terms of value-added, these values drop to an average of $14.12. If we only consider intake water, then values per cubic meter rise. The average is now $59.55 in terms of gross production and $48.58 in terms of value-added. Excluding related services, intake water is most valuable in Oil and Gas Extraction with a production value in excess of $214 per cubic meter.

The value of water in mining is comparable to those in the manufacturing sector. For manufacturing as a whole, production value per cubic meter of total water was $22.2 and for intake water was $47.9. For mining the values are slightly higher for total water and lower for intake water. This is partially due to the slightly larger recycling rate employed by mines. The value of water in terms of value-added is higher in mining than in manufacturing. The values for manufacturing were $6.6 and $14.2 for total and intake water respectively while they are $14.12 and $48.58 for mining. This is primarily due to manufacturing activities having a much lower ratio of value-added to gross production than mining (80% for mining and 30% in manufacturing).

9.7.2.2 Cost of Water Intake, Recycling and Recirculation

The following data comes from Environment Canada's *Industrial Water Use, 1996*. The survey covers all mines but excludes Oil and Gas Extraction activities. The data are highly aggregated but do give a sense of the costs to mining enterprises of acquiring, treating and recirculating water. Table 9.49 reports data on water intake and recirculation as well as costs of water by major mining activity as well as by region. In total, firms responding to the survey paid $18.1M to acquire 518 MCM of water. This is about $34.94 per 1,000m^3 of water as compared to over $1250 per 1,000m^3 for commercial enterprises in municipalities. The cost of recirculating water was $17.1M for an average cost of $14.28 per 1,000m^3 recirculated. Total costs of water include acquisition, intake treatment, and recirculation amounted to $40M in 1996. Total water used, including recirculated water, was 1.715 MCM. This implies an average cost of $23.32 per 1,000m^3. If we use this figure for the marginal cost of recycling, then we have a rough measure of the cost to mining firms of switching from intake water to recycled water. Hence, if firms can increase recycling rates in the face of reductions in access to fresh water, then the average cost of this is quite small.

	Value (in $CAN millions)		Water Use (1000m^3)		Gross Production per m^3		Value-added per m^3	
	Gross Production	Value-added	Total Water	Total Intake	Total Water	Intake Water	Total Water	Intake Water
Gold Mines	2,706	1,850	85,219	50,995	31.75	53.06	21.71	**36.28**
Other Metal Mines	7,151	4,028	511,333	295,545	13.99	24.20	7.88	**13.63**
Iron Mines	1,459	836	1,091,184	227,067	1.34	6.43	0.77	**3.68**
Asbestos Mines	x	x	6,858	6,845				
Non-Metal Mines excluding Coal and Asbestos	2,403	1,787	76,782	38,413	31.30	62.56	23.27	**46.52**
Salt Mines	348	293	29,515	27,590	11.79	12.61	9.93	**10.62**
Coal Mines	1,949	1,318	76,716	34,223	25.41	56.95	17.18	**38.51**
Crude Petroleum and Natural Gas[1]	31,034	27,930	1,157,712	144,714	26.81	214.45	24.13	**193.00**
Quarries and Sand Pits	553	389	74,095	74,095	7.46	7.46	5.25	**5.25**
Services related to mineral extraction[2]	6,293	5,538	5,530	5,530	1138	1138	1001	**1,001**
Sub-total, Mining Industries	**53,896**	**43,969**	**3,114,944**	**905,016**	**17.30**	**59.55**	**14.12**	**48.58**

Notes: Water Use taken from Table 9.47

x. data suppressed for confidentiality reasons.

[1] VA is calculated as 0.90 * production. This is the average of VA to production in oil and gas.

[2] VA is calculated as 0.80* production. This is the average of VA to production in all sectors

Table 9.48 *Value of Water in Production, Canada, 1996*
Source: Value added and gross production taken from; *Statistics Canada, Table 152-0002 – Principal Statistics of the Mineral Industries, Annual.*

	Water USE MCM			Water Costs $M				Recycling Costs ($/1000m^3)	
	Intake	Recycle	Gross	Acquisition Costs[1]	Intake Treatment	Recirculation	Total	Gross Water	Raw Intake
Metal Mines	428	1,114	1,542	10.8	2.8	13.4	27.0	**17.51**	**10.96**
Non-metal Mines	56	40	97	4.2	1.4	3.0	8.6	**88.66**	**63.79**
Coal Mines	34	42	77	3.1	0.6	0.7	4.4	**57.14**	**39.60**
Atlantic	206	759	965	0.5	1.5	0.5	2.5	**2.59**	**-4.71**
Quebec	38	140	178	1.2	0.2	0.9	2.3	**12.93**	**7.69**
Ontario	56	71	126	3.7	1.2	2.9	7.8	**61.90**	**40.28**
Prairies	61	73	134	8.6	1.4	3.6	13.6	**101.80**	**78.92**
British Columbia	143	147	289	3.5	0.5	7.5	11.5	**39.78**	**36.27**
Territories	15	9	24	0.6	0	1.7	2.3	**96.23**	**96.23**
Total	**518**	**1,197**	**1,715**	**18.1**	**4.8**	**17.1**	**40.0**	**23.32**	**14.06**

Note: [1] Acquisition costs include fees paid to provinces, to utilities, and at plant operation and maintenance.

Table 9.49 *Water Use and Recycling Cost, 1996 (excluding Crude Petroleum and Natural Gas)*
Source: *Industrial Water Use, 1996.* 2002.

As with the approach taken with industrial water use, we can impute the value of raw intake water by subtracting the average treatment costs of water. This is also reported in Table 9.49. For Metal Mines, the value of water, once we account for treatment costs, falls to \$10.96 per 1000m^3. Over all, the value of raw water in Canada for mining activities is \$14.06. This compares to an average price in manufacturing applications of \$80 per 1,000m^3.

If we consider a regional breakdown we see that water costs in the Prairies are much higher than the national average. Acquisition costs on the Prairies are \$141 per 1,000m^3. This is still considerably less than that paid by businesses in municipalities. The average cost of water used in total is \$101.80 per 1,000m^3, about four times the national average. For raw water the average value on the Prairies is around \$79 per 1,000m^3. However, these figures exclude Crude Petroleum and Natural Gas and so may not be entirely representative of the mining sector overall. See below.

9.7.3 Total Value of Water in Mining

To estimate the total value of water in the SSRB we use the same approach as we did for manufacturing. However, as the mining sector in Alberta and Saskatchewan is relatively concentrated in a number of firms, Statistics Canada does not report data on some mining activities. Table 9.50 shows these mining activities in Alberta and Saskatchewan reported directly by Statistics Canada or imputed by filling in missing data (particularly for Saskatchewan). Total value-added in Saskatchewan was \$4,001M. Alberta has much more activity totally at \$20,694M.

Census of Canada data on labour show that 32% of Saskatchewan workers in the mining sector reside in the SSRB. For Alberta, it is 52%. If we use these ratios for all sub-sectors we can calculate GDP in the SSRB broken down into mining sectors. This shows that total SSRB mining activity is over \$12B of which over \$10B is in Oil and Gas Extractions. Taking the national value-added coefficients from Table 9.48 and applying them to SSRB value-added implies total water intake of 78 MCM in 1996. Again, most of this is used in Oil and Gas Extractions. This total withdrawal is close to that reported by Kassem.

The average value-added per cubic meter is \$154. This is much higher than the national average of \$48 since oil and gas extractions play a much larger role in the SSRB. Since this sector does not use a lot of water the value-added is correspondingly large.

	VALUE-ADDED (\$M)							**VA/ m^3**	**MCM intake**
	SK Total^2	**%**	**AB Total^2**	**%**	**SSRB SK**	**SSRB AB**	**SSRB Total**		
	Share of labour in SSRB				**0.32**	**0.52**			
Oil and gas extraction	2,552	0.64	18,027	0.87	811	9,411	**10,222**	193	53.0
Coal mining	253	0.06	369	0.02	80	193	**273**	39	7.1
Metal ore mining					0	0	**0**	12	0.0
Non-metallic mineral mining and quarrying	771	0.19	100	0.00	245	52	**297**	18	16.9
Support activities for mining and oil and gas extraction	425	0.11	2,198	0.11	135	1,148	**1,283**	1001	1.3
TOTAL	**\$4,001^1**		**\$20,694**		**\$1,272**	**\$10,804**	**\$12,076**	**154**	**78.2**

Notes: [1] Source: *Table 379-0003 - Gross Domestic Product (GDP) at factor cost, by Standard Industrial Classification, 1980 (SIC) and province, annual (Dollars) *TERMINATED**

[2] Source: *Table 379-0025 - Gross Domestic Product (GDP) at basic prices, by North American Industry Classification System (NAICS) and province, annual (Dollars)*

Table 9.50 *Mining Activities in SSRB, 1996*

The second approach is to take the amount of water withdrawn from Table 9.50 and impute the costs if recycling were employed rather than production restrictions. Since the data shows that the prairie average is 5.61 times the national averages, we inflate the national sectoral costs in Table 9.49 by a factor of 5.61. Unfortunately, expenditures on water for the Oil and Gas sector are not reported in the Industrial Water Use dataset. We can only guess at this point what those costs are. We take as a first estimate the average prairie cost of recycling for all sectors. This is \$78.92 per 1,000m^3.

	MCM intake	**Shadow Price of Raw water CAN (\$/1000m^3)**	**Shadow Price of Raw water SSRB (\$/1000m^3)**	**Total SSRB Cost (\$M)**
Oil and gas extraction	53.0		78.92	4.18
Coal mining	7.1	10.96	61.52	0.44
Metal ore mining	0.0	63.79	358.06	0
Non-metallic mineral mining and quarrying	16.9	39.60	222.27	3.76
Support activities for mining and oil and gas extraction	1.3			
TOTAL	**78.2**		**107.16**	**\$8.38**

Table 9.51 *Shadow Price of Water in the SSRB, 1996*

Taking the withdrawals by sector and imputing the costs of replacing this with recycled water yields a total cost of around \$8.38M. That is, mining firms would have to pay an additional \$8.38M in water recycling costs to offset a total elimination of water intake. This is less than 0.1% of the total GDP of the entire SSRB mining sector.

9.7.4 Discussion

The water values used above are interpreted in the same way, and using the same caution, as those for industrial water use. In general, water is a smaller component to the production process in mining than it is in manufacturing. However, the smaller reliance on water in mining does not imply that water is less critical to the production process. The data tell us that the value of water in mining is higher than for manufacturing as a whole. The value-added per cubic meter is \$154 versus \$21. Similarly, the shadow price of water is also higher (\$107 versus \$80 per 1,000m^3).

9.8 Hydro-Electric Generation

9.8.1 Introduction

Electrical generation uses water in two ways. Hydro-electric power generation uses water directly to produce power but does not consume water directly. All water withdrawn is returned to the river system though some water is lost in the form of evaporation from reservoirs. Thermal generation (coal-thermal and gas-turbine) uses water as a source for steam and for cooling. Water is consumed in the form of increased evaporation after the cooling process is complete. Thermal plants either pass heated water directly into a water source or recycle water in cooling ponds or reservoirs. The type of cooling technique used partially determines the degree of water lost to evaporation. This chapter focuses on hydro-generation. The next chapter considers thermal-generation.

9.8.2 Hydro-Electric Generation

Electricity is generated as water flows through hydraulic turbines connected to a generator. The amount of electricity generated is directly related to the volume of water passing through the turbine, the head (the vertical distance between the surface of the upstream water and the turbine), and the efficiency of converting falling water into electrical energy (Gibbons, 1986).

The method we take to value water in hydro-electric generation is an *output replacement method*. The idea here is that any decrease in available water reduces power generation from that source and so requires the firm to replace this lost generation by some other means. Since all sources of electrical generation are perfect substitutes for each other, the price charged per kilowatt-hour (kwh) is the same across sources. Hydro operators generally do not pay for water withdrawn since all the water is returned to the river system. This implies that, excluding investment in plant and equipment, electricity from hydro is less expensive to produce than thermal generators (and less than newer wind or solar generation). Hence the value of the water used in hydro generation is the cost savings avoided by not having to produce that electricity by more expensive alternatives. We can determine the cost of alternatives depending on whether existing thermal capacity can or cannot make up for lost hydro generation.

9.8.2.1 Short-Run Marginal Value

The *short-run marginal value of water* in hydro-electric generation is the difference in marginal costs of producing the lost electricity by some other means, either in coal-powered or gas-turbine generators, or as a direct purchase (import) from another jurisdiction. These short-run costs include fuel inputs as well as any additional operational and maintenance expenses. Typically, coal-fired plants operate at capacity while gas-turbine generators are used in conjunction with hydro-power to meet peak demands. In the short-run, any lost hydro generation will tend to be made up from gas-turbine generation.

Table 9.52 shows operating, maintenance and fuel cost for four types of generation technologies using US data from 1991 to 2002. Operation and maintenance costs for hydro exceed that for coal and gas-turbine generation by about 50-60%. However, hydro is the cheapest form of generation since fuel costs are zero. Fuel costs as a share of average operating expenses for coal are slightly over 75% for the period and have been at this level for the entire period. The share of fuel costs for gas turbines is now over 80% and has been rising from a low of 56% in 1992. Overall, for the period 1991 to 2002, the average total variable costs (excluding fixed costs) is 7.05 mills/kwh for Hydro, 21.85 mills/kwh for coal, and 40.18 mills/kwh for gas turbines.

Plant Type	2002	2001	2000	1999	1998	1997	1996	1995	1994	1993	1992	1991
Operation												
Nuclear	8.51	8.28	8.39	8.92	9.97	11.01	9.47	9.43	9.80	10.22	10.45	10.52
Fossil Steam	2.53	2.39	2.31	2.21	2.17	2.22	2.25	2.38	2.32	2.37	2.38	2.30
Hydroelectric[1]	5.05	5.78	4.73	4.16	3.85	3.29	3.87	3.69	4.53	3.83	4.34	3.89
Gas Turbine [2]	2.71	3.14	4.56	5.15	3.85	4.43	5.08	3.57	4.58	6.48	10.20	9.63
Maintenance												
Nuclear	5.02	5.00	4.92	5.12	5.78	6.90	5.68	5.21	5.21	5.74	5.94	5.51
Fossil Steam	2.67	2.60	2.45	2.38	2.41	2.43	2.49	2.65	2.82	2.96	2.96	2.99
Hydroelectric	3.57	3.96	2.98	2.60	2.00	2.49	2.08	2.19	2.90	2.65	3.31	2.90
Gas Turbine	2.37	3.32	3.49	4.79	3.43	3.43	4.98	4.28	5.40	7.53	12.17	12.96
Fuel												
Nuclear	4.59	4.66	4.94	5.16	5.38	5.42	5.50	5.75	5.88	5.89	6.13	6.73
Fossil Steam	16.06	18.08	17.65	15.60	15.92	16.79	16.51	16.08	16.69	17.68	17.53	17.95
Hydroelectric												
Gas Turbine	31.72	43.45	39.11	28.68	23.00	24.93	30.58	20.84	22.21	26.43	28.65	31.04
Total (Fuel, Maintenance, and Operations)												
Nuclear	18.13	17.94	18.25	19.20	21.14	23.33	20.65	20.40	20.88	21.84	22.53	22.76
Fossil Steam	21.27	23.08	22.41	20.18	20.50	21.44	21.25	21.11	21.83	23.01	22.87	23.24
Hydroelectric	8.62	9.74	7.71	6.76	5.84	5.78	5.95	5.88	7.44	6.48	7.65	6.79
Gas Turbine	36.81	49.91	47.17	38.62	30.27	32.78	40.64	28.69	32.19	40.44	51.02	53.63
Share of Fuels in Total (in %)												
Nuclear	25.3	26.0	27.1	26.9	25.5	23.2	26.6	28.2	28.1	27.0	27.2	29.6
Fossil Steam	75.5	78.3	78.8	77.3	77.7	78.3	77.7	76.2	76.4	76.8	76.6	77.3
Hydroelectric	0	0	0	0	0	0	0	0	0	0	0	0
Gas Turbine	86.2	87.1	82.9	74.3	76.0	76.0	75.2	72.6	69.0	65.4	56.1	57.9

Notes: [1] Conventional hydro and pumped storage; [2] Gas turbine includes internal combustion, photovoltaic, and wind plants. Further notes to Table 9.52: Expenses are average expenses weighted by net generation. A mill is a monetary cost and billing unit equal to 1/1000 of the U.S. dollar (equivalent to 1/10 of one cent). Totals may not equal sum of components because of independent rounding.

Table 9.52 *Average Operating Expenses for Major U.S. Investor-owned Electric Utilities, 1991-2002.* Values are in mills per kwh in constant 1996 $US
Data Sources: *Federal Energy Regulatory Commission, FERC Form 1, "Annual Report of Major Electric Utilities, Licensees and Others."* http://www.eia.doe.gov/cneaf/electricity/epa/epat8p2.html, GDP deflators are from the Bureau of Economic Analysis.

We can convert the above values into constant Canadian dollars using 1996 as the base year (see Table 9.53). For each kwh of lost hydro generation, the cost of replacing this with the alternative is the additional operating and maintenance costs of the alternative. For 2002, this is 1.985¢ for coal and 4.426¢ for gas turbine. Over the period 1991 to 2002, the average is 2.047¢ for coal and 4.570¢ for gas turbine. The actual value will be some linear combination of the two figures and is determined by the fraction of hydro power that would be replaced by gas-turbine and the fraction by coal-thermal. As we do not yet have this data, we report a high and a low value.

	2002	2001	2000	1999	1998	1997	1996	1995	1994	1993	1992	1991	AVG
TOTAL VARIABLE COSTS: Operation + Maintenance + Fuels													
Nuclear	28.46	27.78	27.11	28.53	31.36	32.30	28.16	28.00	28.51	28.18	27.23	26.07	**28.47**
Fossil Steam	33.39	35.75	33.27	29.98	30.41	29.68	28.97	28.97	29.81	29.69	27.64	26.62	**30.35**
Hydro-electric	13.54	15.08	11.46	10.04	8.67	8.00	8.11	8.07	10.16	8.36	9.24	7.78	**9.88**
Gas Turbine	57.80	77.31	70.05	57.38	44.91	45.39	55.41	39.38	43.96	52.17	61.67	61.45	**55.57**
Ratio of O&M Costs of Hydro to Alternatives													
Hydro/ Coal	1.66	1.95	1.62	1.47	1.28	1.24	1.26	1.17	1.45	1.21	1.43	1.28	**1.42**
Hydro/ Gas	1.70	1.51	0.96	0.68	0.80	0.74	0.59	0.75	0.75	0.46	0.34	0.30	**0.80**
Ratios of TOTAL VARIABLE COSTS of Hydro to Alternatives													
Hydro/ Coal	0.41	0.42	0.34	0.33	0.29	0.27	0.28	0.28	0.34	0.28	0.33	0.29	**0.32**
Hydro/ Gas	0.23	0.20	0.16	0.18	0.19	0.18	0.15	0.21	0.23	0.16	0.15	0.13	**0.18**
Difference in TOTAL VARIABLE COSTS per kwh between Hydro and Alternatives													
Hydro-Coal	-19.85	-20.67	-21.82	-19.94	-21.74	-21.69	-20.86	-20.90	-19.66	-21.33	-18.40	-18.85	**-20.47**
Hydro-Gas	-44.26	-62.23	-58.59	-47.34	-36.24	-37.39	-47.30	-31.31	-33.81	-43.81	-52.43	-53.67	**-45.70**
Gas-Coal	24.41	41.56	36.77	27.40	14.49	15.71	26.44	10.41	14.15	22.48	34.03	34.82	**25.22**

Table 9.53 *Average Variable Cost Measurements and Selected Ratios for Major U.S. Investor-owned Electric Utilities, 1991 - 2002*
Values are in mills per Kwh in Constant 1996 $CAN
Data Source for Canada-US exchange rates: Bank of Canada and *World Development Indicators*

9.8.2.2 Long-Run Marginal Value Of Water

If water volumes are permanently lower, then hydro-power generation is also permanently lower (assuming all water is passed through turbines rather than by-passed). This lost capacity can be made up by building new thermal plants or expanding existing facilities. This *long-run replacement capacity value of water* would include the cost of new thermal capacity less the production costs of the hydroelectricity lost. However, the firm can avoid building new capacity by simply raising electrical prices. Hence this approach ignores demand side factors unless one assumes electrical demand is completely inelastic (Gibbons, 1986, p 90).

An alternative is to find the *long-run average value of water* which is the difference between the total cost of thermal generation (capital plus variable inputs) less the total cost of hydro-power. Note that this may underestimate the actual costs since it assumes that the fixed cost of hydro infrastructure is recouped.

At this point we do not have values for the average cost of thermal generation so cannot estimate the value of water in the long run. In addition, as long as some shortfalls can be made up by imports from other jurisdictions then the short-run values may be a good approximation of long-run values.

9.8.3 Hydro-Power Generation in the SSRB

Table 9.54 shows the major hydro generating plants in the SSRB used in the WAUM model. The first two columns indicate whether the station is used to supply peak demands for electricity or base load demands. Stations are typically used in both roles. The next column shows the actual power generated in 1996 as well as the capacity utilization rate. In general, stations sit idle for 30 to 90% of the time. This partly reflects their use as peaking stations but also reflect the water supply conditions on site. SaskPower's Coteau Creek Power Station on the Gardiner Reservoir has the highest capacity rating of 66%.

	Production Type		**Useable Storage (1000m^3)**	**Actual Power annual (Mwh)**	**Capacity Factor (%)**
	Peaking	**Base-Load**			
Outlet Works				30	
Cascade	1	1	225	61,492	21
Rundle	1		177	90,099	21
Spray	1		177	265,236	28
Three Sisters		1	177	3,922	11
Bearspaw		1	138	74,583	53
Ghost	1	1	925	190,432	43
Horseshoe		1	9	80,366	61
Kaminski's		1	2	98,958	59
Barrier	1	1	248	44,396	41
Interlakes	1	1	1033	9,675	14
Locaters	1	1	632	29,124	22
Coteau Creek	1		9364	1,084,666	66

Table 9.54 *Hydro Production in the SSRB, 1996*
Source: *Kassem 2004*

9.8.4 Value of Water in Hydro-Generation

The value of water is site specific. Each acre-foot per foot of water produces 0.87 kwh of electricity (Gibbons, 1986, p89). A reduction in water flow will have different impacts on power production depending on where the water is lost (accumulated head in the water system below the point considered) and how the lost water affects the accumulated head downstream. The cost savings depend on the amount of power generated by the water by all hydro generators downstream and the costs associated with the alternative source used to replace any lost electrical output.

To calculate the value of water at a particular site we need to know how much power is generated by 1,000m^3 of water at that site, how much water passes through the turbine, and the cost of alternative power generation. The cost of alternatives is taken to be the short-run marginal costs and was calculated in the previous section. These values are both the short-run average value of water and the marginal value of water since the relationship between the volume of water passing through the turbines and power output is constant.

Table 9.55 summarizes actual power generation and water flows at each station for 1996. Two million mwh of power was generated by all sources with slightly over half generated at the Coteau Creek power station on the Gardiner reservoir. If we cost alternative sources of power per kwh at 2.047¢ or 4.570¢

when we use coal or gas-turbine respectively, we can estimate the short-run savings to the power companies of having free water. This gives us the willingness to pay for access to water as well as the shadow price of water. This works out to over $41M if coal-thermal is used to replace the lost hydro power and over $92M if we use gas-turbines. Total measured flow over the stations was in excess of 370 thousand MCM. This volume is corrected for monthly spills so only counts water used in generation.

Dividing total savings by total volume of water gives us a measure of the average value per 1,000m^3 of water at each station. For instance, at Coteau Creek the total savings per 1,000m^3 is between $2.15 and $4.79. Values at the other stations are much smaller. This is primarily due to the smaller head at these stations.

	Power (MWh)	**Value of Generation ($1000)**		**Average flow per month (m^3 per sec)**	**Water flow per year (MCM)**	**Value ($ per 1000m^3)**	
		LOW	**HIGH**			**LOW**	**HIGH**
		0.02047	0.0457			0.02047	0.0457
Outlet Works	30	1	1	1,472	46,484	**0.00**	**0.00**
Cascade	61,492	1,259	2,810	251	7,887	**0.16**	**0.36**
Rundle	90,099	1,844	4,118	428	13,525	**0.14**	**0.30**
Spray	265,236	5,429	12,121	428	13,525	**0.40**	**0.90**
Three Sisters	3,922	80	179	288	9,103	**0.01**	**0.02**
Bearspaw	74,583	1,527	3,408	1,898	60,008	**0.03**	**0.06**
Ghost	190,432	3,898	8,703	2,800	88,505	**0.04**	**0.10**
Horseshoe	80,366	1,645	3,673	1,328	41,966	**0.04**	**0.09**
Kananaskis	98,958	2,026	4,522	1,975	62,378	**0.03**	**0.07**
Barrier	44,396	909	2,029	438	13,826	**0.07**	**0.15**
Interlakes	9,675	198	442	148	4,661	**0.04**	**0.09**
Pocaterra	29,124	596	1,331	223	7,015	**0.08**	**0.19**
Coteau Creek	1,084,666	22,203	49,569	328	10,340	**2.15**	**4.79**
TOTAL all SOURCES	**2,032,979**	**41,615**	**92,907**	**12,005**	**379,225**	**0.11**	**0.24**

Table 9.55 *Shadow Price of Water, 1996, SSRB*
Source: *Kassem 2004*, and own calculations

9.8.5 Discussion

The value of water in hydro-generation is a function of the location of that water, the fraction of water that remains in the water system, and the costs of replacing any lost power.

- The value of a given 1,000m^3 at a specific location in the watershed varies depending on how many subsequent power sites it passes though as well as what fraction of that water arrives at downstream sites. For instance, a large fraction of the water from the mountains eventually passes though the Coteau Creek power station. Suppose 1,000m^3 passes through the Spray Lakes power station and all of it reaches Coteau Creek. The value of the water above the Spray power station is the sum of two values (0.40 and 2.15 = $2.55).

- Consider the above example once more. If only 50% of the water that passes through the Spray Lakes station reaches the Coteau station, then the value of water above the Spray power station is smaller at (0.40 + 2.15/2 = $1.48). Without additional information on how much water gets diverted between stations we cannot estimate the total value of water at a particular point in the watershed. This also implies that the location of withdrawals by other users will affect power generation to different extents. The higher up the watershed the withdrawals, the greater the impact on generation.

- The type of replacement power determines the cost of replacement. The replacement source depends on how much power needs replacing and when it is required. In general, hydro-power is used for peak demands though some is used for base-loads as well. Hence, any small reduction in water will tend to require power replacement at peak times. This implies higher costs since peak demands would be satisfied by gas-turbine generation. On the other hand, given that power grids across North America are becoming more integrated, it may be possible to import power from other jurisdictions. Assuming that much of this could be met through conventional steam-generation, the costs may turn out to be lower.

- If there is a sustained and large reduction in water available for hydro-generation, then some base-load demand would have to be satisfied with increased conventional steam generation. The cost reported above do not include capital costs so would underestimate the true costs. On the other hand, if the reductions were still deemed to be transitory (say five years) then the utility may find it more profitable to avoid building capacity and will instead rely on gas-turbine capacity or power imports. Hence, even in the event of a prolonged drought, costs will typically fall below the high value reported above.

- Replacement costs of power are likely to rise. Table 9.53 shows that operating, maintenance, and fuel costs, in real terms, have an upward trend. Hence the value of water will likely rise in the future.

- The shadow prices of water reported here are for water withdrawals so that they are comparable to the values for households, industry, and agricultural users. Hydro-generation differs from these other uses in that little of the water is consumed in the process. This implies that the social cost of withdrawing water from the river system for hydro-generation is small, if not zero: greater water withdrawals by hydro utilities simply have little effect on other users. This is not the case with irrigators or industry. Their water use does impact downstream users since not all the water is returned to the river. Hence the optimal social allocation of water would need to value water on a consumed basis and so account for lost access down river. The values reported her, however, do not account for the social willingness to pay, just the private willingness to pay.

9.86 Appendix

The following Table 9.56 shows the hydro generating facilities in Saskatchewan and Alberta. SaskPower owns and operates all the facilities in Saskatchewan. Alberta deregulated its power generation in 2001 and so currently has four private-public operators.

Plant Name	Operator	Location	Water Source	River system	MW	On-Stream
SASKATCHEWAN [1]						
Coteau Creek	SASKPOWER	Elbow	Gardiner Reservoir	Saskatchewan River	186	1958
Nipawin Hydro Station	SASKPOWER	Nipawin		Saskatchewan River	255	1991
E.B. Campbell Hydro Station	SASKPOWER	Nipawin		Saskatchewan River	288	1991
Island Falls Hydro Station	SASKPOWER	Man-Sask border		Churchill River	101	
Athabasca Hydro Stations	SASKPOWER	Uranium City		Waterloo, Wellington and Charlot River	23	
ALBERTA [2]						
Barrier	TAU	Seebe	Barrier Lake Res	Bow River	13	1947
Bearspaw	TAU	Calgary	Bow River	Bow River	17	1954
Cascade	TAU	Banff	Lake Minnewanka	Bow River	36	1942
Ghost	TAU	Cochrane	Ghost Reservoir	Bow River	51	1929
Horseshoe	TAU	Seebe	Bow River	Bow River	14	1911
Interlakes	TAU	Kananaskis	Upper Kananaskis Storage Reservoir	Bow River	5	1955
Kananaskis	TAU	Seebe	Kananaskis and Bow Rivers	Bow River	19	1913
Pocaterra	TAU	Kananaskis	Lower Kananaskis Storage Reservoir	Bow River	15	1955
Rundle	TAU	Canmore	Spray Lakes Storage Reservoir	Bow River	50	1951
Spray	TAU	Canmore	SLSR	Bow River	103	1951
Three Sisters	TAU	Canmore	SLSR	Bow River	3	1951
Oldman River	ATCO	Pincher Creek	Oldman River	Oldman River	32	2003
Chin Chute	IRRICAN	Cranford	St. Mary Main Canal.	Chin Reservoir	13	1994
Raymond Reservoir	IRRICAN	Raymond	SMMC	St. Mary Main Canal.	18	
Belly River	CAN hydro	Glenwood	Waterton-Belly Diversion Canal			1991
Waterton	CAN hydro		Waterton Reservoir.	Waterton River		1992
St Mary	CAN hydro		St. Mary Dam	St. Mary River		
Bighorn	TAU	Nordegg	Lake Abraham	North Saskatchewan	120	1972
Brazeau	TAU	Drayton Valley	Brazeau River	Brazeau River	355	1965
Taylor Hydro	CAN hydro	Magrath	Taylor Coulee chute		12	

Notes: [1] Source: http://www.saskpower.com/aboutus/genfac/genfac.shtml; [2] Source: http://www.transalta.com/

Table 9.56 *Hydro Stations*

9.9 Thermal-Electric Generation

9.9.1 Introduction

There are three primary types of thermal-electric power generation technologies used in Canada: coal-fired, gas-turbine, and nuclear. Each form of generation has water as an integral input into power generation. Each uses water differently. Saskatchewan and Alberta rely primarily on coal-fired plants to provide base generation and gas-turbine plants to supplement base demand as well as to meet peak demands. Water is used as a source for steam or to cool the steam for recirculation. Water used for stream is generally in a closed system so that water consumption or losses is not a significant factor. Water used for cooling, however, leads to increased evaporation, less water is returned to the water system, and so water is consumed by the process of cooling. The degree to which water is lost depends on the cooling technology. Water is also used in nuclear plants as a source for steam and cooling though the primary use (at least in Canada) is as a source of heavy water (heavier isotopes of water).

9.9.2 Generation of Electric Power

Table 9.57 shows power generation in 1996 for Canada based on type of generation. Total production was 506M mega-watt hours (mwh) with Quebec and Ontario the biggest producers. Production in Saskatchewan was 16.1M mwh and 49.0M mwh in Alberta.

Overall, Canada generated about 63% of its power in hydro and 17% in nuclear plants. Conventional steam generation made up almost 19% with the remaining 1.2% contributed by gas-turbine and internal combustion generators. Alberta and Saskatchewan, however, rely much more heavily on conventional steam with Saskatchewan generating 72% and Alberta 93% of its power this way. Gas-turbines contributed 0.9% and 2.4% respectively. Saskatchewan produced 27% of its power from hydro while Alberta only 4.6%. Neither generates nuclear power.

	HYDRO	CONVENTIONAL STEAM	GAS - TURBINE	INTERNAL COMBUSTION	NUCLEAR	TOTAL	Share of NUCLEAR
NF	34.9	1.4	0.0	0.1	0.0	36.4	**0.0**
PEI	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
NS	1.1	8.5	0.0	0.0	0.0	9.6	**0.0**
NB	2.8	5.5	0.0	0.0	3.7	12.0	**40.7**
QUE	145.0	0.4	0.2	0.2	5.2	151.0	**89.8**
ON	39.9	20.8	4.2	0.1	77.7	142.7	**75.6**
MAN	30.9	0.2	0.0	0.0	0.0	31.1	**0.0**
SK	4.4	11.6	0.1	0.0	0.0	16.1	**0.0**
AB	2.3	45.5	1.2	0.1	0.0	49.0	**0.0**
BC	56.6	1.0	0.0	0.1	0.0	57.7	**0.0**
CAN	**318**	**95**	**6**	**1**	**87**	**506**	**46.3**

Table 9.57 *Electric Power GWH (utilities) 1996*
Source: Statistics Canada

If we consider only thermal generation (conventional steam, gas-turbine, and nuclear) then Ontario produces 76% with nuclear. 90% of Quebec's thermal production is nuclear.

9.9.3 Water Intake and Consumption in Thermal Generation

Table 9.58, as taken from *Industrial Water Use, 1996* (Scharf, et al, 2002, Environment Canada), shows water extraction, recycling, and consumption for regions in Canada. The Prairie Provinces had a total of 2,337 MCM of water intake in 1996. Over 99% of the total intake was used by power utilities with only 4.3 MCM used by allied and Paper industries for generation.

To gauge the scale of this intake we can estimate the total intake by municipalities in the MUD dataset. For 1996 population covered in the MUD for Manitoba, Saskatchewan, and Alberta was 3.6209 million and average water flow was 1.713 MCM per day (or 625 MCM per year). Census populations taken from Statistics Canada show that actual population in 1996 is about 1.51 times larger than the MUD sample. Assuming communities outside of the MUD data set have similar water consumption coefficients as those within implies a total yearly municipal intake of water of approximately 945MCM. Hence water intake by thermal plants in the Prairies was almost 250% larger than municipal intakes.

The recycling of water was also very different across provinces. In the Prairies, 3,639 MCM was recycled for a total recycle rate of 156%. This was much higher than the rest of the country which had a recycling rate of only 30%. For Atlantic Canada, recycle rates were about 8%.

	Number of Plants	Intake	Recycle	Recycle Rate[1]	Gross Water Use	Discharge	Consumption	Cons. Rate[2]
Atlantic	19	2,372	201	8	2,572	2,298	74	3.1%
Quebec	3	809	0.01	0	809	809	0	0.0%
Ontario	15	23,228	7,816	34	31,044	23,224	4	0.0%
Prairies	20	2,337	3,639	156	5,975	1,907	430	18.4%
BC	3	4.2	0.1	1	4.3	4.2	0.1	2.4%
Total	**60**	**28,750**	**11,656**	**41**	**40,404**	**28,242**	**508**	**1.8%**

Notes: [1] Recycle Rate = Recycle as a% of Intake; [2] Cons. Rate = Consumption Rate = Consumption as a % of Intake

Table 9.58 *Selected Characteristics of Water Use (MCM) by characteristic and region, 1996*
Source: *Industrial Water Use, 1996*, 2002, Table 33

Water is lost to the river system when it evaporates. The degree to which water is lost is a function of the uses for water as well as the technologies used in cooling water. Consumption rates are much lower than intake rates. For instance, about 18% of the intake water in the Prairies was ultimately lost (consumed) in the operations of the power plants. This is very close to the 16% lost in municipal water use (calculated as total ADF intake divided by total ADF in sewers for 1999). This implies that water consumption in thermal plants was 284% higher than that for municipal consumption. Note that in the rest of Canada the consumption rate was very low at 0.30%. Again, this partly reflects the use of nuclear power in Ontario. Consumption rates in Atlantic Canada were just over 3%. Hence consumption of water on the prairies is much more significant than in the rest of Canada.

We can use Table 9.58 to calculate the amount of water used in the production of electrical generation. This is reported in Table 9.59. In total intake terms, the Prairie Provinces produce 1 mega-watt-hour of power per 40m^3 of water taken in. However, in terms of actual water used up in the process only 7.3m^3 of water is consumed per mwh. This is the highest value for any region and partially reflects the heavier reliance on conventional thermal generation. In Atlantic Canada, 124m^3 of intake water is used per mwh but only 3.9m^3 is consumed. Atlantic Canada takes in more water to generate power but consumes less. This is also true for Quebec and Ontario but this partly reflects their reliance on nuclear power.

	WATER USE (MCM)			Generation (M mwh)	COEFFICIENTS (m^3 per mwh)		
	Intake	Gross Water Use	Consumption		Intake	Gross	Consumption
Atlantic	2,372	2,572	74	19.1	124.3	134.8	3.9
Quebec	809	809	0	5.8	138.8	138.8	0.0
Ontario	23,228	31,044	4	102.7	226.1	302.2	0.0
Prairies	2,337	5,975	430	58.6	39.9	102.0	7.3
BC	4.2	4.3	0.1	1.0	4.3	4.5	0.1
Total	**28,750**	**40,404**	**508**	**187.2**	**153.6**	**215.9**	**2.7**

Table 9.59 *Water Use Coefficients for Thermal Generation, 1996*
Source: *Industrial Water Use, 1996*, 2002, Table 33 and own calculations

9.9.4 Expenditures on Water and Water Treatment

Environment Canada also reports expenditures on water and separates acquisition costs from treatment costs. In the Prairies, utilities paid a total of $14.6M on water related activities (see Table 9.60). About 40% of total expenditures were on operations and maintenance while about 55% was spent on intake treatment. Acquisition costs paid for water access made up only 3.4% of total expenditures.

REGION	Public Utilities	Operation and Maintenance	Provincial License Fees	Intake Treatment	Total
Atlantic and Quebec	2	2.5	0	6.7	11.2
Ontario	0.3	1.8	0	7,138.30	7140.4
Prairies and British Columbia**	0.5	5.9	0.2	8.0	14.6
Total	2.8	10.2	0.2	7153	7166.2
% of Total Water Costs	**0.04%**	**0.14%**	**0.00%**	**99.82%**	**100.0%**

Note: regions have been combined due for confidentiality reasons.

Table 9.60 *Water Acquisition and Intake Treatment Costs ($M) in Thermal Power Generation, by Cost Component, Industry Group, and Region, 1996*
Source: *Industrial Water Use, 1996*, 2002, Table 32

9.9.5 Valuation of Water in Thermal Electricity Production

For thermal generation (coal or gas thermal), the lack of available water forces the firm to invest in alternative cooling infrastructure or to shut-down production. Alternatives include increasing the recycling of water by using cooling ponds for reuse or switching to a less water intensive technology (say, gas-turbines). The value of water in these instances is the cost savings of using the more water-intensive cooling technology or of avoiding higher cost production such as gas-turbines. As such, the approach is very similar to valuing water in hydro-electric production in that the price of electricity is not relevant, only the costs of production.

Ideally, we need to identify the cost differentials between technologies related to water use intensity. In the very short run, technologies cannot be easily changed; the only way to reduce water use is to shut-down production. The marginal cost of alternative energy is the cost of providing it in another form (gas-turbine) or by importing power from another jurisdiction. In the long-run, new technologies that use less water can be deployed. The cost of decreasing water use is the difference in average production costs between the water-intensive and water-saving techniques.

Unfortunately there is no publicly available data to identify the difference in costs of using alternative cooling technologies. To provide an estimate we use three approaches: an output replacement approach, a cost comparison calculation, and an imputed cost calculation.

9.9.5.1 Method 1: Output Replacement

To estimate the value of water in thermal-electric production, we can use the difference in total variable costs between coal-thermal and gas-fired plants to estimate the cost savings associated with using conventional thermal generation rather than gas-turbine plants. The assumption is that reducing the reliance on coal increases the reliance on gas turbines or on imported power. This raises costs. We can calculate the costs savings and associate this with the water used in production. Returning to Tables 9.57 and 9.68 we see that the Prairie Provinces produced 57.3M mwh of electricity using conventional steam plants. If all of this were to be replaced by gas turbines, then using the cost differential between coal and gas-turbines of 25.22 mills per kwh (reported in Table 9.53 previously) implies a total additional cost (excluding fixed costs) of about \$2.39B. Total water intake in 1996 was 2,341 MCM. This then converts into a value of \$627 per 1,000m^3 of water intake or \$3413 per 1,000m^3 of water consumed (see Table 9.53). This is the shadow price of water since this is what utilities would pay, on average, to avoid reducing conventional generation.

	GENERATION (M mwh)								
	HYD	CONST M	GAS	INT COMB	TOT	REPLACEMENT COST ($M)	Intake (MCM)	Gross water use (MCM)	Cons (MCM)
MAN	30.9	0.2	0.0	0.0	31.1	397			
SK	4.4	11.6	0.1	0.0	16.1	525			
AB	2.3	45.5	1.2	0.1	49.0	1,468			
TOT	**37.6**	**57.3**	**1.3**	**0.1**	**96.2**	**2,390**	**2,341**	**5,979**	**430**
IMPUTED COST SAVINGS ($ per m^3) of water by use:							**0.627**	**0.246**	**3.413**

Table 9.61 *Cost of Replacement Power, 1996*

9.9.5.2 Method 2: Cost Comparison Method

The second approach to valuation is to compare the associated costs of power production across regions in Canada based on differences in water use intensities. Using the information from Table 9.60 we see that total water costs associated with water intake treatment and operating and maintenance costs is \$13.9M for the Prairie Provinces and British Columbia. As noted above, power generation in the Prairie Provinces uses less water for intake per mwh produced, has higher recycling rates, and ultimately consumes more water than in other regions. Suppose it were possible to avoid all these costs by using water more intensively. Then the maximum cost savings would be the \$13.9M. However, other technologies also have associated costs and so the total savings are likely to be lower.

To find this cost differential we compare Atlantic Canada with the Prairies provinces. The idea is that Atlantic Canada uses more intake water, recycles less, and consumes less than the Prairies per unit of power generated. Furthermore, their operating and maintenance costs are slightly lower on a per mwh basis. Hence if the Prairies could adopt the more water-intensive Atlantic generation techniques, their power costs would fall. We can then take the costs savings and impute the value of additional water used in production. Ontario does not offer a particularly good comparison as it relies extensively on nuclear power generation which has quite different requirements for water.

To make this comparison we need to account for the fact that New Brunswick and Quebec also have nuclear plants. 90% of Quebec's thermal generation is from nuclear sources (though this makes up a small fraction of total generation). Its average intake of water per mwh is about 140m^3. Recall that the Prairies have an intake of about 40m^3 per mwh. Ontario's average intake coefficient is 226 with 75% of their thermal power derived from nuclear sources. By imposing a value of 150m^3 per mwh of intake water, a recycle rate of 0%, and a consumption rate of 0% (all taken from Table 9.58 for Quebec) we can impute how much water was used as intake and consumed by conventional thermal power in Ontario and Atlantic Canada. This is reported in Table 9.62 below. The difference between this and Table 9.58 is that intake coefficients for Eastern Canada are closer to the Prairie average.

	WATER USE (MCM)						COEFFICIENTS m^3 per mwh		
	Intake	**Recycle**	**Recycle rate**[1]	**Gross water use**	**Discharge**	**Consumption**	**Intake**	**Gross**	**Consumption**
Atlantic	1,810	201	11	2,011	1,736	74	94.9	105.4	3.9
Quebec	24	0	0	24	24	0	4.1	4.1	0.0
Ontario	11,574	7,816	68	19,390	11,570	4	112.7	188.7	0.0
Prairies	2,337	3,639	156	5,976	1,907	430	39.9	102.0	7.3
BC	4	0	2	4	4	0	4.3	4.5	0.0
Total	**15,749**	**11,656**	**74**	**27,406**	**15,241**	**508**	**84.1**	**146.4**	**2.7**

Table 9.62 *Water Use (MCM) by Conventional Steam, 1996*
Source: own calculations

The second step in this process is to allocate the expenditures on water between nuclear and conventional steam. See Table 9.63 to follow. When we account for water used in nuclear power we find that conventional generation takes up about 35% of the intake water in Atlantic Canada and 23% in Ontario. If we use these ratios to allocate operating and maintenance costs associated with water to conventional steam generation, we can calculate the imputed costs per mwh or per thousand cubic meters of intake water. The calculated values for intake treatment costs are $0.148 per mwh in Atlantic Canada and $0.134 in the Prairies. This is quite close so likely reflects water quality differences rather than technological differences. The imputed operating and maintenance costs, however, are almost double on the Prairies compared to Atlantic Canada ($0.099 per mwh versus $0.055). On a volume of water basis, costs are much higher on the Prairies since the Prairies take in proportionately less water than the Atlantic regions.

If we take the difference in operating and maintenance costs between the Prairies and Atlantic Canada as the relevant difference in costs of using different cooling technologies, we can impute the additional costs associated with the different technologies. Currently, the Prairies pay $5.9M in operating and maintenance. If we use the cost coefficient for Atlantic Canada of 0.055 per mwh, the deflated cost for the prairies would be $3.27M. Hence, the Prairie Provinces pay an additional $2.62M (or $1.119 per 1,000m^3 of intake water and $6.022 per 1,000m^3 of water consumed) by using a less water-intensive technology. If we assume that marginal costs of switching to cooling technologies is constant, then these values can be interpreted as the increase in costs that would occur if access to water were further restricted to thermal electricity producers.

9.9.5.3 Method 3: Imputed Value

The basis of valuing water withdrawn from a basin and used as an input to a production process is that this water replaces alternatives and so reduces costs for the firm. The generating firm's willingness to pay for that water is the cost savings of a unit of water. If markets are formally established, then the market price paid for water tells us the firm's marginal willingness to pay. Such a market for water does not exist for thermal-electric producers so we must use a different method to identify the willingness to pay. To do this we assume that firms can freely choose between taking in new water or recycling water already taken in. This is the same approach we used in the manufacturing and mining sectors. At the margin, the value of intake water would be equal to the value of recycled water. The lack of detailed information forces us to assume that marginal costs are constant. This implies that the average cost per unit of intake water (intake fees, treatment costs, and operating and maintenance of intake equipment) is equal to the average costs of a unit of recycled water (treatment costs and associated operating and maintenance costs of recycling plant and equipment). We can find this average cost as total water costs divided by gross water use. Total costs paid for water and water related activities in the Prairie Provinces were $14.6M (taken from Table 9.60). Total gross water use was 5,980 MCM (taken from Table 9.58). This gives us an average cost per unit of treated intake water (either intake or recycled) of $2.44 per 1,000m^3 and $33.95 per 1,000m^3 for consumed water.

	INTAKE TREATMENT COSTS		**OPERATING AND MAINTENANCE COSTS**		**INTAKE**	**GROSS WATER USE**	**CONSUMPTION**
	$/mwh	**$/1000m^3**	**$/mwh**	**$/1000m^3**	**MCM**	**MCM**	**MCM**
Atlantic and Quebec	0.148	2.11	0.055	0.79	1,834	2,035	74
Ontario	65.749	307.31	0.017	0.08	11,574	19,390	4
Prairies and British Columbia	0.134	3.42	0.099	2.52	2,341	5,980	430
AVERAGE	**16.488**	**187.98**	**0.072**	**0.82**	**15,749**	**27,406**	**508**

Table 9.63 *Water Costs Conventional Steam, 1996*
Source: own calculations

We would like to calculate the value of raw water taken directly from the watershed. We do this by subtracting intake treatment costs from the value of treated water. However, the quality of the data does not allow us to do that with any reliability. The average cost of intake treatment (calculated at $3.63 per 1000m^3) for raw water is higher than the calculated value for treated water. In other words, utilities would need to be paid to accept raw water. As this is clearly not the case, it means that the marginal costs of intake treatment are lower than the average cost. This would occur if there are economies of scale in treatment. This would also be consistent with the average costs of recycled water at $1.62 per 1,000m^3. An alternative explanation is that marginal treatment costs are higher than $3.63. Since we cannot determine which case holds, we take a neutral position and just report the average cost of process water.

9.96 Value of Water in Thermal Generation in the SSRB

Kassem (2004) reports power generation by the two largest thermal plants in the SSRB. These are the plants at Medicine Hat and at Sheerness. Table 9.64 reports these data. Note that Kassem excludes the Queen Elizabeth plant in Saskatoon, whereas we have included it using data from SaskPower's *Annual Report* for 1998. Since data on water intake and discharge from the Queen Elizabeth station is not reported, we use the data for Medicine Hat as a proxy. The Sheerness station is much larger then the other two but uses less water. This is because Sheerness is located away from the river and uses a local lake for cooling. Both Medicine Hat and Queen Elizabeth are on rivers and so do not use cooling ponds.

Table 9.64 shows power generation, water intake, and imputed willingness to pay for that water using the three methods outline above. If each plant is forced to shut down due to a water shortage, then the cost of replacing that output with gas-turbine production is quite high at $74M per year.

If the plants can convert to more water efficient processes, then the costs fall to only $0.132M. However, given the current location of the Medicine Hat and Queen Elizabeth plants, it is unlikely that they could alter processes by using cooling ponds. The Sheerness station is already more water efficient (in terms of intake) than the other two so it may not be able to alter its cooling techniques.

If each plant can increase recycling so that no intake is required, then the cost is $0.287M per year. Of course, such scale of recycling is probably not feasible. Recycling to a lesser degree is reasonable.

	Generation M kWh	**Capacity MW**	**Water Intake MCM**	**Discharge MCM**	**Intake water per kWh**	**Output Replacement costs $M**	**Cost Comparison $M**	**Recycling costs $M**
						$0.627 per MCM	$0.001119 per MCM	$0.00244 per MCM
Medicine Hat	577	205	70.94	70.94	0.12295	**44.48**	**0.079**	**0.173**
Sheerness	5,342	800	18.24	8.69	0.00341	**11.44**	**0.020**	**0.045**
Queen Elizabeth	965[1]	232	28.52[2]	28.52	0.12295	**17.88**	**0.032**	**0.070**
Total	**15,570**	**1,237**	**118**	**108**	**0.00756**	**73.80**	**0.132**	**0.287**

Notes: [1] Source: *1998 SaskPower Annual Report*

[2] Calculated by using the same intake per kwh for the Medicine Hat plant

Table 9.64 *SSRB Conventional Generation, 1996*

9.9.7 Discussion

The three approaches to valuing water in thermal electric production give very different results. Using the output replacement method we get a marginal cost of a reduction in water available of $627 per 1,000m^3 of water intake or $3413 per 1,000m^3 of water consumed. Using the cost comparison method gives values of $1.119 per 1,000m^3 of intake water and $6.022 per 1,000m^3 consumed. The imputed cost method gives a value of $2.44 per 1,000m^3 for intake water and $28.74 per 1,000m^3 consumed.

One way to interpret these values is to consider the output replacement method to be an ultra short-run cost where power plants cannot replace a shortage of intake water by any means. They must shut down production and replace it by some other non-water using technology (gas-turbine). The cost comparison method can be interpreted as short-run costs where the firm reduces intake water by increasing recirculation and/or recycling. In the long-run, firms can choose different technologies and so reduce their reliance on intake water.

A caution is in order in interpreting these values. It is unlikely the case that no water will be allocated to thermal generation unless we experienced a severe, prolonged, and unprecedented drought. If all water were withdrawn from thermal generation, then some other source, other than gas-turbine, may be chosen as this appears to be the most costly alternative technology. For instance, Manitoba still has untapped hydro capabilities that will tend to be cheaper than gas-turbine. Hence the costs of full replacement will likely be lower than the $1.468 B reported above. However, the values here can be viewed as the marginal cost of reducing reliance on fossil fuels where the alternative is to use excess capacity in the gas-turbine sector. This makes sense for small reductions in water availability if power plants are forced to shut-down during a temporary water shortage or in periods of maximal evaporation.

9.10 Summary

This section summarizes the chapters above by showing how we might determine the impact of a water shortage on water users individually or as a whole. Consider the base scenario of a 10% reduction in available water withdrawals from the SSRB. We assume that water discharges are zero in the relevant time period so that aggregate withdrawals are equal to the sum of individual withdrawals. (Over a longer time frame we would have to account for return flows. This would imply that the sum of individual withdrawals would be larger than net withdrawals since water would be recycled by other users. (Note the WAUM model accounts for this).

Important in the calculations is how the water shortage is implemented. As a baseline we assume that each user must reduce intake by 10%. As shown in Chapter 9.3, this is probably not the cost-minimizing approach. For hydro-electric generators, the reduction in intake is taken to imply a reduction in water allowed through turbines. For instance, this could occur in the event of a drought if plants are forced to restrict flows to maintain reservoir levels. Alternately, hydro plants may face smaller in-stream flows over the year and so have less generation.

Table 9.65 below shows the major use categories in the SSRB, water withdrawals in 1996, and average costs per cubic meter of a water shortage of 10% using the range of cost estimates reported above. The short-run costs assume households and firms cannot alter consumption techniques easily. This would occur if the restriction was unanticipated. Households do reduce consumption but do so reluctantly. Producers reduce output, at least temporarily. As a result, the implied cost of a water shortage, and the resulting shadow price of water, will be high.

The long-run costs assume firms and households anticipate the restriction and so can undertake investments that reduce the impact of the shortage. Households can replace worn out appliances with newer, water–efficient ones. Firms can increase recycling. Irrigators can alter crop mixes and invest in more water-efficient irrigation equipment. Livestock operators can build water storage facilities. Hydro operators can plan for replacement power. The result of these pro-active actions is to lower the cost of the shortage.

If we assume each user group is forced to reduce intake by 10%, then we can calculate the total reduction in water intake and the total impact on each user. Costs are higher for large intake users as well as those with high shadow prices.

The total impact of this degree of restrictions is about $6.8B in the short-run and $0.23B in the long-run. In the short-run, the biggest financial impact is on manufactures and mining firms. They are large users and, in the short-run, have high values for water. In the long-run, the biggest impact is on irrigators since they cannot find ready substitutes for intake water. For municipal users the total impact is about $47M in the short-run and falling to $36M if anticipated. Like irrigators, municipal users can adapt to water shortages.

We can also consider a different scenario. Suppose the goal is to reduce total intake by 10MCM. We can calculate the impact on each user if each is forced to absorb the entire reduction themselves rather than have that reduction distributed across all users. In this scenario each is capable of meeting the objective. Table 9.66 shows these calculations. We use the same assumptions as above. Note that the cost to municipal users now reflects the relative size of the reduction. For households this is a 6% reduction but for Industrial users it is 14% and for Commercial users it is a 22% reduction. Recall that average cost rise with the degree of the reduction.

	Water Intake MCM	**Restriction MCM**	**Short-Run (unanticipated)**		**Long Run (anticipated)**	
			Weighted average cost per m^3	Total cost of restriction $M	Weighted average cost per m^3	Total cost of restriction $M
MUNICIPAL[1]				**47.06**		**36.31**
Household	156	15.6	1.39	21.71	1.27	19.84
Industrial	72	7.2	2.17	15.56	1.41	10.11
Commercial	45	4.5	2.17	9.79	1.41	6.36
AGRICULTURE				**323**		**165**
Irrigation	2,864	286.4	0.19	55.28	0.11	31.50
Livestock[2]	58	5.8	46.32	267.73	23.16	133.86
INDUSTRY[3]				**6,475**		**25**
Manufacturing	245	245.2	21.43	5,255	0.08	19.62
Mining	78	7.8	154	1,204	0.11	0.86
Hydro-electric	379,225	37,926	0.00024	9.10	0.00011	4.17
Thermal Electric	118	11.8	0.627	7.40	0.002	0.02
TOTAL	**382,861**	**38,510**	**0.18**	**6,845**	**0.01**	**226**

Notes: [1]Assumes a short-run elasticity of -0.3 and a long-run elasticity of -0.6 for Households and -0.1 and -0.4 for Industrial and Commercial customers. Also assumes uniform reductions in all communities and all users.
[2]Assumes long-run costs are 50% of short-run herd reductions
[3]Assumes output falls in the short-run but recirculation is possible in the long-run.

Table 9.65 *Costs of a 10% Reduction in Water Withdrawals by User Group, 1996*

In the short-run, irrigators and hydro-electric can absorb the shortage most easily at a cost of less than $2M for irrigators. This reflects their ability to alter production to accommodate the water restriction. Thermal-electric operators also have a relatively low cost. On the other hand, manufactures, livestock operators, and mines have very high costs if the water restriction leads to a shut-down in operations. Raw water is critical to production and the restriction can lead to lost output.

In the long-run, the relative costs change depending on how easily the user can adapt to the restriction. Livestock producers are still a high cost user since water cannot be substituted though water could be stored. Municipal users are also high cost users since they are unwilling or unable to eliminate water use significantly. Irrigators again can absorb the reduction fairly easily though manufactures, miners, and thermal plants now have lower adjustment costs.

	Water Intake MCM	Restriction MCM	Short-Run (unanticipated)		Long Run (anticipated)	
			Weighted average cost per m^3	Total cost of restriction $M	Weighted average cost per m^3	Total cost of restriction $M
MUNICIPAL[1]						
Household	156	10	1.26	**12.60**	1.21	**12.10**
Industrial	72	10	3.03	**30.30**	1.51	**15.10**
Commercial	45	10	4.42	**44.20**	1.63	**16.30**
AGRICULTURE						
Irrigation	2,864	10	0.19	**1.93**	0.11	**1.10**
Livestock[2]	58	10	46.32	**463**	23.16	**231**
INDUSTRY[3]						
Manufacturing	245	10	21.43	**214**	0.08	**0.80**
Mining	78	10	154	**1,540**	0.11	**1.10**
Hydro-electric	379,225	10	0.00024	**0.0024**	0.00011	**0.0011**
Thermal Electric	118	10	0.627	**6.27**	0.002	**0.02**

Table 9.66 *Costs of a 10% reduction in Water Withdrawals by User Group, 1996*

If we alter the municipal shadow price of water to reflect an ability to implement the water shortage across communities to minimize costs, then the average costs per cubic meter falls to for households in the short-run and in the long-run. This is also true for enterprises. However, the average unit cost of water is still much higher (above $0.50/m^3) than for irrigation in both the short and long-runs given the size of reductions called for. Recall, however, that for small changes (reductions in the 1% to 2% range) the efficient municipal reduction implied costs in the $0.10/m^3 range. Hence, even if we could apply shortages efficiently across communities, we would not force all the adjustment to fall on municipalities. We would force municipalities to absorb some restrictions but also force irrigators to absorb a greater share of the burden.

One aspect missing from the above is a finer breakdown in shadow prices across livestock or industrial/mining users. For instance, if the reduction is applied only to Food producers, then the average cost in the short-run is double the cost in Table 10.2 ($43.30 versus $21.43 from Table 6.6). If the reduction is targeted at Paper and Allied Product manufactures, then the cost is quartered to $4.82/m^3. Without better information about who must face the reduction, there is little point exploring these sub-cases.

The two scenarios above give a flavor to what impact we might expect from a given water shortage. What actually occurs depends on who must absorb the reduction, what assumptions are made about their ability to adapt quickly to those changes, and how long the reduction lasts.

References:

Agriculture, Food, and Rural Development, Government of Alberta, 2002. *Alberta Dairy Enterprise Returns and Cost of Components*: (Dollars Per Cow). http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/econ5191?opendocument

Bank of Canada, Monthly Average Exchange Rates, http://www.bankofcanada.ca/en/exchange-avg.htm

Bureau of Economic Analysis*, National Income and Product Account*, Table 1.1.4. Price Indexes for Gross Domestic Product, http://www.bea.gov/bea/dn/nipaweb/SelectTable.asp?Selected=Y

Burke, David W., Luis Leigh and Valerie Sexton, 2001. *Municipal Water Pricing, 1991-1999*, Environmental Economics Branch, Environment Canada. http://www.ec.gc.ca/erad/

Federal Energy Regulatory Commission, FERC Form 1, "Annual Report of Major Electric Utilities, Licensees and Others." http://www.eia.doe.gov/cneaf/electricity/epa/epat8p2.html

Crane Management Consultants Ltd., 1992. *Net Economic Values of Recreationists for Outdoor Experiences in the Fraser River Basin*. Prepared for Environment Canada, Vancouver, B.C.

Gibbons, Diana C., 1986. *The Economic Value of Water*, Resources for the Future, Washington.

Jenkins, Marion W., 2000. Appendix B-2 *Urban Value Function Documentation*. http://cee.engr.ucdavis.edu/faculty/lund/CALVIN/.

Kassem, Atef, *2004. WAUM Database*, results calibrated for the SSRB project, Environment Canada, Ottawa.

Kulshreshtha, Suren and Wayne Thompson, 2004. *South Saskatchewan River Basin Input-Output, Employment and Water Use Model: Technical Documentation*.

Prairie Farm Rehabilitation Administration, Agriculture and Agri-Food Canada, (AAFC-PFRA), Regina, 2003. *Socio-Economic Database*. In collaboration with the Prairie Adaptation Research Collaborative (PARC).

Renzetti, Steven, 1987. *The Economic Aspect of Water Use*, Environment Canada, Inland Water Directorate, Ottawa.

Scharf, Dave, David W. Burke, Michel Villeneuve, Luis Leigh, 2002. *Industrial Water Use, 1996*, Environmental Economics Branch, Environment Canada.

Irrigation Water Management Study Committee, 2002. *South Saskatchewan River Basin: Irrigation in the 21st Century. Volume 5*: Economic Opportunities and Impacts, Alberta Irrigation Projects Association.

Statistics Canada

- Environmental Accounts and Statistics Division
- Table 001-0010 - Estimated areas, yield, production and average farm price of principal field crops, in metric units, annual.
- Table 003-0025 – Value per head of livestock at July 1, annual (Dollars).
- Table 379-0003 - Gross Domestic Product (GDP) at factor cost, by Standard Industrial Classification, 1980 (SIC) and province, annual (Dollars) *TERMINATED*
- Table 379-0001 - Gross Domestic Product (GDP) at factor cost, system of national accounts benchmark values, by industry, annual (Dollars).
- Table 379-0025 - Gross Domestic Product (GDP) at basic prices, by North American Industry Classification System (NAICS) and province, annual (Dollars)

United Nations, 2002. *World Development Indicators*.

10 The Rationale for a Scenario-Driven Approach within a Socio-Economic Framework

10.1 Introducing the Scenario-Driven Approach

A pragmatic strategy is presented here for building socio-economic scenarios relating climate-change induced water supply change to sector water use in the South Saskatchewan River Basin (SSRB). This approach identifies exploratory and normative scenarios rather than uses forecasts *per se*. The aim is to provide a limited range of possible future outcomes to help identify critical areas of impacts. These impacts can be intuitively understood by stakeholders under a selective dove-tailed approach, combining the physical (climatic and hydrological) conditions impacting on overall and seasonal instream flows with the established economic patterns of water use, sector sensitivities and flexibility (as reflected in each sector's usage, investments, and shadow prices). This base analysis set can be used for both economic policy and infrastructure simulations: for example, one can simulate how the sectors may react if encouraged or constrained in their water use through economic instruments or policy, or how changing configurations and capacities of water storage and distribution may impact on water use, supply and quality. The potential to explore broad regional or provincial impacts has been established under Section 7.0, and the converse focus upon more localized impacts, at the sub-basin or nodal level, has been described in Section 6.6 and Appendix C, with much effort made to date to ensure database compatibility with established simulation programs such as the Water Use and Analysis Model (WUAM).

Consultation with key water use stakeholders within the SSRB has led to a simplified scenario approach rather than the pursuit of innumerable iterations geared largely to precision. This approach is justified not only by the acknowledgement of cascading uncertainties associated with climate change dynamics and hydrological response, but also with the many other significant economic, trade and socioeconomic variables of concern to decision-makers. These stakeholders are known to chart courses and make decisions with *continuous* re-assessment of conditions and impacts, considering how resource availability of water, energy, and raw materials intersects with the synergies or competing demands made by multiple parties or forces. Climate change may be viewed as one such force.

To support this decision-making approach, our project has considered three different socioeconomic dimensions. These dimensions are: Business as Usual, Economic Dynamism, and Ecological Sensitivity. With the Business as Usual dimension, we use industry, agricultural, and population forecasts interacting with hydrological forecasts to identify potential vulnerabilities. The Economic Dynamism dimension assumes faster economic growth emerging from increased inter-provincial migration into the West, accelerated irrigation adoption in Saskatchewan, and more value-added activities associated with agricultural production across the Prairies. This approach can also be used to decompose total impacts between climate-induced changes and changes due to economic growth. International demand for water-intensive products, as well as increased energy demand, is incorporated into this second scenario. The final dimension, Ecological Sensitivity, assumes more effort is applied to preserving water resources and adopting more water conservation methods. The focus is on preserving instream flows, promoting investments in water conservation, increasing application of water pricing and markets for incentives, and reducing the frequency or severity of water shortages. The basis for each scenario, data sources, strengths and weaknesses are laid out below, along with efforts to identify where the greatest uncertainties arise.

10.2 The Socio-economic Profile of the SSRB

It is necessary to first understand the socioeconomic framework of the SSRB itself, as the fabric of both settlement and anticipated migration impact not only on resource use and investments made, but the institutional and policy decisions made to balance economic growth with ecological integrity.

10.2.1 Population

The current population of the SSRB is estimated at 1.5 million people, with the largest concentration in Alberta. Of the total population, an estimated 20% reside in the Saskatchewan portion of the basin and 80% in the Alberta portion. Less than 5% of the overall population is estimated to live within rural communities. The 2001 population estimates (by CSD) for communities with over 1,000 people is shown in Figure 10.1. The change in population (%) for these communities from 1995 to 2001 is shown in Figure 10.2. The majority of communities show increases in population during this period.

10.2.2 Economic Activity

Economic activity within the region is very diverse and differences in resource availability, institutions and policies, and economic activities have produced very different economic response between Alberta and Saskatchewan. For instance, manufacturing is the predominant industry in Alberta, followed by mining and agriculture, whereas in the Saskatchewan portion of the SSRB, agriculture is the major industry followed by manufacturing and mining. A summary of the economic activity within the Alberta portion of the basin has been given by Alberta Environment (2002). The major economic activities by sub-basin include:

Red Deer River Basin
- Forestry
- Agriculture (crop and livestock)
- Oil and gas
- Recreation
- Service and industry important to the City of Red Deer

Bow River Basin
- Agriculture (crop and livestock)
- Oil and gas
- Manufacturing
- Service
- Recreation and tourism
- Education
- Corporate activities important to the City of Calgary

Oldman River Basin
- Agriculture (crop and livestock)
- Value-added processing
- Transportation
- Tourism
- Oil and gas
- Service and education important to the City of Lethbridge

South Saskatchewan River Basin (Alberta and Saskatchewan portions)
- Natural gas (Alberta portion)
- Transportation and service important to the City of Medicine Hat
- Agriculture (crop and livestock – both Alberta and Saskatchewan portions)
- Mining
- Manufacturing
- Service and education important to the City of Saskatoon

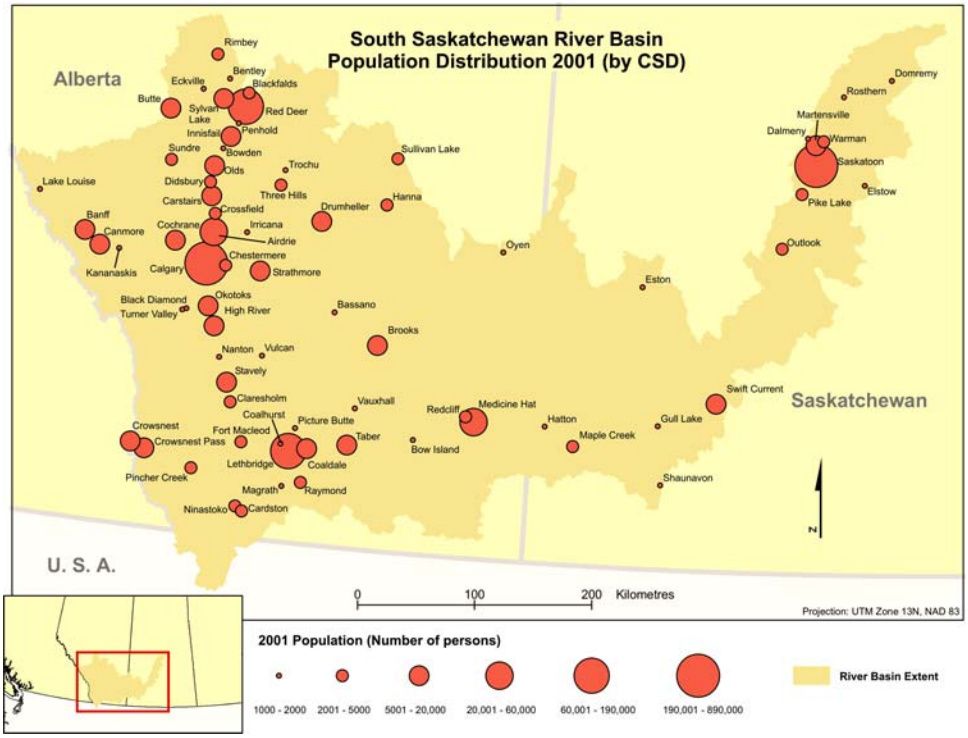

Figure 10.1 *2001 populations (by CSD) for various communities in SSRB. Map produced by GIServices, University of Saskatchewan.*

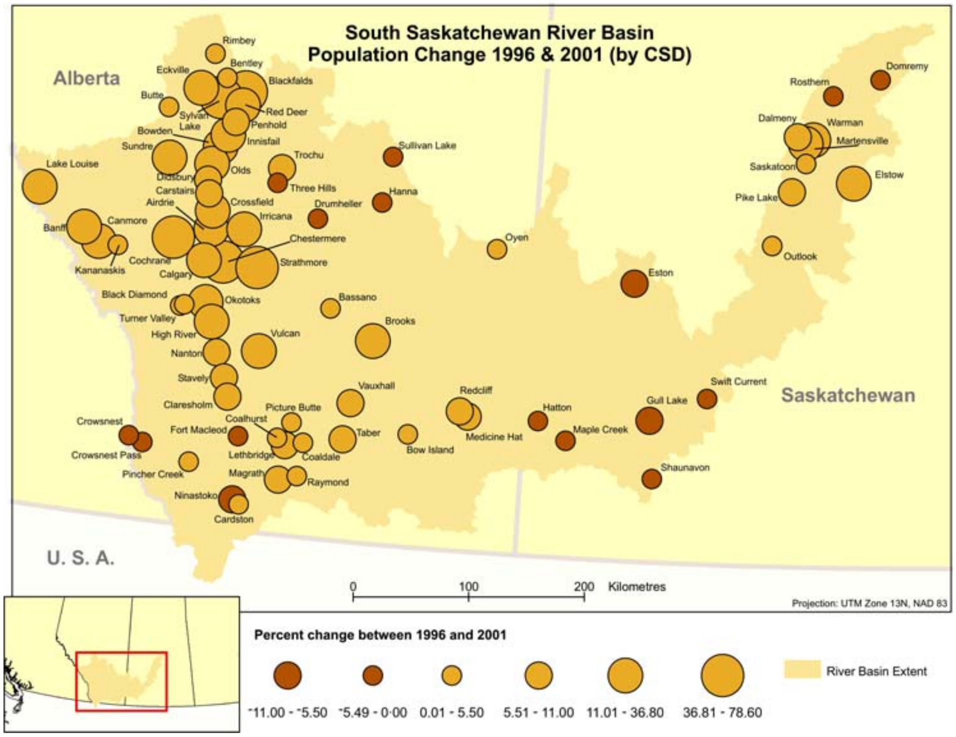

Figure 10.2 Change in population (%) from 1995 to 2001 (by CSD) for various communities in SSRB. Map produced by GIServices, University of Saskatchewan.

10.3 Factors Determining Water Use

To consider resource impacts across economic and social domains, it is necessary to understand the intersecting dynamics. Within the SSRB, there are multiple and often competing factors affecting the demand for water resources. (See the prior Section 8 prior for details of current water uses patterns within the SSRB, reflecting these demands). Water use and non-use within the basin are influenced by regional bio-geophysical characteristics which impact social, political, and economic development. Not only do system-wide geographic characteristics and the institutional legacy of water management and licensing set overall constraints in terms of instream flow, but there are also sub-basin, localized and site-specific attributes which determine opportunities and constraints on water use and non-use (Kulshrestha et al., 2001). Accordingly, the factors affecting water use are driven by multiple objectives serving both public and private interests. Although weather has always been a significant factor affecting water use in the basin, there is now far more uncertainty as to water use and demand due to increasing climate variability, more frequent and prolonged droughts and other extreme events, reduced glacial runoff and in-stream flow upstream in Alberta, and accelerated flows downstream in the SSRB.

10.3.1 Population and Power Needs

The nature of the population in and around the South Saskatchewan River Basin (SSRB) impacts on water withdrawal and wastewater management. Demographic characteristics such as age, settlement, distribution, occupation and income contribute to demands made on housing and rural and municipal water systems. The demographics and associated lifestyles not only directly impact residential water and energy demand, but influence consumer activities which draw on water use in commerce, industry and agriculture. Continuing urbanization creates increased demand for wastewater infrastructure, as do urban standards with regard to landscaping and lawn-watering. Municipal zoning restrictions and water pricing policies will also impact upon increasing demand for land-based recreational uses, such as golf courses and swimming pools.

Demographics and consumption patterns, described above, significantly impact energy consumption. Within the SSRB, much of the residential and commercial energy need is satisfied by hydroelectric power which does not directly consume water in the production process but helps regulate instream flow. Dam construction contributes to energy needs and a grid infrastructure that also creates smaller-scale hydro and energy export opportunities; hydroelectric power generation in turn makes significant local economic contributions and often strengthens purchasing power through exports. Dams and water diversions also reduce flood damage, maintain minimum instream flows, and create *in-situ* water-based recreational opportunities. However, water managers within the basin must increasingly take into account a broader range of public interests which reflect evolving ecological and ethical perspectives.

Environmental awareness is now a significant factor in all production processes, impacting not only the processes used, but also on input pricing and market opportunities. Instream demands for hydroelectric power may diminish as alternative energy sources become more attractive and full social and economic costing becomes implemented. To the extent that power generation within Saskatchewan and Alberta still relies on coal-fired plants, international policies regarding greenhouse-gas emissions may become more of a factor with incentives prompting the accelerated development and implementation of wind and solar energy. The use of nuclear energy remains heavily dependent on water use and strict waste management. It also depends upon public perception, as does continued reliance upon gas-fired turbines, which is in turn dependent on domestic reserves, domestic and export demand, and extraction technology. Energy management strategies used to regulate peak demand and support new markets (for example, bio-fuels) will also emerge as factors that affect both water pricing and demand. The SSRB is likely to face not only localized and regional but also continental markets, environmental and political influences; for example, the transformation of the American southwest to bolster bio-fuel production is likely to have significant impacts upon both competitors of such products and the markets for continental agricultural goods (i.e. livestock) and inputs (i.e. feed and water).

10.3.2 Economic Activity – Primary Production

There are many factors which impact water withdrawal and recovery during primary goods production. Within the basin, water is used intensively in agriculture, mining, and oil and gas extraction.

The demand for water in agricultural production depends on crop and livestock choice, weather conditions, farming practices, and market pricing of inputs and outputs. Reliance on irrigation is impacted by these factors as well as access to existing irrigation systems and licenses, and irrigation alternatives such as direct draw from the river, artesian wells, aquifers, micro-climatic advantages, etc.). The management of agricultural runoff has become an increasing important issue which may impose additional costs and force farmers to reassess their methods, input and output choices, which in turn will affect water demands.

Industrial standards and government regulations set the stage for capital investment, the adoption of technology, and access to natural resources. The oil and gas energy sector has good prospects for expansion, given increasing continental and international demand, robust prices, and declining (land-based) reserves. Emerging markets in Asia have recently bolstered the mining sector, and this demand is likely to grow given Asia’s focus on industrial growth and the lag in implementing environmental policy. Nevertheless, mining represents a small proportion of demand for water resources in the basin, and expansion in this sector is likely to increase in the more northerly region.

Industries differ in the extent to which they are forced to rely upon water directly within the production process (without any viable substitutes) and/or indirectly as used in power production and process control (heating and cooling). Given this combination of factors, a producer might also enjoy site-specific advantages or disadvantages, for example, either being downriver from major settlements or upriver from prime recreational areas.

10.3.3 Economic Activity – Manufacturing and Other Services

The interplay between primary, light industrial and commercial production is a dynamic which could increase water demand. Given Canada’s expertise in many technical areas, there will be opportunities for value-added economic activity, which extend the foregoing factors to manufacturing. As mentioned prior, consumer behaviour, both domestic and abroad, will also be factors that drive the demand for goods manufactured in the basin, or in peripheral areas reliant on the basin’s resources (such as hydroelectric production, transportation network, services and food and energy supplies). Public attitudes, shifting consumer preferences, demographics, and health considerations are likely to be factors influential in the growth or decline of vertically-integrated sectors, for example, agribusiness which services restaurants and provides pre-packaged or fast foods. Conversely, technological development in food processing and packaging, coupled with improved transportation and information logistics, may offset any losses in this sector. Given adequate services but relative affordability of real estate, the Saskatchewan portion of the SSRB may become increasingly attractive as a magnet not only for light industry and manufacturing, but also for service industries such as finance and insurance, which in turn, is likely to put pressure on housing demand and prices, as well as residential and municipal water systems.

10.3.4 *In-Situ* Water Use and Water Non-Use

Instream flows contribute to *in-situ* water use and non-use values. These *in-situ* values are assessed separately from withdrawal values, as typically determined for land-based commercial, industrial, municipal and residential uses. There are several reasons for this separation, although *in-situ* use and non-use can factor both positively and negatively into riverside activities. Parks and housing may border waterways which add to their enjoyment and add to property values or conversely, erode these values if rising or declining waters and water quality are an issue. The separate calculation of *in-situ* water use and non-use values is justified by the economic dilemma which accompanies “public goods”: there is no clear ownership, persons can often simultaneously benefit from the resource without diminishing others’ enjoyment, and markets either do not reflect the overall value of the resource or simply do not exist at all. This makes it far more difficult to determine both activity-based individual and aggregate demand as well as marginal values on incremental *in-situ* use and non-use. It also makes it more difficult to assign overall inventory and water contribution values as factor into social benefit costing and input-output frameworks.

10.4 Forecasts, Scenarios and Optimization Models

Given the framework and complex dynamics impacting water use as described above, it was necessary to first identify several approaches which could prove suitable, given the divergent interests and needs of the key water use sectors within the SSRB. The decision was thus made to explore three broad strategies: forecasts, scenarios and optimization models.

Forecasts provide a “best-guess” of the actual future outcomes expected to take place This best-guess is typically formed by extrapolating current trends and tracing their effects through modeled interactions (such as with the Global Climate Models (GCMs)). The SSRB Physical co-team (Pietroniro and Toth) pursued this approach as it intended to forecast water supplies in the SSRB. Due to uncertainties, alternative forecasts can be made to create an “envelope” of possibilities. Water demand forecasts in turn may account for population and industrial growth, changes in the composition of production, as well as changes in water use technologies.

The use of scenarios is quite different. Scenarios are intended to highlight a particular dimension of the problem at hand. They can, of course, be a forecast. However, scenarios need not be a probable outcome or, indeed, an entirely realistic outcome. Herein is one of the differences between the physical sciences and the social sciences which made this dove-tailing analytical exercise so challenging. An underlying assumption in the physical sciences seems to be that natural processes are not overly sensitive to human policy initiatives (at least in a short time span). Climate change forecasts account for human actions but generally rely on current trends as the driving factor. For instance, the GCM models predict continued global warming even if current CO_2 emissions were to fall. In the social sciences, human activities are at the center of the analysis and can be very sensitive to current policy initiatives. Even more complicated, from a forecaster’s perspective, is the fact that current behaviour can be sensitive to anticipated policies. From a social science perspective, policy choices are political in nature and not amenable to forecasts: it may be considered simply irresponsible to forecast policy choices and so it is not possible to forecast demands well into the future with a high degree of certainty. One can, nevertheless, trace out the effects of alternative policies and offer information about potential tradeoffs, so that approach is considered here.

For instance, one scenario we contemplated was a total freeze of all socio-economic activities at current (1996) levels. Call that baseline maintenance of the “status quo”, without any growth. One can use this exploratory scenario to identify whether climate change is likely to be the driving force behind shortages, or whether future growth in population and economic activities might be. There is no suggestion that such a freeze is possible, desirable, or even contemplated. This scenario does, however, allow us to identify the relative importance of climatic influences versus economic and population growth. The exploratory use of scenarios also allows us to analyze potential policy choices. For instance, one can ask what the demand for water would be if we introduced water trading or doubled the price of residential water. Alternately, one can ask what would happen if irrigation were to expand significantly.

Scenarios also allow you to take a counter-factual approach. For instance, we can ask how much improvement in water efficiency would be required to offset supply shortages. This normative approach allows us to ask if improvements in efficiency can offset supply shocks induced by climate change. It also helps identify what policy options may be required to achieve the desired outcome.

The third approach considered is optimization. The idea here is to directly model the decision process of agents (governments, household, and firms) and integrate the dynamics of this process with the bio-physical and institutional environment. The aim is to identify and quantify feedback effects and individual responses to climate change. For instance, we know that investments in and use of irrigation will continue to be a primary factor in water demands in the SSRB, in Saskatchewan in particular. How irrigators adjust to climate change directly, how they react to changes in agricultural prices, and how changes in water pricing alter on-farm practices are all important. Modeling those decisions directly can be important in understanding the impact of climate change as well as the *net* socioeconomic impacts due to intersecting response strategies.

One advantage of this optimization approach is that you can identify the water use that maximizes collective welfare. This use level can then be used as a benchmark to assess the relative benefits of a particular policy (such as water trading). A variation on this takes an evolutionary approach to model the way in which agents learn and adapt to climate change. This evolutionary framework can account for complex and “non-linear” reactions.

10.5 Risk Versus Uncertainty

An important aspect in analyzing the impacts of climate change on water resources and water users is to account for uncertainties. Jannsen (1998, 44) offers a useful classification. *Certainty* exists when the probability distribution is known and reduces to just one value. *Weak uncertainty* occurs when the probability distribution is known but does not reduce to just one value. Here, we know the probability of an event occurring but cannot guarantee that it occurs. *Strong uncertainty* exists when the probability distribution is not reliably known. Here, we may not know all the possible outcomes and/or do not have confidence in the stated probabilities. *Near ignorance* occurs when none of the conceivable probability distributions are reliable. Here, we cannot say with any certainty the likely outcomes or the probabilities associated with outcomes: we simply have no reliable information of the future.

As explained prior, the problem we face in identifying the impact of climate change on water resources is one of *cascading uncertainties*. Climate change models typically exhibit strong uncertainty. That CO_2 emissions are rising and will likely continue is well established. There is some uncertainty that depends on how aggressively nations tackle emissions. A similar claim can be made for global warming: we are confident it is occurring. Strong uncertainty arises as we are not entirely sure of the connection between anthropogenic greenhouse gas emissions and global warming. More uncertainty arises when we infer in-stream water flows from down-scaled GCM models: the relationship between climate change and rainfall-evapotranspiration is not fully understood. Further, the GCM models lack detail that can be easily mapped into sub-basins within the SSRB. As Lins *et al.,* (1997, 63) states: “With techniques in hand to reduce the limitations imposed by scale discordance, water resource professionals must now confront a more fundamental constraint on the use of climate models – the inability to produce accurate representations and forecasts of regional climate”. Further uncertainty arises when we consider both political and economic responses to climate change.

Two other critical aspects of uncertainty arise. First, model simulations and scenarios typically offer relatively precise values. One must not confuse this precision for certainty. Although not always explicitly stated, such reported values are contained in a bounded region. Secondly, the possibility of an event occurring can ensure that it does not. For instance, the possibility of severe drought that devastates livestock herds can lead to investments in water conservation and retention or herd reductions that in turn reduce the possibility of the bad outcome. The drought may occur but the impact is lessened. Alternately, the possibility of a particular outcome can ensure that it does comes about (a self-fulfilling prophesy). For instance, a scenario that incorporates water trading may convince policy makers that such a scheme is worth pursuing. Hence, the probabilities themselves are endogenous; this endogeneity can either raise the degree of uncertainty or lower it. Herein is another observed difference between the physical and social sciences. Humans are forward-looking so they can anticipate future events. Potential future outcomes must incorporate such forward-looking behaviour. Physical systems, in contrast, are not self-aware and cannot anticipate a future event. One cannot model human behaviour using purely physical modeling techniques.

The result of these cascading uncertainties is that we can neither predict specific outcomes nor offer specific probabilities over outcomes. This does not mean that we cannot offer insights. A necessary first step in any study is to identify possible outcomes and relevant polices. Further study is then required to pin down details.

10.6 Socio-Economic Down-Scaling

One challenge faced in identifying the impacts of climate change within a particular water basin is to build socio-economic scenarios that are relevant to that particular basin. This fine scale presents some significant hurdles. For instance, most population and economic growth forecasts are (at best) formulated at a provincial or national level. The SSRB, however, is both sub-provincial and inter-provincial. Down-scaling from national/provincial forecasts, like the down-scaling used in GCM models, relies on strong assumptions. These strong assumptions reduce their reliability. Furthermore, scenarios for the SSRB need to incorporate two separate provincial scenarios since each portion of the SSRB relies on different policy initiatives.

A particular disadvantage of using a water-basin as the unit for analysis is a decrease in the degree of certainty. For instance, the distribution of population within the basin depends on local birth and death rates, net immigration (both international and inter-provincial), and rural/urban migration. As noted by George *et al*., (2001, 41): “Internal migration is the most unstable component of population growth in Canada”. There are simply too many idiosyncratic factors that apply to a basin that “wash out” at the aggregate level. Although we may feel confident about populations in a province, we may not be able to identify the precise location of that population. This is made more difficult since past trends in migration may fail to capture future pressures.

Another difficulty is due to data limitations. Two aspects emerge. First, much economic data relies on the census *Headquarter’s Rule*. This rule assumes that the location of production is the same as the location of the firm’s head office or headquarters. For instance, it is possible for intensive “livestock production” to take place in downtown Calgary depending on how many companies list their headquarters in Calgary. This treatment is unlikely to raise problems at a provincial level since the location of production and the head office are likely in the same jurisdiction, but the lack of firm geographic information about livestock water demand is an obvious challenge for adapting to highly localized climate change.

A second issue arises from confidentiality issues. Canadian law prohibits the publishing of statistics that can be used to identify a particular individual or firm. For instance, if there is only one steel manufacturer in the basin, then data identifying any aspect of that firm must be suppressed. Similar rules apply for individuals. Aggregate data for a province is often, but not always, available. Hence it is sometimes impossible to find public data that can identify production in a basin. One is left with making strong assumptions about the spatial distribution of production and populations.

On the other hand, an advantage of a basin analysis is that we do not have to worry about strong feedback effects. That is, shortages of water in the SSRB are unlikely to affect national populations. Hence national population forecasts can safely ignore basin-specific factors. Furthermore, world prices for commodities are unlikely to change with agricultural production in the SSRB. Thus we can treat certain national or international variables as constants that are exogenously determined and simply model activities in the SSRB as responding to those variables. This allows us to safely model basin activities to broader, world scenarios.

10.7 Applying a Scenario Framework

To make the analysis more tractable we focus on a small number of scenarios that we believe provide maximum insight. These also form a template for future research. As described prior, we chose to use three dimensions of analysis. In each scenario, we could use a simplified, dove-tailed physical-socioeconomic approach (Section 10) or rely on the WUAM model to identify water supply “bottlenecks” where demands for water (at the prevailing marginal prices) would not be met without adjustments to infrastructure and policy. If these bottlenecks are identified, one can also attempt to assess the economic cost of altering water withdrawals to meet available supplies. Economic costs as such can be identified in two ways. First, we could use the input-output (IO) approach (Section 7) to identify sectors most directly affected and trace through the impact of any water shortages. Secondly, we could use marginal (or average) valuations for water to assess direct impacts upon water users. One can also identify the degree of uncertainty we judged for each scenario; this would be used not only to interpret results but also identify possible future research.

10.7.1 *Business-As-Usual*

The first dimension identified was *business-as-usual*. Here, we do not envision any significant policy changes or significant feedback from climate changes into water demands. Population growth, production activities, water pricing and allocations are expected to broadly follow past trends. We focus on changes in water supplies interacting with economic and population growth. The aim is to assess to what extent current practices and growth patterns, interacting with changing hydrological factors, create episodes of water stress. We seek to identify the locations and degree of water stress as well as opportunities for greater water utilization, as well as sectors or communities at risk and the degree of risk. The *business as usual* approach helps form a benchmark for further analysis.

Climate change is expected to change the volume, timing and intensity of in-stream water flows. The primary aim of these scenarios is to forecast instream shortages and their impact on key water users. Three subsidiary scenarios are thus envisioned, with the data for these scenarios coming from the down-scaled GCM models:

- A “best guess” forecast of mean supply. This forms the base case and is used to identify sectors at risk.
- A “low risk” scenario for a (moderately) lower supply.
- An “extreme risk” scenario for highly compromised flows.

Changes in population and economic activity will evidently change the demand for water in the SSRB. Demand for water, both as withdrawals and for *in-situ* activity, will likely increase over the foreseeable future. The primary aim of the scenarios is to identify how changing demand will affect water surpluses or deficits. The primary demand factors are:

- Population in/outflow and internal re-distributions from rural to urban centers
- Economic growth continuing based on little change to the input-output composition of production

Data for population will come from national and provincial forecasts with appropriate down-scaling to the SSRB. Statistics Canada has population projections under a number of different scenarios for the period 2000 to 2026 (see George *et al.*, 2001). At this point, we assume that economic growth will follow broad historical trends. We also assume that the composition of production will follow past trends and that water shortages will not affect the scale or composition of production to a great extent. Data for this analysis comes from Kulshreshtha and Thompson (2004).

10.7.2 *Economic Dynamism*

The second dimension explores scenarios related to economic development. Water use, like energy use, is often a critical component of production. Any significant increase in economic activities will tend to simultaneously increase water demands. The scenarios given here are intended to gauge the ability of the watershed to accommodate increased economic activities in the presence of climate change. The drivers for economic development can include increased migration to the West (inter-provincial or international), increased international demand for water-intensive production (such as agriculture and livestock), or increased investments in irrigation capacity (particularly in Saskatchewan). Four subsidiary scenarios are envisioned:

- Economic growth and population frozen at 1996 levels
- Increased population growth (using Statistics Canada projections)
- Increased irrigation demand due to climate change
- Increased demand for agricultural products induced by changes in export opportunities

The first scenario is an attempt to decompose any identified water stresses into separate components. One component is due to climate change and the other due to economic growth. The second scenario traces the effects of population growth and attendant economic activities on water resources. The distribution of populations within and without the basin will be important. The third scenario considers the impact of increasing irrigation that might result from changes in growing conditions on the Prairies. The fourth considers how the *virtual trade in water* might provide economic opportunities in the basin if other growing areas (like the American Midwest) suffer severe water shortages. This is an example of how we want to identify potential benefits as well as potential constraints.

10.7.3 *Ecological Sensitivity*

The third dimension considers changes in the policy environment that governs water users. We split this dimension into three areas. The first are changes in water use efficiency. Improvements in water use follow from technical innovation and investments, as can be driven by an increased price of water. Scenarios include:

- Technical improvements in irrigation efficiencies (given current growth in area irrigated)
- Improved water use and recycling in commercial, industry and municipal applications

The aim of these scenarios is to assess the ability of technical innovation to offset climate change. Of special interest is whether or not current technologies or trends in technical efficiencies are sufficient to offset climate change. If not, then more intrusive policy initiatives need to be considered.

The second area considers changes in water use induced by institutional changes that reflect an increasing awareness of the instream benefits of water. Scenarios might include:

- Changes in minimum flow requirements to preserve ecological objectives
- Investments in water reservoirs, monitoring and diversion capabilities to offset anticipated future shortages

The aim of these scenarios above is to assess the impact that particular regulatory policies may have on water resources. Again, we do not intend these to offer specific policy recommendations at this point.

The third area considers changes in water use induced by institutional changes that reflect the management of water resources. These policy initiatives include:

- Introduction of water trading as a means of instituting economic efficiency
- Changes in water licensing arrangements within large user groups
- Changes in inter-provincial apportionments

The aim of these scenarios above is to identify some of the mechanisms that may affect water users in different ways.

10.11 Summary of Scenarios and Conclusions

This section identifies the scenarios considered to assess interaction between anticipated water supplies and population/economic growth within the SSRB. Table 10.1 to follow summarizes the list of potential scenarios, based on the arguments set out above, with assumptions stated in terms of climate, population, economic growth and policy initiative. In addition to these assumptions, there remain not only the problems faced in downscaling to the basin level, but also the inherent uncertainties that follow from any attempt to forecast complex systems such as the climate and hydrological cycles. Additional uncertainties are added when one attempts to forecast forward-looking human behaviour. The use of these scenarios, and their results, are as such being presented as a pragmatic planning tool. The assumptions forecast over the fifty year period, from 1996 to 2046, are likely to be continually revisited, with new scenarios added and some further refined, with methods of measurement, analysis and monitoring assumed to improve.

	TITLE	ASSUMPTIONS (1996 to 2046)			
		CLIMATE	POPULATION	ECONOMIC GROWTH	POLICY INITIATIVE
1	**BAU-MEAN**	Forecast means	Statistics Canada Medium Immigration Assumption	Forecast growth consistent with past trends and population	1996 Rules
2	**BAU-LOW RISK**	Low supply 5%	Statistics Canada Medium Immigration Assumption	Forecast growth consistent with past trends and population	1996 Rules
3	**BAU-HIGH RISK**	Low supply 1%	Statistics Canada Medium Immigration Assumption	Forecast growth consistent with past trends and population	1996 Rules
4	**NO GROWTH**	Forecast means	1996 data	1996 data	1996 Rules
5	**HIGH SSRB POPULATION GROWTH**	Forecast means	Statistics Canada High Immigration to the WEST	Consistent with Population growth	1996 Rules
6	**HIGHER IRRIGATION DEMAND**	Forecast means	Statistics Canada Medium Immigration Assumption	Consistent with Population growth and increased Agricultural Production	1996 Rules
7	**INTERNATIONAL DEMAND**	Forecast means	Statistics Canada Medium Immigration Assumption	Consistent with Population growth and increased Agricultural Production	1996 Rules
8	**TECHNICAL EFFICIENCY in IRRIGATION**	Forecast means	Statistics Canada Medium Immigration Assumption	Consistent with Population growth and increased Agricultural Production	1996 Rules
9	**TECHNICAL EFFICIENCY in INDUSTRY**	Forecast means	Statistics Canada Medium Immigration Assumption	Consistent with Population growth and changes in Agricultural Production	1996 Rules
10	**MINIMUM FLOW**	Forecast means	Statistics Canada Medium Immigration Assumption	Production consistent with higher minimum flow requirements	Higher minimum flow requirements
11	**EFFICIENT PRICING**	Forecast means	Statistics Canada Medium Immigration Assumption	Production consistent with marginal cost pricing	Marginal Cost Pricing
12	**INTERPROVINCIAL APPORTIONMENT**	Forecast means	Statistics Canada Medium Immigration Assumption	Production consistent with changes in water supply	Reallocation of water among Prairie Provinces
13	**WATER TRADING (IRRIGATION)**	Forecast means	Statistics Canada Medium Immigration Assumption	Production consistent with changes in water pricing	Introduction of Water Trading in Irrigation Sector

Table 10.1 *Summary of Scenarios*

References:

George, M.V., S. Loh, R. B.P. Verma, and Y. E. Shin, 2001. *Population Projections for Canada, Provinces and Territories 2000-2026*, Statistics Canada

Jannsen, M., 1998. *Modelling Global Change: The Art of Integrated Assessment Modelling*, Advances in Ecological Economics, Edward Elgar, Cheltenham UK.

Kulshreshtha, S. N., G. Pearson, G. Brown, S. Roy and W. Thompson, 2001. Cost Recovery Criteria under Multiple Goods Production: A Case of Public and Private Goods in Southwest Saskatchewan Water Supply Systems. *Canadian Water Resources Journal*, 26(3): 283-305.

Kulshreshtha S. N., G. and W. Thompson, 2004. *South Saskatchewan River Basin Input-Output, Population, and Water Use Model: Technical Documentation,* South Saskatchewan River Basin Study*,* Climate Change Impacts and Adaptation Program.

Lins H. F., D. M. Wolock and G. J. McCabe, (1997). Scale and Modeling Issues in Water Resources Planning, *Climatic Change,* 37(1): 63-88.

11 Dove-tailed Physical and Socioeconomic Results in the SSRB

11.1 Introduction

The purpose of this report is to identify, using broad strokes, the risks and challenges facing the human and aquatic communities in the SSRB that derive from anticipated climate change and economic growth. The approach taken here is to bring together the supply and demand for water in a simple, straight forward method that is easily understood. Our intention is to provide analysis as a guide to policy frameworks rather than a water balance analysis suitable for water managers.

Two driving factors are considered. First are the hydrological impacts of climate change that might occur for the SSRB as a whole and for individual sub-basins within the SSRB. These impacts result from possible changes to temperature, precipitation, and resulting evapotranspiration (evaporation from water bodies and soil and transpiration from plants). The second driver is growth in human activities that create demand for water resources. Growth can come from expansion of population, increases in economic activities, and/or increases in per capita water use. A third driver, minimum inflow needs (IFN) for ecological sustainability, is also important and included in our analysis.

Our primary focus is to identify the extent and magnitude of potential water shortages (or gains) across the SSRB that may emerge with anticipated climate and socioeconomic changes in the future. We focus on scenarios. These are not forecasts of the future. Rather, they offer possible plausible futures that allow us to identify particular ramifications based on reasonable projections from the current state. They guide our understanding.

We build our scenarios by first identifying changes in the hydrology of the basin under a suite of climate change scenarios that capture trends in global warming. This is the supply side for water. The downscaled climate models suggest a risk of significant reductions in water availability. However, the suite of models also incorporates little or no change as well so the possibility of significant decreases remains uncertain. These potential changes are not uniform across the SSRB though they are consistent. In general, the foothills of the Rocky Mountains will not dry out as much as the prairies regions. As a fraction of the current water regime, the models suggest that changes in streamflows in individual basins can range from -32 percent to +12 percent. The average of the scenarios suggests a decrease in net water of about 9 percent. Though significant, this need not be catastrophic.

We then add socio-economic growth scenarios (the demand side) to the climate change scenarios to get a total impact on water resources. One primary result is that growth in non-irrigation consumption is unlikely to be a problem. The reason is that the non-irrigation sectors take up only a small fraction of available water (currently around 2.5 percent). This is overshadowed by the potential climate change effects. Even under the highest growth scenario, non-irrigation consumption of water remains under 6 percent of the 1961-1990 base water regime. In other words, the potential impact of climate change is much greater than potential economic growth in non-irrigation sectors.

Irrigation is, however, much larger than non-irrigation withdrawals and diversions can account for up to 30 percent of available water (based on the 1961-1990 calibration period). This implies that irrigation withdrawals are of potentially greater impact than climate change. It means that irrigation withdrawals can also be seriously threatened by climate change even if non-irrigation demand grows at a slow pace.

We discuss, but do not expressly consider, mitigation of climate change. Mitigation would entail a decrease in human consumption equivalent to the decrease in water supply. However, such a study is properly set within a cost-benefit framework. Rather, we compare climate change to demand growth and to the scale of demand to gauge whether mitigation is possible. In general, climate change is in the same order of magnitude as demand growth. Further, it is about one fifth of current human demands. This suggests mitigation is entirely possible given that irrigation is the greatest portion of demand. Whether irrigation should be reduced to offset water shortages is an important question left for further research.

We also consider monthly flows. Annual results tend to underestimate the impact on mid-summer flows. Although natural flows are highest in the summer, so too are human demands. Climate change can make this worse since summer flows will tend to decrease more than the average yearly flow. More importantly, summer demands are likely to rise significantly since the largest component of demand growth is likely to come from irrigation. The net effect is that summer flows can fall close to, or below, 50 percent of the natural flows. Though this may not indicate that a critical biological threshold has been past, it does suggest that we may be approaching such a threshold.

The layout of the section is as follows. Section 11.2 discusses the supply of water under current and future climate scenarios. Section 11.3 looks at current irrigation and non-irrigation demand relative to current water supplies. Section 11.4 considers future demands in conjunction with future climate. Section 11.5 considers the best and worst case scenarios and Section 11.5 the monthly flows. Section 11.7 concludes.

11.2 Establishing a Net Annual Basin Water Supply

The hydrology of the basin derives from three sets of climate models: the ECHAM model from the Max Plank Institute for Meteorology in Germany, the NCAR model from the National Center for Atmospheric Research in the USA, and the HADLEY model from the Hadley Centre for Climate Prediction and Research in UK. These climate models closely approximated current climatology in their 1961-90 estimates of temperature and precipitation (Töyrä *et al*., 2005).

Future GCM climatology is based on SRES emission scenarios as defined by the IPCC-TGCIA (1999). They describe the possible future concentration and emissions of greenhouse gases. Four main socio-economic trends for the future are defined: A1, A2, B1 and B2. The A1 and B1 trends are the result of global development, while the A2 and B2 focus on more regional growth. The A1 and A2 predict more aggressive growth and higher cumulative emissions, while the B1 and B2 predict emissions will level off with time (IPCC-TGCIA, 1999). The A2 and B2 scenario results for a range of time lines are publicly available and were used for the future climate estimates.

The hydrology of the basin is first calibrated to the climate in the period 1961-90. This is the base period. Using the calibration parameters, future hydrology can be imputed by imposing each climate change scenario on the model and tracking the changes. Each scenario yields a particular precipitation, temperature, and evapotranspiration pattern across sub-basins. Scenarios, both across models and across assumptions about green-house gas accumulations, generate different patterns. This is typical of climate change models as each incorporates slightly different factors and use different solution techniques. We interpret the results as offering an envelope of possibilities. We do not impute any probability to a particular scenario. We interpret the un-weighted average as a measure of central tendency only.

Figure 11.1 below shows the study area as well as the breakdown by sub-basin and nodes. For each node we can find the natural streamflow that would occur in the absence of human withdrawals. This is calculated by adding all human consumption back to measured streamflows. These calculations do not account for changes in land use patterns that would also affect streamflows. For instance, changing land from pasture to urban use can increase the runoff during rain episodes. The natural flow calculations do not account for this difference. Neither does the natural flow calculation account for reservoir evaporation. This is considered a “natural” phenomenon rather than a human demand. Lake Diefenbaker

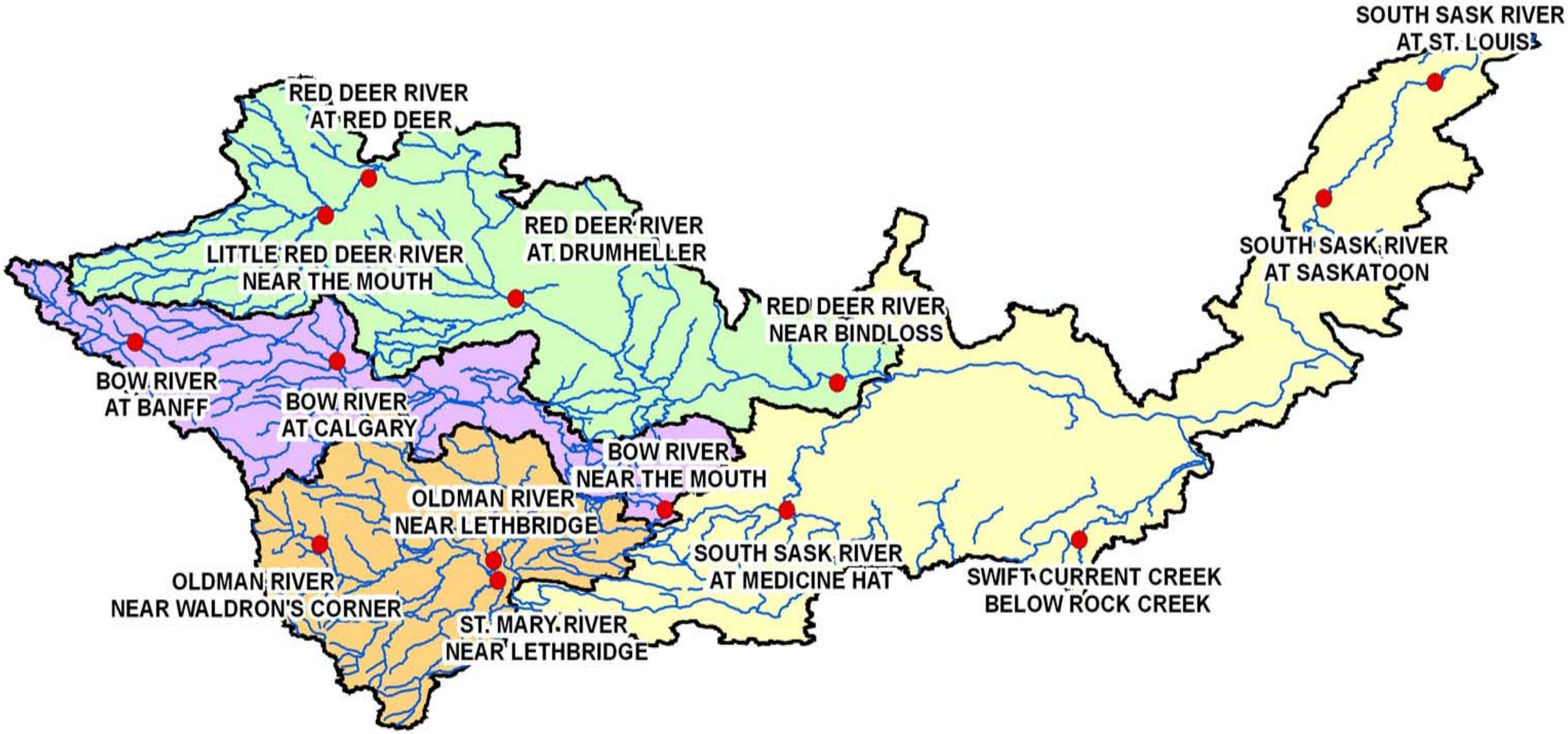

Figure 11.1 *Basin Nodes and Major Sub-Basins*

is a large reservoir and has significant evaporation. This means that modeling flows below the reservoir is complicated and, as reported below, current natural flow for the 1961-90 period differ strongly from modeled flows for the same period. This is not the case for streamflows above the lake.

11.2.1 Annual Natural Flow

Table 11.1 shows the results of the hydrological models under the six climate change scenarios by sub-basin in the SSRB. The modeling data is an average of the monthly flow in cubic meters per second. We convert these to million cubic meters (MCM) per year for summary purposes.

The top part of the table shows the annual naturalized flow of water through each respective hydrographic node. The first row is the current yearly naturalized flow calculated for the base period 1961-1990. The naturalized flows account for all human withdrawals and diversions. Note that current flows at Saskatoon (node HG001) are lower than the flow upstream at Medicine Hat (node AJ001). This appears to be due to Lake Diefenbaker where significant evaporation takes place during the year. The naturalized flows do not account for this dimension of human impact on water flows.

The second row provides the modeled flow for the 1961-1990 calibration period. These differ from the calculated naturalized flows since a perfect calibration is not possible.

Following these are the anticipated flows from the six future climate scenarios. These were calculated by inflating (or deflating) the current naturalized flows by the percent change in modeled flow. For instance, if a future scenario generated a 10 percent reduction in flow relative to the modeled flow, then we reduce the current natural flow by 10 percent to get the scaled future scenario. This change field approach is consistent with the techniques used to calibrate the model in terms of temperature and precipitation.

As modeled, all basins suffer a net reduction in available water based on the average of the six climate scenarios. However, in all sub-basins, there are some climate scenarios that yield an increase in water availability. In general, the ECHA climate scenarios lead to the driest outcomes with the lowest flows. The NCARA scenarios tend to be wettest.

The difference between the wet scenarios and dry can be quite dramatic. For instance, in CB001 (headwaters of the Red Deer River) scenario flows range from a low of 89 MCM to a high of 148 MCM. The current natural flows are 133 MCM for the base period. On average, the scenarios are for 114 MCM which is an average loss of 14 percent. However, water flow may rise by 11 percent or fall by 33 percent depending on the scenario used.

We see a similar pattern in all the sub-basins. The Bow River sees only a minimal gain under the wettest scenario but losses of under 20 percent in the driest. The Oldman River tends to see slightly larger increases in the wettest scenario and smaller decreases in the driest. The South Saskatchewan, as the downstream collector, gets an average of these results with a potential rise of 7 percent under the wet scenario and a decrease of 14 percent under the dry.

As a measure of dispersion, we also report the difference between the wettest and driest scenarios as a ratio to the average scenario. For the Red Deer River, the difference between the wet and dry scenarios is around 50 percent of the average scenario. For the Bow and Oldman rivers, the dispersion is about 20-25 percent. For the South Saskatchewan the dispersion is higher at around 30 percent. These relatively large differences show two things. First, the climate scenarios, that are the basis for the hydrological modeling,

	RED DEER RIVER				BOW RIVER			OLDMAN RIVER				SOUTH SASKATCHEWAN RIVER			
	CB001	**CC002**	**CE001**	**CK004**	**BB001**	**BH004**	**BN012**	**AA023**	**AE006**	**AD007**	**AG006**	**AJ001**	**HD036**	**HG001**	**HH001**
NATURALIZED FLOWS (1961-1990)	**133**	**1352**	**1593**	**1665**	**1241**	**2853**	**3841**	**385**	**879**	**3286**	**3292**	**7099**	**32**	**6445**	**6264**
MODELED FLOWS	**346**	**1853**	**2562**	**3014**	**1079**	**2426**	**4198**	**358**	**641**	**3188**	**3892**	**7857**	**102**	**11382**	**11524**
CLIMATE SCENARIO															
echa21a	89	941	1082	1131	1099	2318	3094	316	750	2838	2832	5906	26	5026	4877
echb21b	99	1028	1197	1247	1096	2353	3143	316	755	2845	2845	5987	27	5204	5049
hada21a	113	1181	1381	1454	1241	2665	3545	378	886	3333	3283	6941	32	6114	5930
hadb21b	97	1044	1193	1248	1181	2511	3337	360	834	3142	3131	6486	29	5555	5391
ncara21a	148	1483	1781	1878	1253	2852	3896	402	939	3513	3532	7521	35	6985	6777
ncarb21b	137	1397	1647	1715	1225	2764	3760	388	897	3361	3304	7164	32	6513	6329
CLIMATE SCENARIOS															
AVERAGE	**114**	**1179**	**1380**	**1446**	**1182**	**2577**	**3462**	**360**	**844**	**3172**	**3155**	**6667**	**30**	**5900**	**5726**
(max-min)/avg	0.52	0.46	0.51	0.52	0.13	0.21	0.23	0.24	0.22	0.21	0.22	0.24	0.30	0.33	0.33
avg/current	0.86	0.87	0.87	0.87	0.95	0.90	0.90	0.94	0.96	0.97	0.96	0.94	0.96	0.92	0.91
GAIN/LOSS[1]															
AVERAGE GAIN/LOSS	**-19**	**-173**	**-213**	**-220**	**-59**	**-276**	**-378**	**-25**	**-36**	**-114**	**-137**	**-431**	**-1**	**-546**	**-538**
as a fraction of NATURAL FLOW	-0.14	-0.13	-0.13	-0.13	-0.05	-0.10	-0.10	-0.06	-0.04	-0.03	-0.04	-0.06	-0.04	-0.08	-0.09
MAXIMUM FLOW	**15**	**131**	**188**	**213**	**11**	**0**	**55**	**17**	**60**	**227**	**240**	**423**	**4**	**540**	**513**
as a fraction of NATURAL FLOW	0.11	0.10	0.12	0.13	0.01	0.00	0.01	0.04	0.07	0.07	0.07	0.06	0.12	0.08	0.08
MINIMUM FLOW	**-44**	**-411**	**-511**	**-535**	**-145**	**-535**	**-747**	**-69**	**-130**	**-448**	**-460**	**-1192**	**-5**	**-1420**	**-1386**
as a fraction of NATURAL FLOW	-0.33	-0.30	-0.32	-0.32	-0.12	-0.19	-0.19	-0.18	-0.15	-0.14	-0.14	-0.17	-0.17	-0.22	-0.22

[1] Gain/Loss calculated as (Flow in Climate Scenario – Natural Flow)

Table 11.1 *Annual Water Flow (AWF) by Climate Scenario for SSRB Sub-Basins*

	RED DEER RIVER				BOW RIVER			OLDMAN RIVER				SOUTH SASKATCHEWAN RIVER			
	CB001	**CC002**	**CE001**	**CK004**	**BB001**	**BH004**	**BN012**	**AA023**	**AE006**	**AD007**	**AG006**	**AJ001**	**HD036**	**HG001**	**HH001**
NATURAL BWS (1961-1990)	**133**	**1219**	**241**	**72**	**1241**	**1612**	**988**	**385**	**879**	**2022**	**6**	**-34**	**32**	**-2350**	**-182**
MODELED BASE BWS	**346**	**1507**	**709**	**452**	**1079**	**1346**	**1772**	**358**	**641**	**2189**	**704**	**-233**	**102**	**409**	**142**
CLIMATE SCENARIO															
echa21a	89	852	141	49	1099	1219	775	316	750	1772	-6	-20	26	-2038	-148
echb21b	99	929	169	50	1096	1257	789	316	755	1775	0	-1	27	-2056	-155
hada21a	113	1068	200	73	1241	1424	881	378	886	2068	-49	113	32	-2312	-185
hadb21b	97	947	149	55	1181	1330	826	360	834	1948	-10	17	29	-2208	-164
ncara21a	148	1335	298	97	1253	1600	1044	402	939	2172	19	94	35	-2450	-208
ncarb21b	137	1260	250	68	1225	1539	997	388	897	2076	-58	100	32	-2398	-184
CLIMATE SCENARIOS															
AVERAGE	**114**	**1065**	**201**	**65**	**1182**	**1395**	**885**	**360**	**844**	**1968**	**-17**	**50**	**30**	**-2244**	**-174**
(max-min)/avg	0.52	0.45	0.78	0.74	0.13	0.27	0.30	0.24	0.22	0.20	-4.36	2.62	0.30	-0.18	-0.34
avg/current flow	0.33	0.71	0.28	0.14	1.10	1.04	0.50	1.01	1.32	0.90	-0.02	-0.22	0.30	-5.49	-1.22
GAIN/LOSS															
AVERAGE GAIN/LOSS	**-19**	**-154**	**-40**	**-7**	**-59**	**-217**	**-103**	**-25**	**-36**	**-54**	**-23**	**85**	**-1**	**107**	**7**
as a fraction of BASE BWS	-0.14	-0.13	-0.17	-0.10	-0.05	-0.13	-0.10	-0.06	-0.04	-0.03	-3.92	-2.48	-0.04	-0.05	-0.04
MAXIMUM GAIN (or min loss)	**15**	**116**	**57**	**25**	**11**	**-12**	**56**	**17**	**60**	**150**	**13**	**147**	**4**	**313**	**33**
as a fraction of BASE BWS	0.11	0.10	0.24	0.34	0.01	-0.01	0.06	0.04	0.07	0.07	2.11	-4.29	0.12	-0.13	-0.18
MINIMUM GAIN (or max loss)	**-44**	**-367**	**-100**	**-24**	**-145**	**-393**	**-213**	**-69**	**-130**	**-250**	**-63**	**15**	**-5**	**-100**	**-27**
as a fraction of BASE BWS	-0.33	-0.30	-0.41	-0.33	-0.12	-0.24	-0.22	-0.18	-0.15	-0.12	-10.62	-0.43	-0.17	0.04	0.15

Table 11.2 *Basin Water Supply (BWS) by Climate Scenario for SSRB Sub-Basins*

are quite different in their implications for temperature and precipitation. Second, the hydrological implications at the basin level are sensitive to the choice of scenario: change the scenario and you change the outcomes dramatically. This uncertainty of which climate scenario to use makes predicting future flows very difficult. As such, these scenario outcomes are viewed as potential guides to future outcomes and not as predictions *per se*. Although the climate change scenarios do not (and cannot) predict catastrophic changes in the SSRB, they do point to a risk of significant reductions in water.

11.2.2 Basin Water Supply

We can quantify the net hydrological effects in each sub-basin by calculating the difference between the upstream node(s) and the basin (downstream) node. There is no adjustment necessary for headwaters since there is no upstream node. This *basin water supply* (BWS) accounts for all precipitation, evaporation, and net transfers into ground water that occurs within each sub-basin. Whatever is unused (either by humans or nature) flows downstream. The BWS provides a measure of the available water that can be used for human or ecological purposes and is comparable to water withdrawals/consumption data.

Annual data is reported in Table 11.2. For instance, node CE001 (Red Deer River at Drumheller) has a downstream flow of 1593 MCM and an upstream flow of 1352 MCM coming from CC002 (as taken from Table 11.1). Hence the net new contribution to water to the river is the difference of 241 MCM. We do this calculation for each node and for each scenario.

As with the flow data, virtually all basins see a net decrease in available water under the average of scenarios. The exception is in the South Saskatchewan where BWS might actually rise a small amount. However, the area incorporating the Diefenbaker dam has negative BWS. This is presumably due to the evaporation losses in the Gardiner reservoir. Also, the modeling of naturalized water flow is difficult since water in the reservoir is used for hydro-power generation. This means that measured winter flows at Saskatoon are higher in the winter whereas naturalized flows are highest in the late spring. This discrepancy makes the model outcomes below the Diefenbaker node less reliable. Since measured BWS is negative in this area (less water leaves the basin than enters) the rise in BWS merely offsets the negative BWS.

Again, there is much variability across the scenarios with NCAR and HADLY scenarios wetter than the base period. Note also that most of the water derives from areas closer to the mountains with only small net contributions from the prairies. This is consistent with the view that the prairies are a dry climate.

We can further aggregate the BWS into the four major river basins (Table 11.3). On average, the SSRB had a modeled basin water supply in the base period of 6264 MCM. This was the total amount of water supplied by all contributing areas in the SSRB. The average of the scenarios yields a decrease of around 538 MCM. The maximum gain is 513 MCM with the maximum loss of 1386 MCM. This suggests that basin water supply may rise by 8 percent or fall by 22 percent with an average loss of 9 percent. This is a dispersion of around 33 percent.

As noted above, the scenarios suggest that all river systems may see a rise in available water under the wettest scenarios. However, the scenarios suggest that the South Saskatchewan River would see a nominal increase in BWS even under the dry scenario. On average, it sees a rise though this is merely offsetting somewhat the negative BWS. Nonetheless, the net decrease in the other basins leads to a net decrease in the SSRB as a whole.

NET WATER SUPPLY (MCM)	RD	BR	OM	SSR	SSRB
NATURAL BWS (1961-1990)	**1665**	**3841**	**3292**	**-2535**	**6264**
CLIMATE SCENARIO					
echa21a	1131	3094	2832	-2179	4877
echb21b	1247	3143	2845	-2185	5049
hada21a	1454	3545	3283	-2353	5930
hadb21b	1248	3337	3131	-2325	5391
ncara21a	1878	3896	3532	-2529	6777
ncarb21b	1715	3760	3304	-2451	6329
AVERAGE CLIMATE SCENARIO	**1446**	**3462**	**3155**	**-2337**	**5726**
as a fraction of BASE BWS	0.87	0.90	0.96	0.92	0.91
DRIEST CLIMATE SCENARIO	**1878**	**3896**	**3532**	**-2179**	**6777**
as a fraction of BASE BWS	1.13	1.01	1.07	0.86	1.08
WETTEST CLIMATE SCENARIO	**1131**	**3094**	**2832**	**-2529**	**4877**
as a fraction of BASE BWS	0.68	0.81	0.86	1.00	0.78
AVERAGE GAIN/LOSS	**-220**	**-378**	**-137**	**198**	**-538**
as a fraction of BASE BWS	-0.13	-0.10	-0.04	0.08	-0.09
MAXIMUM GAIN (or min loss)	**213**	**55**	**240**	**355**	**513**
as a fraction of BASE BWS	0.13	0.01	0.07	0.14	0.08
MINIMUM GAIN (or max loss)	**-535**	**-747**	**-460**	**5**	**-1386**
as a fraction of BASE BWS	-0.32	-0.19	-0.14	0.00	-0.22

Table 11.3 *Gains/Losses due to Climate Change by Major Sub-Basin*

11.3 Human Withdrawals and Consumption

We can interpret the change (gain or loss) in water under each climate scenario as a “net demand” on the current water regime that is imposed by climate change. That is, a reduction in BWS of 100 MCM is equivalent to an increase in human consumption of 100 MCM. This allows us to aggregate anticipated human demand with modeled climate change to get a measure of potential net “new” demands in each basin. We can use this information to identify the relative magnitude of climate change and/or human activities on the hydrology of the SSRB. It also allows us to gauge whether economic and population growth is consistent with preserving ecological integrity in the basin or whether mitigation of climate change is possible.

11.3.1 Basin Withdrawals and Consumption

Current water withdrawals and consumption can be mapped into each sub-basin (see Table 11.4). Non-irrigation demands derive from municipal, industrial and mining activities, livestock watering, and thermal-electric generation. See Bruneau (2006) *South Saskatchewan River Basin Water Withdrawal Forecasts and Scenarios* for details of the estimation process as well as finer detail by hydrographic node. Note, however, that we do not separate irrigation demand into separate nodes since this information was not available. Irrigation is aggregated into the four sub-basins. This precludes a more disaggregated analysis.

1996 WITHDRAWALS and CONSUMPTION (MCM)	RD	BR	OM	SSR	SSRB
CURRENT NATURAL FLOWS (1961-90)	**1,665**	**3,841**	**3,292**	**6,264**	**6,264**
CURRENT NATURAL BWS (1961-90)	1,665	3,841	3,292	-2,535	6,264
NON-IRRIGATION WITHDRAWALS	89	196	64	165	514
IRRIGATION DIVERSIONS	613	932	499	478	2,522
TOTAL HUMAN WITHDRAWALS	**702**	**1128**	**563**	**643**	**3,036**
NON-IRRIGATION CONSUMPTION	41	55	26	32	155
IRRIGATION CONSUMPTION	421	776	343	388	1,928
TOTAL HUMAN CONSUMPTION	**462**	**831**	**369**	**420**	**2,083**

Source: Joel F. Bruneau (2006), South Saskatchewan River Basin Water Withdrawal Forecasts and Scenarios.

Table 11.4 *Withdrawals and Consumption by Major Sub-Basin (1996)*

In 1996, total non-irrigation withdrawals were 514 MCM. This constituted 8.2 percent of total water supply in the basin. The consumption of water from non-irrigation users is estimated at 155 MCM. This 155 MCM constitutes only 2.5 percent of total natural water supply available in the SSRB for the base period 1961-90.

In the SSRB, irrigation withdrawals are much higher than non-irrigation demands. In 1996, irrigation withdrawals in the SSRB were 2,522 MCM whereas non-irrigation withdrawals were only 514 MCM. Irrigation diversions, then, constitute about 40 percent of SSRB water supplies.

The low fraction of water used in non-irrigation demands suggests that human impact on the available water supply is not driven primarily by non-irrigation demand *per se*. Rather, the impact derives from irrigation demand as well as changes in natural flows created by reservoirs and drainage of wetlands. Direct consumption by human and livestock populations constitutes only a small share of water resources and so only a small component of water stress.

Of course, not all water that is diverted for irrigation use is lost to the river. In Alberta, the average return flow for the Bow River is 36 percent and 17 percent in the Oldman River. This is about 26 percent on average. Accounting for the net flow would decrease the net impact of irrigation to about 1,928 MCM overall or 31 percent of the current water regime. Note that data from Alberta Irrigation shows that 1996 was drier than average with gross diversions in the Oldman River 22 percent above the long-run 1976-2004 average and up 3 percent on the Bow River (see Bruneau (2006), *South Saskatchewan River Basin Water Withdrawal Forecasts and Scenarios* for more details). In total, withdrawals from all sources in 1996 affected 48 percent of the water in the basin while consumption removed 33 percent of total available water (based on 1961-1990 base values).

11.3.2 Net Basin Flow

We can look at this in a slightly different way than just a basin-by-basin approach. We can look at current natural flows after accounting for human consumption at each point in the river. We do this by taking the flow at a point and subtracting all upstream human consumption. This tells us how much water remains in the river.[1] Table 11.5 shows these calculations. The first row gives the current natural flow. The second row gives consumption from all sources. The adjusted flow is the difference between current natural flow and human consumption. If we add climate change as a "consumer" of water, then we can account for it as well.

	RD	BR	OM	SSR
CURRENT NATURAL FLOW (1961-90)	**1665**	**3841**	**3292**	**6264**
UPSTREAM CONSUMPTION	**462**	**831**	**369**	**2083**
as a share of natural flow	0.28	0.22	0.11	0.33
Flow Adjusted for Irrigation and Non-irrigation Consumption	**1203**	**3009**	**2923**	**4180**
as a share of natural flow	0.72	0.78	0.89	0.67
AVG CLIMATE CHANGE NET GAIN/LOSS	**-220**	**-378**	**-137**	**-538**
as a share of natural flow	-0.13	-0.10	-0.04	-0.09
Flow Adjusted for Irrigation and Non-irrigation Consumption and Climate Change	**983**	**2631**	**2786**	**3642**
as a share of natural flow	0.59	0.68	0.84	0.58

Table 11.5 *Adjusted Flow by Major Sub-Basin (1996)*

For the Red Deer River, current flow is 1665 MCM. Consumption from all sources in 1996 in the sub-basin was 462 MCM. Net flow, accounting for the sub-basin consumption, falls to 1203 MCM (or 72 percent of natural flows). We do this for each basin. Overall, net flow falls in all basins with total flow down to 67 percent of natural flow by the time the river exits below St. Louis on the South Saskatchewan River.

We can also add in the average of the climate change scenarios. As noted above, the average of the scenarios reduces water flow in each basin. Compared to human consumption though, climate change is small. That is, the loss in net supply is smaller, by an order of magnitude, than total human consumption demand. For example, in the Red Deer River, climate change could reduce water supply by 220 MCM. Human consumption from irrigation and non-irrigation sectors is 462 MCM, over twice the climate change effect. Overall, the climate change effect of 538 MCM is about one quarter of the human demand for water.

11.3.3 Discussion

This difference between human consumption and climate change "consumption" suggests that mitigation of climate change is quite possible. The size of human demand relative to climate change is large. In the Red Deer, Bow, and Oldman Rivers, human consumption is currently more than twice the average anticipated climate "consumption". In the SSRB as a whole it is four times as much.

We could reduce human demands to absorb climate change so as to maintain current water flows. The primary question is whether we should. From a monetary point of view, the costs of reducing demand may not be worth the reduction (and hence impact) of reduced water flows. A full cost-benefit analysis

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[1] Note that the values here and below are based on the flow leaving the sub-basin and are not necessarily indicative of stream flow in upstream nodes. In general, since irrigation takes place in the downstream areas, actual flows in the upstream stretches will be higher.

would be required. Nonetheless, we can get a ballpark figure for the direct costs such an endeavour could cost. For instance, suppose irrigators were to absorb the entire loss in water supply by reducing their consumption one-for-one. The direct cost of reducing water withdrawals by irrigators is estimated to be around $0.11 per cubic meter or $110,000 per MCM (taken from Bruneau (2004), *Economic Value of Water in the South Saskatchewan River Basin*). This is equivalent to a cost of $145,000 per MCM of decreased water consumption (assuming a consumption rate of 76 percent in irrigation). If we "replace" the lost water (538 MCM) by reducing irrigation consumption, then the direct cost to irrigators in terms of lost net revenues is about $78M. Note that indirect costs to industries that rely on irrigation would be much higher. The GDP for Saskatchewan and Alberta in 1996 was $123B while SSRB GDP was $69B (see Kulshreshtha and Thompson (2004) *South Saskatchewan River Basin Input-Output, Employment and Water Use Model: Technical Documentation)*. In other words, we can mitigate the effects of climate change on the water supply for less than 0.11 percent of local GDP. This does not seem impossible. Whether it is a useful, or desirable, way to spend $78M is an open question.

11.4 Growth and Climate Change Effects by Major Sub-Basin

We now turn to anticipated economic growth in conjunction with anticipated climate change. The goal is to see whether economic growth can be sustained by the future water supply or whether ecological integrity is threatened by these joint processes. A further aim is to assess the relative magnitude of climate change and economic growth.

There are three points of comparison are made and taken up below:

1. The first is to consider future water supply with current water demand. This identifies the effect climate change might have on our ability to manage current demands. It also isolates the effect of climate on future water stress.
2. The second is to consider future demand as a share of current water resources. This identifies stresses on water resources that derive purely from economic growth.
3. The third is to consider both future demand and supply to identify potential future water stresses.

11.4.1 Growth in Consumption

There are three growth scenarios used to anticipate non-irrigation demands (see Table 11.6). See Bruneau (2006) for the details of the growth scenarios for irrigation and non-irrigation withdrawals and consumption.

The LOW growth scenario assumes low population and economic growth and slower (or negative) growth in per capita withdrawals. Irrigation is assumed to hold at current levels. The MEDIUM growth scenario assumes moderate population and economic growth with little change in per capita withdrawals. Irrigation grows moderately with irrigation area and water applications rising while return flows fall. The HIGH scenario assumes fast population and economic growth and potential increase in per capita withdrawals. Irrigation grows more quickly although it stays within current legislated limits on withdrawals.

Note that that the direct effect of climate on consumption demand is entirely ignored. That is, we know that if climate change raises average temperatures, then the demand for water would rise above and beyond that implied through growth in the size of user groups would suggest. For instance, a rise in temperature will raise livestock watering requirements in the future above those assumed for current consumption. Hence future consumption in livestock watering would reflect both herd growth but also increased water requirements. We ignore this climate-induced effect since, as we show below, total consumption from non-irrigation demand is only a small share of total water supply and so precise estimates of future consumption are not critical to an overall assessment of water risks. On the other hand, this climate induced effect is likely to be much more important in the irrigation sector. However, there is currently little research identifying this effect.

The growth scenarios are presented in Table 11.6. Also presented are the shares of the individual components as a share of current water flow or of the average of the potential future water flows. This provides a sense of magnitude.

	RD	BR	OR	SSR	SSRB
CURRENT NATURAL FLOW (MCM)	**1665**	**3841**	**3292**	**6264**	**6264**
AVERAGE CLIMATE SCENARIO (MCM)	**1446**	**3462**	**3155**	**5726**	**5726**
NON-IRRIGATION CONSUMPTION (1996)	**41**	**55**	**26**	**32**	**155**
2046 LOW GROWTH	**70**	**89**	**36**	**62**	**258**
as a fraction of BASE FLOW	0.042	0.023	0.011	0.010	0.041
as a fraction of AVG CLIMATE SCENARIO	0.048	0.026	0.012	0.011	0.045
2046 MED GROWTH	**84**	**114**	**41**	**74**	**313**
as a fraction of BASE FLOW	0.050	0.030	0.013	0.012	0.050
as a fraction of AVG CLIMATE SCENARIO	0.058	0.033	0.013	0.013	0.055
2046 HIGH GROWTH	**99**	**147**	**47**	**88**	**380**
as a fraction of BASE FLOW	0.059	0.038	0.014	0.014	0.061
as a fraction of AVG CLIMATE SCENARIO	0.068	0.042	0.015	0.015	0.066
IRRIGATION CONSUMPTION (1996)	**421**	**776**	**343**	**388**	**1928**
2046 LOW GROWTH	**421**	**776**	**343**	**388**	**1928**
as a fraction of BASE FLOW	0.253	0.202	0.104	0.062	0.308
as a fraction of AVG CLIMATE SCENARIO	0.291	0.224	0.109	0.068	0.337
2046 MED GROWTH	**541**	**921**	**440**	**466**	**2368**
as a fraction of BASE FLOW	0.325	0.240	0.134	0.074	0.378
as a fraction of AVG CLIMATE SCENARIO	0.374	0.266	0.139	0.081	0.414
2046 HIGH GROWTH	**581**	**1009**	**473**	**510**	**2573**
as a fraction of BASE FLOW	0.349	0.263	0.144	0.081	0.411
as a fraction of AVG CLIMATE SCENARIO	0.402	0.291	0.150	0.089	0.449
TOTAL CONSUMPTION (1996)	**462**	**831**	**369**	**420**	**2083**
as a fraction of BASE FLOW	0.278	0.216	0.112	0.067	0.333
as a fraction of AVG CLIMATE SCENARIO	0.320	0.240	0.117	0.073	0.364
2046 LOW GROWTH	**491**	**865**	**379**	**450**	**2186**
as a fraction of BASE FLOW	0.295	0.225	0.115	0.072	0.349
as a fraction of AVG CLIMATE SCENARIO	0.340	0.250	0.120	0.079	0.382
2046 MED GROWTH	**625**	**1035**	**481**	**540**	**2681**
as a fraction of BASE FLOW	0.375	0.270	0.146	0.086	0.428
as a fraction of AVG CLIMATE SCENARIO	0.432	0.299	0.153	0.094	0.468
2046 HIGH GROWTH	**680**	**1156**	**520**	**598**	**2953**
as a fraction of BASE FLOW	0.408	0.301	0.158	0.095	0.472
as a fraction of AVG CLIMATE SCENARIO	0.470	0.334	0.165	0.104	0.516

Source of consumption growth: Joel F. Bruneau (2006), *South Saskatchewan River Basin Water Withdrawal Forecasts and Scenarios*

Table 11.6 *Total Consumption by Economic Groups by Major Sub-Basin (2046)*

Consider each of the different growth scenarios. Looking only at non-irrigation sectors we see that consumption almost doubles in each region even in the low growth scenario. However, as a fraction of the base period supply of water in each basin, consumption does not exceed 5 percent of water supplies. Even in terms of future water supply, consumption from non-irrigation sources does not exceed 7 percent even under a high growth scenario. This, again, suggests that non-irrigation demand, though contributing to water stress, is not necessarily a significant contributor.

In terms of irrigation demand, however, future growth consumes a large fraction of water resources. For instance, under the medium growth scenario, irrigation consumption rises by 440 MCM for the basin as a whole. This is an increase of 23 percent. This raises the share of water used in irrigation, relative to current supply, from about 31 percent to 38 percent. In terms of the average of future scenarios, the share rises from 34 to 41 percent. This is a large increase in its share. Note that the rise in the share is higher than for non-irrigation demand even though the percentage growth in non-irrigation demand is larger. This emphasizes the point that a small increase in irrigation demand has a large impact on water resources since it absorbs such a large part of current supply.

With low growth, total water demand rises by 103 MCM for the entire basin. By assumption, this is driven solely by non-irrigation demands. The share of available water consumed rises from 33 percent in 1996 to 38 percent in 2046 based on the average of the climate models. With medium growth, total demand rises by 598 MCM while the share of water rises from 33 to 46 percent. With high growth, demand rises by 870 MCM with the share rising to 52 of available future water. This increase in demand is fully 13.9 percent of available water in the 1961-90 regime.

If climate change had not taken place, the shares in 2046 would have been 35, 43, and 47 percent respectively. In other words, human demands for water would continue to increase the stress on the water ecosystem. The question is whether the additional demand, in the face of climate change, pushes the water ecosystem beyond some critical thresholds. Given the large demands for water, this is clearly possible.

11.4.2 Consumption Growth and Climate Change

We can combine the effects of climate change and economic growth since both are measured by net changes in basin water supply. For ecological integrity within the river system, streamflow is critical. In this section we consider naturalized streamflow after accounting for both climate change and human consumption. The idea here is to identify the effect climate change and socio-economic growth might have on in-stream flows so as to identify potential water shortages as we move down the river system. Note however that this is not a detailed analysis since we cannot identify the precise location of withdrawals. In particular, irrigation withdrawals are not sufficiently detailed to identify on a node by node basis. A more detailed modeling approach is required such as (WAUM or WRRM). Rather we offer a coarser analysis to highlight potential problems. Once identified, a more detailed analysis could be constructed.

We calculate the net total effect as the total demand from all human sources less any gains in basin water supply due to climate change. We compare these to current natural flow to get a measure of the net impact of climate change and economic growth. We begin with the average of the scenarios and consider, in the next section, some sensitivity analysis. These calculations are displayed in Table 11.7.

NET BASIN WATER SUPPLY (MCM)	RD	BR	OR	SSR	SSRB
CURRENT NATURAL FLOW (MCM)	**1665**	**3841**	**3292**	**6264**	**6264**
CURRENT 1996 CONSUMPTION	**462**	**831**	**369**	**420**	**2083**
Human Consumption as a fraction of base flow	0.278	0.216	0.112	0.067	0.333
AVERAGE CLIMATE SCENARIO	**1446**	**3462**	**3155**	**5726**	**5726**
Average Gain/Loss	**-220**	**-378**	**-137**	**-538**	**-538**
COMBINED ECONOMIC and CLIMATE CHANGE (1996)	**682**	**1210**	**507**	**958**	**2621**
as a fraction of base flow	0.410	0.315	0.154	0.153	0.418
2046 LOW GROWTH	**711**	**1243**	**517**	**988**	**2724**
as a fraction of base flow	0.427	0.324	0.157	0.158	0.435
Human Consumption as a fraction of base flow	0.295	0.225	0.115	0.072	0.349
2046 MED GROWTH	**845**	**1414**	**619**	**1078**	**3219**
as a fraction of base flow	0.507	0.368	0.188	0.172	0.514
Human Consumption as a fraction of base flow	0.375	0.270	0.146	0.086	0.428
2046 HIGH GROWTH	**900**	**1534**	**657**	**1136**	**3492**
as a fraction of base flow	0.540	0.399	0.200	0.181	0.557
Human Consumption as a fraction of base flow	0.408	0.301	0.158	0.095	0.472

Table 11.7 *Effects of Consumption and Climate Change as a Fraction of Base Flow (2046)*

Interpretation of Table 11.7 is straight-forward. Current natural flow exiting the Red Deer River at Blindloss is 1665 MCM per year. Total consumption from irrigation and non-irrigation users is 462 MCM. This is 28 percent of current base flow. Hence the adjusted net flow is 1203 MCM per year (or 72 percent of natural flow in the 1961-90 regime). We can add the effect of climate change to current consumption to get a total effect of 682 MCM. This constitutes 41 percent of current base flow.

For the Bow River at the confluence with the Oldman River, adjusted net flow is 3009 MCM per year which is 78 percent of natural flow. For the Oldman River, whose confluence with the South Saskatchewan River is above the confluence of the Bow and South Saskatchewan, we can do the same thing. The adjusted net flow is 2922 MCM per year or 88 percent of natural flow. For the SSR at St. Louis, the adjusted net flow is 4181 MCM per year or 67 percent of natural flow.

We can take the climate scenarios and match them with socio-economic growth scenarios to get a sense for the streamflows that could emerge in the future. Current natural flow for the SSRB as a whole is 6264 MCM with the average of the climate scenarios at 5726 MCM. This is an average loss of 538 MCM. Current human demand for water is 2083 MCM. Together, human demands and potential future demand would remove a total of 2621 MCM from the SSRB. This constitutes 41.8 percent of the current water availability.

If we include economic growth, then total net water supply falls. Under the low growth scenario, total water demand by humans rises by 103 MCM to 2186 MCM. As noted above, this assumes zero changes in irrigation demand. Together, human demand and climate change rises to 2724 which reduces net water supply by 43.5 percent. The effect of the increases in economic activity is that additional consumption demand from non-irrigation sources is only 16 percent of the total combined change in both climate change and economic growth. In other words, as long as human demand grows slowly, the additional water stress is caused primarily by climate change.

If we consider the medium growth case, human consumption rises by 598 MCM to 2681 MCM. Adding the 538 MCM lost due to climate change implies a net reduction of 3219 MCM (a 51.4 percent reduction in available water). The increase in human demand makes up 53 percent of the total combined change in both climate change and economic growth. Of this, growth in irrigation demand of 440 MCM contributes 74 percent of the new human effect.

If we consider the high growth case, human consumption rises by 870 MCM to 2681 MCM. Adding the 538 MCM lost due to climate change implies a net reduction of 3492 MCM (a 55.7 percent reduction in available water). The increase in human demand makes up 62 percent of the total combined changes in both climate change and economic growth. Of this, growth in irrigation demand of 645 MCM contributes 74 percent of the new human effect. In effect, high irrigation demand leads to reductions in water availability that is approximately equal to the impact of climate.

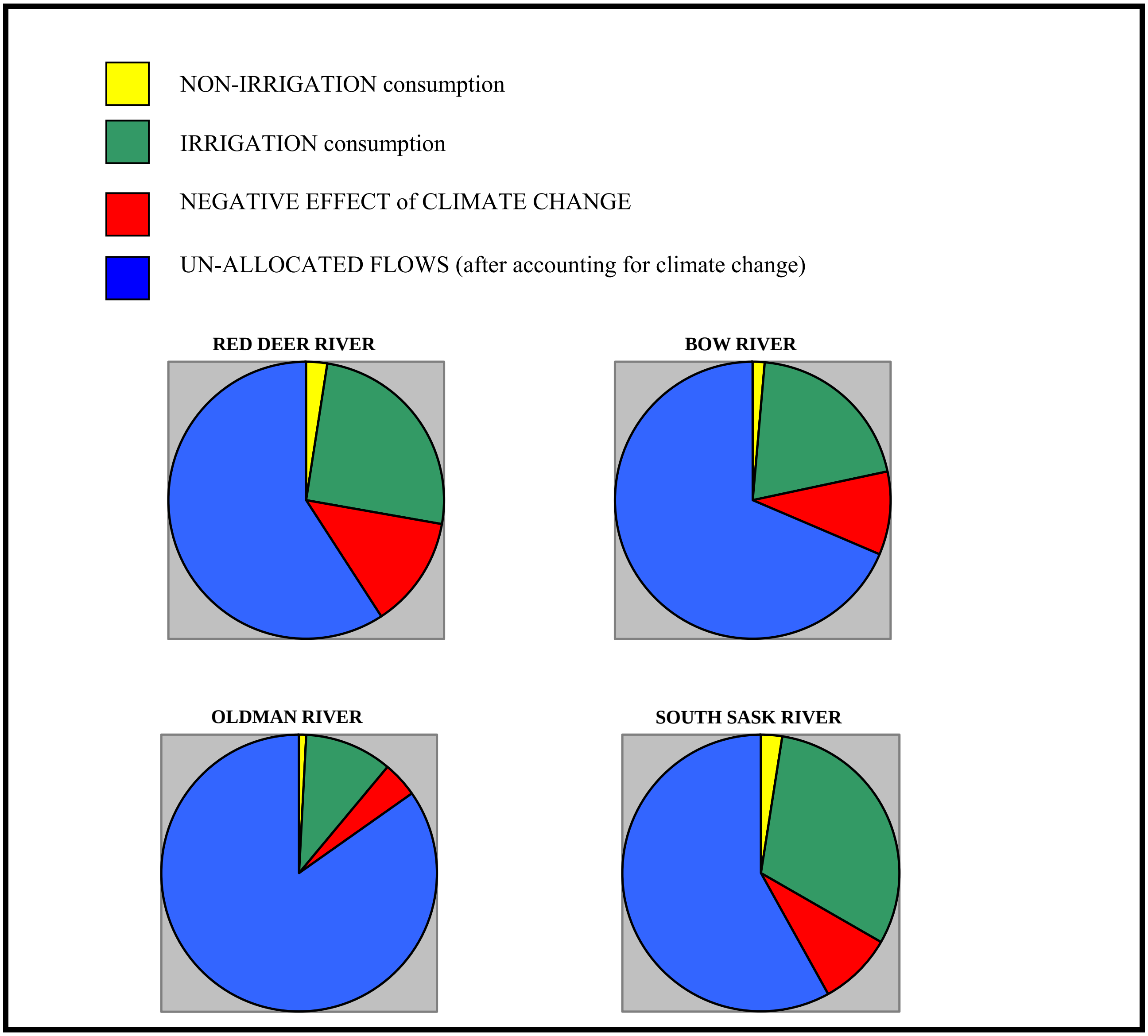

Figure 11.2 *Current Consumption with Average Climate Change*

We can illustrate the above effects using Figure 11.2 just prior. The whole "pie" represents the natural streamflow in the sub-basin. To this we subtract irrigation and non-irrigation demands in that sub-basin or, in the case of the SSR, all upstream consumption. We then subtract the effect of the average climate change scenario. The remainder is un-allocated streamflow after accounting for climate change.

We can see that for each basin, non-irrigation demand is very small while irrigation consumption is large. Without climate change (the sum of the blue and red areas), the unallocated flows are well above the 50 percent threshold. Hence, current activities, at least on an average annual basis, do not constitute a severe ecological threat. Even if we subtract the effects of the average climate scenarios, unallocated flows are still above the 50 percent threshold.

11.5 Sensitivity Analysis

The above analysis is based on the average of the climate scenarios. However, we cannot set probabilities on which scenario is most likely to come about. We can identify "worst" or "best" case scenarios to get a sense of the risks inherent to climate change, combining the growth scenarios with the climate scenarios to get the maximal range of outcomes.

11.5.1 Worst Case Scenario

For the worst case we pick ECHA21a, the driest climate scenario, and impose the three economic growth scenarios. Table 11.8 shows these calculations. Figure 11.3 also illustrates our findings. Relative to the base regime, ECHA21a reduces available water flows by 1386 MCM or 22 percent for the basin as a whole. The changes are more pronounced in the Red Deer River with a decrease in natural flow of 32 percent. The reduction in the other sub-basins is somewhat less but still significant.

	RD	**BR**	**OR**	**SSR**	**SSRB**
CURRENT NATURAL FLOW (1961-90)	**1665**	**3841**	**3292**	**6264**	**6264**
CURRENT 1996 CONSUMPTION	**462**	**831**	**369**	**420**	**2082**
Human Consumption as a fraction of base flow	0.278	0.216	0.112	0.067	0.332
DRIEST CLIMATE SCENARIO	**1131**	**3094**	**2832**	**4877**	**4877**
Gain/Loss	-535	-747	-460	-1386	-1386
Driest Scenario as a fraction of BASE flow	-0.32	-0.19	-0.14	-0.22	-0.22
COMBINED HUMAN CONSUMPTION (1996) and DRIEST CLIMATE SCENARIO	**997**	**1579**	**829**	**1807**	**3468**
as a fraction of 1961-90 flow	0.599	0.411	0.252	0.288	0.553
Combined Demand Growth and Climate Change					
2046 LOW GROWTH	**1026**	**1612**	**839**	**1837**	**3572**
as a fraction of 1961-90 flow	0.616	0.420	0.255	0.293	0.570
Human Consumption as a fraction of base flow	0.295	0.225	0.115	0.072	0.349
2046 MED GROWTH	**1160**	**1782**	**941**	**1926**	**4068**
as a fraction of 1961-90 BWS	0.696	0.464	0.286	0.308	0.649
Human Consumption as a fraction of base flow	0.375	0.270	0.146	0.086	0.428
2046 HIGH GROWTH	**1214**	**1903**	**980**	**1984**	**4340**
as a fraction of 1961-90 flow	0.729	0.496	0.298	0.317	0.693
Human Consumption as a fraction of base flow	0.408	0.301	0.158	0.095	0.472

Table 11.8 *Instream Flows: Worst Case Scenario by Major Sub-Basin (2046)*

We can add the net new consumption under each growth scenario to the net change in water flows due to climate change. Comparing this to the base regime shows that, even under the low growth scenario, more than 55 percent of the water that is currently in the SSRB will either disappear or be consumed by humans. Under the high growth scenario, more than 69 percent disappears.

The potential fall in water supplies is still smaller than all current consumption demands by humans in the SSRB (2082 MCM versus 1386 MCM). In other words, if current human consumption is close to ecological limits, then the worst case climate change can make current consumption unsustainable. We can see this since the share of potential future water supply consumed would be 45 percent even if consumption were limited to 1996 levels. Under the high growth scenario, human consumption would permanently remove 47 percent of the available water for the basin as a whole. So even a small change in the water supply pushes us closer to ecological limits.

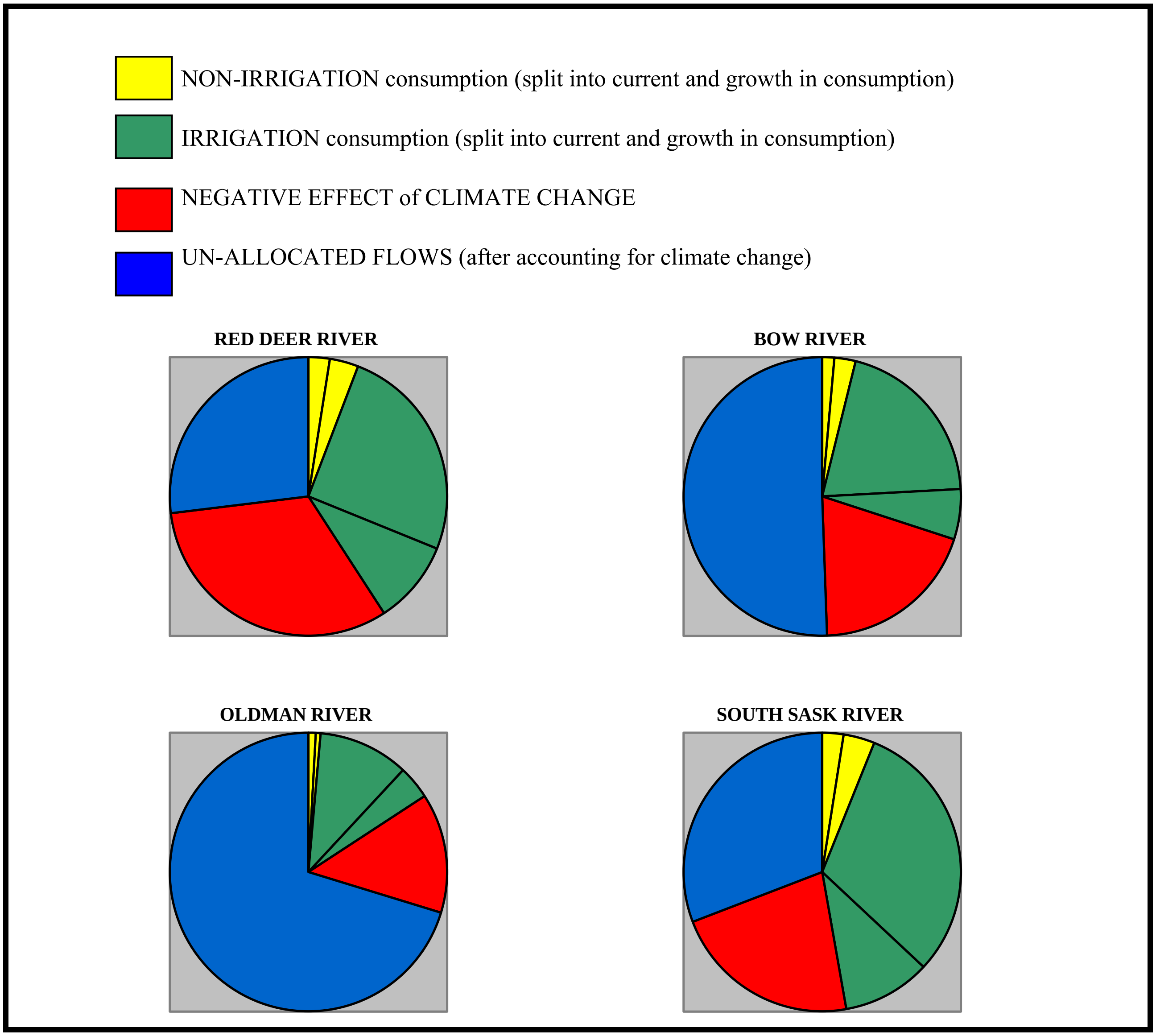

Figure 11.3 *High Growth Consumption with Dry Climate Change*

Even under the driest scenario, the magnitude of the change in water supply is still smaller than the total (1996) human consumption. In fact, it is smaller than the total irrigation consumption. This suggests that mitigation is still possible but, to the extent that climate change is now relatively larger, is more difficult.

We now look at the effects of high consumption growth in the driest climate scenario. For the Red Deer River, both non-irrigation and irrigation consumption rises. If there were no climate change, unallocated flows (the red and blue areas) would remain above the 50 percent threshold. With severe climate change, however, annual flow falls well below the threshold. This suggests that the Red Deer River faces the highest risks over the other basins.

For the Bow and Oldman Rivers, the severe climate change can bring flows down to the critical threshold. This suggests less risk associated with climate change. The South Saskatchewan River is much like the Red Deer where human consumption takes us close to ecological limits but not necessarily across them.

In all, severe climate change would generate a significant source of water stress. However, that stress also comes from growth in human demands. Together, they can push us beyond ecological limits. Note however, that given the magnitude of human demands, mitigation is possible.

11.5.2 Best Case Scenario

For the best case scenario we pick the wettest climate scenario. This is NCARA21a. Table 11.9 shows these calculations. Relative to the base regime, this raises available water by 513 MCM or 8 percent. All of the sub-basins see a rise in water.

NET BASIN WATER SUPPLY (MCM)	**RD**	**BR**	**OR**	**SSR**	**SSRB**
CURRENT NATURAL FLOW (1961-90)	**1665**	**3841**	**3292**	**6264**	**6264**
CURRENT 1996 CONSUMPTION	**462**	**831**	**369**	**420**	**2083**
Human Consumption as a fraction of base flow	0.278	0.216	0.112	0.067	0.333
WETTEST CLIMATE SCENARIO	**1878**	**3896**	**3532**	**6777**	**6777**
Gain/Loss	+213	+55	+240	+513	+513
Wettest Scenario as a fraction of BASE flow	0.13	0.01	0.07	0.08	0.08
COMBINED HUMAN CONSUMPTION (1996) and DRIEST CLIMATE SCENARIO	**249**	**776**	**130**	**-93**	**1570**
as a fraction of 1961-90 flow	0.150	0.202	0.039	-0.015	0.251
Combined Demand Growth and Climate Change					
2046 LOW GROWTH	**278**	**809**	**140**	**-63**	**1673**
as a fraction of 1961-90 flow	0.167	0.211	0.043	-0.010	0.267
Human Consumption as a fraction of base flow	0.295	0.225	0.115	0.072	0.349
2046 MED GROWTH	**412**	**980**	**242**	**27**	**2168**
as a fraction of 1961-90 flow	0.247	0.255	0.073	0.004	0.346
Human Consumption as a fraction of base flow	0.375	0.270	0.146	0.086	0.428
2046 HIGH GROWTH	**467**	**1101**	**280**	**85**	**2440**
as a fraction of 1961-90 flow	0.280	0.287	0.085	0.014	0.390
Human Consumption as a fraction of base flow	0.408	0.301	0.158	0.095	0.472

Table 11.9 *Instream Flows: Best Case Scenario by Major Sub-Basin (2046)*

The net effect of climate change, even in the wettest scenario, cannot fully offset even current human demand. Total human demand in 1996 was 2083 MCM. The rise in net supply offsets this but only partially. Further, the rise in human demand under the high growth scenario is 870 MCM which is more than the rise in available water. Hence, even in the best case scenario, climate change might not fully offset the effects of human demand growth. In other words, human demands will still place stress on water resources. Nonetheless, since water supply would increase, the impact of human demands on water resources would be offset somewhat.

11.6 Monthly Streamflow Analysis

The analysis above was in terms of annual flows. This annual data can hide some important seasonal variations. The following section analyses flows on a monthly basis to identify particular periods in which monthly flows may approach critical thresholds. In particular, we want to identify periods and basins for which flows approach minimum flow requirements. Though these are not specified explicitly, we take as any flow less than 50 percent of flows in the 1961-90 regime as indicative of a potential problem.

Some caveats apply to this analysis. First, monthly consumption will be sensitive to the timing and intensity of irrigation. We showed earlier that irrigation demand is the largest component of human consumption by far. On an annual basis it is twelve times larger than all non-irrigation sectors combined. Irrigation is also concentrated in the summer months (May through September). When irrigation begins and ends as well as the intensity through the irrigation season is not well established or modeled. Timing and intensity may change with the climate but we do not, at this time, know what these changes may be. As such, the monthly consumption figures are indicative only.

Second, the timing of water flow is also stochastic in that the scenarios used are for a water regime extending over a period of time and not for a specific year. At best, the scenarios offer an average monthly flow over a period of time. Actual monthly flows in any particular year will differ.

Third, the location of return flows from irrigation typically differs from the point of intake. This could mean that flows can fall below the basin average along some sections. Unfortunately, we cannot model this.

This suggests that the following analysis is a rough guide to potential problems. We focus on the pattern that emerges rather than specific monthly values.

11.6.1 Monthly Flow under Climate Change

The data for climate scenarios is generated on a monthly basis. Table 11.10 to follow shows the monthly variation in streamflow for each basin. It shows the natural streamflow for the 1961-90 regime as well as the wettest, average, and driest climate scenario. The shaded cells show a rise in monthly water supply relative to the base period.

In most of the basins, peak flow is typically in June with very low flows in the winter months. The Red Deer River is different in that there is a double peak in natural flows with April flows higher than mid-summer flows. This may reflect an early spring runoff followed later by summer rains. The SSR is also different in that the flow is high in the winter and in the mid summer. This double peak may be due to the evaporation that takes place on Lake Diefenbaker.

	RED DEER RIVER				BOW RIVER			
	1961-90	WET	AVG	DRY	1961-90	WET	AVG	DRY
January	18	26	17	13	72	107	76	62
February	17	23	16	11	75	107	82	72
March	64	82	63	49	133	163	152	139
April	300	338	294	251	190	219	211	205
May	213	209	191	166	437	420	406	367
June	305	301	265	218	985	962	898	785
July	296	306	246	185	754	575	500	442
August	175	195	133	92	468	429	337	286
September	116	152	89	57	305	378	262	216
October	93	124	73	49	232	272	198	172
November	46	58	38	28	123	151	115	98
December	22	28	19	14	68	87	68	60
ANNUAL	**1665**	**1878**	**1446**	**1131**	**3841**	**3896**	**3462**	**3094**

	OLDMAN RIVER				SOUTH SASKATCHEWAN RIVER			
	1961-90	WET	AVG	DRY	1961-90	WET	AVG	DRY
January	57	106	80	71	642	979	706	617
February	66	104	91	96	549	848	640	556
March	126	141	144	132	508	661	566	499
April	210	226	226	213	500	562	532	478
May	731	603	556	488	463	457	442	396
June	1000	933	879	745	725	689	629	540
July	473	481	411	341	725	703	607	497
August	193	212	144	103	411	390	293	228
September	134	183	107	78	333	399	257	188
October	131	169	113	93	397	507	324	249
November	102	155	117	100	457	589	410	331
December	68	99	87	85	554	745	552	461
ANNUAL	**3292**	**3532**	**3155**	**2832**	**6264**	**6777**	**5726**	**4877**

Table 11.10 *Natural Streamflow (MCM per month)*

Figure 11.4 illustrates these results and shows the differences across the scenarios. In general, the 1961-90 regime has higher summer flows than even the wettest climate scenario. Also, the peak summer flow occurs earlier in the base year than in the future scenarios. Winter flows, under climate change tends to raise winter flows. This can even happen with the driest of the scenarios. See Pietroniro and Toth (2006) for more details.

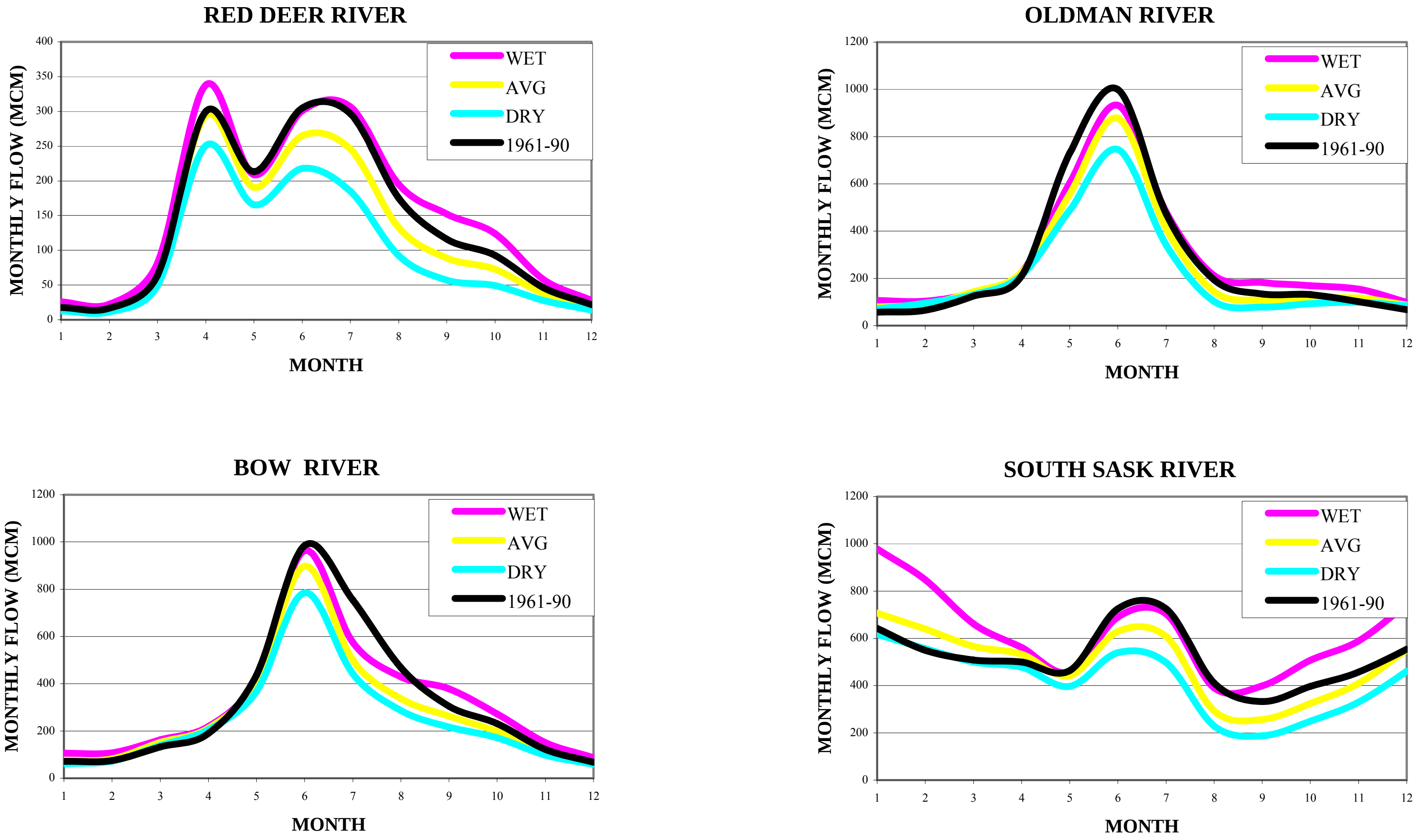

Figure 11.4 *Natural Streamflow (MCM monthly)*

11.6.2 Monthly Consumption

We can convert annual non-irrigation and irrigation consumption into monthly consumption by allocating annual consumption across individual months. Unfortunately, monthly data on water consumption is hard to come by. The following table shows the monthly shares of annual consumption for different user categories. Data for municipal demand comes from municipal consumption in the Vancouver area (*GVRD Water Consumption Statistics, April 2004*). In the absence of other data, we assume that livestock and industrial demand is constant throughout the year. This likely underestimates summer consumption. We assume that irrigation withdrawals take place from May to September with peak demand in June, July, and August.

	MUNICIPAL	LIVESTOCK	INDUSTRIAL	THERMAL	IRRIGATION
January	0.074	0.083	0.083	0	0
February	0.074	0.083	0.083	0	0
March	0.075	0.083	0.083	0	0
April	0.077	0.083	0.083	0	0
May	0.084	0.083	0.083	0.370	0.20
June	0.092	0.083	0.083	0.100	0.22
July	0.105	0.083	0.083	0.126	0.22
August	0.103	0.083	0.083	0.169	0.22
September	0.088	0.083	0.083	0.234	0.14
October	0.078	0.083	0.083	0	0
November	0.075	0.083	0.083	0	0
December	0.074	0.083	0.083	0	0

Municipal shares calculated from: http://www.gvrd.bc.ca/water/pdfs/ConsumptionStatistics2004.pdf

Table 11.11 *Monthly Share of Consumption*

We can take the above share rules and apply it to annual consumption per basin. Table 11.11 shows the monthly consumption by sub-basin. Not surprisingly, the monthly consumption of water is highest in the summers. This is because irrigation is 12 times larger than non-irrigation demands on an annual basis. During the winter months, when irrigation does not take place, total SSRB consumption is around 11 or 12 MCM per month (or 1 percent of annual consumption). In the summer, during the peak irrigation demand, consumption rises to 439 MCM per month (or 21 percent of annual consumption). This peaking of demand is much more pronounced then the peaking of summer flows.

The monthly pattern of consumption amongst sub-basins is virtually identical to the SSRB as a whole since the shares across consumption sectors is quite similar. Also, irrigation dominates the monthly pattern and all basins have significant irrigation activity.

We can also look at future consumption broken down by month. We assume that the distribution of consumption across months does not change over the period. Table 11.12 reports the rise in monthly consumption under the medium growth scenario by sub-basin. The most important change is a rise in consumption that takes place in the summer. This is because irrigation growth, in absolute terms, far outstrips non-irrigation demands. For the basin as a whole, summer consumption rises by over 100 MCM per month. This is equivalent to a 25 percent rise in mid-summer consumption. In the winter, consumption rises by around 11 MCM per month. This is a doubling of consumption. Note that summer consumption rises by 10 times as much as winter consumption. Again, this is because irrigation is over 10 times larger than non-irrigation demands.

	RD	BR	OR	SSR	SSRB	% share
January	2.57	4.25	2.12	2.53	**11**	0.01
February	2.57	4.25	2.12	2.54	**11**	0.01
March	2.57	4.26	2.12	2.54	**12**	0.01
April	2.59	4.36	2.14	2.57	**12**	0.01
May	90.38	159.87	70.81	80.29	**401**	0.19
June	96.29	175.72	77.74	88.18	**438**	0.21
July	96.64	176.24	77.85	88.37	**439**	0.21
August	97.03	176.15	77.83	88.34	**439**	0.21
September	63.85	113.46	50.26	57.07	**285**	0.14
October	2.60	4.41	2.16	2.60	**12**	0.01
November	2.57	4.28	2.13	2.55	**12**	0.01
December	2.57	4.24	2.12	2.53	**11**	0.01
ANNUAL	**462**	**831**	**369**	**420**	**2083**	

Table 11.12 *Monthly Consumption by Basin*

	RD	BR	OR	SSR	SSRB	% rise SSRB
January	2.3	4.5	1.2	3.4	**11.5**	100%
February	2.3	4.5	1.2	3.4	**11.5**	100%
March	2.3	4.5	1.2	3.4	**11.5**	100%
April	2.3	4.6	1.2	3.4	**11.6**	100%
May	31.6	33.9	20.6	19.1	**105.3**	26%
June	30.2	37.2	22.6	20.7	**110.7**	25%
July	30.7	37.7	22.7	20.8	**111.7**	25%
August	31.3	37.6	22.7	20.7	**112.2**	26%
September	22.5	25.4	14.8	14.4	**77.2**	27%
October	2.3	4.7	1.2	3.5	**11.7**	100%
November	2.3	4.6	1.2	3.4	**11.5**	100%
December	2.3	4.5	1.2	3.4	**11.5**	100%
ANNUAL	**163**	**204**	**112**	**120**	**598**	**29%**

Table 11.13 *Rise in Monthly Consumption under Medium Growth Scenario (MCM)*

11.6.3 Adjusted Monthly Flow 1996

We can now subtract consumption from natural flow to yield adjusted net flow for 1996. Table 11.14 shows the adjusted net flow as well as the share of natural flow that remains in the river for each month. Note that these are for the mouth of the river. Upstream nodes will tend to have more flow since most water comes from the foothills of the mountains but most irrigation takes place in the prairie regions.

The results for annual flows showed that streamflow was above 67 percent of natural flows in each sub-basin. However, this masks significant seasonal variation. In the winter months, because consumption is so small, adjusted flows are close to 98 percent of natural flows. Natural flows are low, but human demand is small even relative to this. Human consumption is restricted to municipal, livestock, and industrial processes. As a share of consumption, these are small values. On the other hand, natural flows are also small. Nonetheless, the reduction in natural flow is small and, from a statistical viewpoint, probably insignificant.

	RD	as % of BASE	**BR**	as % of BASE	**OR**	as % of BASE	**SSR**[1]	as % of BASE
January	15.14	0.86	67.64	0.94	55.30	0.96	630.28	0.98
February	14.13	0.85	70.75	0.94	63.49	0.97	537.21	0.98
March	61.60	0.96	129.15	0.97	123.99	0.98	496.87	0.98
April	297.21	0.99	185.78	0.98	208.34	0.99	488.15	0.98
May	122.78	0.58	277.42	0.63	660.42	0.90	61.47	0.13
June	208.63	0.68	808.95	0.82	921.98	0.92	287.04	0.40
July	199.80	0.67	577.52	0.77	394.71	0.84	285.79	0.39
August	78.30	0.45	291.85	0.62	115.39	0.60	-28.09	-0.07
September	52.29	0.45	191.09	0.63	83.85	0.63	48.34	0.15
October	90.30	0.97	227.18	0.98	129.16	0.98	385.10	0.97
November	43.93	0.94	118.22	0.97	99.74	0.98	445.85	0.97
December	19.15	0.88	63.79	0.94	66.20	0.97	542.40	0.98
ANNUAL	**1,203**	**0.72**	**3,009**	**0.78**	**2,923**	**0.89**	**4,180**	**0.67**

[1] The value for the SSR is taken at the mouth and accounts for all upstream consumption.

Table 11.14 *Adjusted Monthly Base Flow (MCM per month) for 1996*

In the summer, however, adjusted flows fall significantly below that which would have occurred in the absence of human activities. For instance, in the Red Deer River, adjusted flows in August and September are about 45 percent of natural flows. If we assume that flows below 50 percent of natural flows constitute ecological stress, then we see that this occurs only in the late summer. Of course, water regulators can manage their reservoirs to avoid this by releasing water during the drier months.

The South Saskatchewan River is interesting as it reflects the idiosyncratic flow below Lake Diefenbaker as well as total basin consumption. For the months May through September, we have adjusted flows below 50 percent. In fact, in August, adjusted flow is negative. This suggests that consumption exceeds natural flows. Of course, this is not possible unless reservoir capacity is released. However, the current practice is to withhold releases from the Gardiner Dam during the summer so that hydro-power generation can be concentrated in the winter months. The more likely explanation for these negative net flows is more prosaic. Most of the irrigation takes place above Lake Diefenbaker. So the adjusted flows are better represented by the flows in the Red Deer, Oldman and Bow Rivers. Flows are lowered in the summer but not to critical levels. The existence of Lake Diefenbaker complicates this since it alters the "natural flow" in a significant way.

11.6.4 Monthly Flow under Average Climate and Medium Growth

We now consider the average climate scenario with medium growth as a possible outcome. This offers a guide to the likely monthly adjusted flows that could emerge in the future. The expectation is that summer net flows, which were already low relative to natural flows, will fall even more. The question is whether they fall below the 50 percent level.

Table 11.15 shows the change in consumption and the change in net flow for each month in each sub-basin. As noted above, consumption rises more in the summer than in the winter. Water supply falls more in the summer than in the winter. Together, these imply that water stress rises in the summer. The shaded cells are where water supply rises under the average of the climate scenarios relative to natural flows in the base period.

	RD		**BR**		**OR**		**SSR**		**SSRB**	
	CON	FLOW	CON	FLOW	CON	FLOW	CON	FLOW	CON	FLOW
January	2.3	-1	4.5	4	1.2	22	3.4	65	11.5	65
February	2.3	-1	4.5	7	1.2	26	3.4	91	11.5	91
March	2.3	-1	4.5	19	1.2	18	3.4	58	11.5	58
April	2.3	-6	4.6	21	1.2	15	3.4	33	11.6	33
May	31.6	-22	33.9	-31	20.6	-175	19.1	-21	105.3	-21
June	30.2	-40	37.2	-87	22.6	-121	20.7	-96	110.7	-96
July	30.7	-51	37.7	-254	22.7	-61	20.8	-118	111.7	-118
August	31.3	-43	37.6	-131	22.7	-50	20.7	-118	112.2	-118
September	22.5	-27	25.4	-42	14.8	-27	14.4	-76	77.2	-76
October	2.3	-20	4.7	-34	1.2	-19	3.5	-73	11.7	-73
November	2.3	-8	4.6	-8	1.2	15	3.4	-47	11.5	-47
December	2.3	-3	4.5	0	1.2	18	3.4	-2	11.5	-2
ANNUAL	**163**	**-220**	**204**	**-378**	**112**	**-137**	**120**	**-538**	**598**	**-538**

Table 11.15 *Changes in Supply and Demand under Average Climate and Medium Growth (MCM per month)*

For the SSRB as a whole, the rise in demand is about equal to the fall in supply. The relative magnitudes for each month are roughly similar although flows are higher in the winter than under the current water regime. The effect is to concentrate the decreases in water availability to the summer months.

The equality of climate change effects and rises in human consumption suggests that we have the ability to mitigate climate change if we wished to. Recall also that current irrigation consumption is around 400 MCM per year. The rise in irrigation raises consumption by 100 MCM in the summer months. Total irrigation consumption, on a monthly basis, is still four to five times the fall in monthly summer flows. Hence, even on a monthly basis, we have the capacity in demand to offset the fall in water supplies, at least for the basin as a whole. However, this ability to mitigate is somewhat harder on an individual sub-basin basis since there is less “diversification” of supply.

Results vary by sub-basin. For the Red Deer River, we see that consumption demand rises in each month with the greatest increase in the summer. Water supply falls in each month with the greatest fall also taking place in the summer as well. On average, the rise in demand is similar in magnitude to the fall in water supply. For the Bow River, the annual fall in water supply is almost twice as large as the rise in demand. However, the fall in summer water supply is much more pronounced than the rise in summer demands. This tends to exacerbate the summer flow problems. Winter flows, on average are actually higher than the current water regime. For the Oldman River, the rise in demand is about equal to the fall in supply. However, the largest fall in supply is in the early summer. However, since early summer flows are high, this decrease is not as severe as the smaller, but proportionally more important, late summer flows.

Table 11.16 shows adjusted flows under both medium consumption growth and the average of the climate change scenarios. Also reported are the anticipated flows as a fraction of natural flows in the 1961-90 water regime. Shaded cells show months where flows fall below 50 percent of the current natural flows.

	RD	as fraction of BASE	**BR**	as fraction of BASE	**OR**	as fraction of BASE	**SSR**	as fraction of BASE
January	12.0	0.68	67.3	0.94	76.5	1.33	683.4	1.06
February	10.9	0.65	72.9	0.97	87.8	1.34	617.0	1.12
March	58.2	0.91	143.6	1.08	140.9	1.12	543.2	1.07
April	289.3	0.96	202.1	1.06	222.3	1.06	509.1	1.02
May	68.7	0.32	212.6	0.49	464.7	0.64	-64.5	-0.14
June	138.5	0.45	684.7	0.70	778.2	0.78	80.2	0.11
July	118.6	0.40	286.3	0.38	310.6	0.66	56.5	0.08
August	4.4	0.02	123.6	0.26	43.1	0.22	-258.4	-0.63
September	2.6	0.02	123.2	0.40	42.3	0.32	-104.9	-0.32
October	67.6	0.73	188.8	0.82	109.4	0.83	300.4	0.76
November	33.3	0.72	105.8	0.86	113.6	1.11	387.1	0.85
December	13.9	0.64	58.8	0.86	83.2	1.22	529.0	0.96
ANNUAL	**818**	**0.49**	**2270**	**0.59**	**2473**	**0.75**	**3278**	**0.52**

Table 11.16 *Monthly Flow under Average Climate and Medium Growth (MCM per month)*

For the Red Deer River, flows in May through September can fall below 50 percent of the 1961-90 regime. This is due to a 35 percent increase in annual consumption matched with a decrease in water supply of around 13 percent. The net effect is that, on an annual basis, average adjusted flows fall from 72 percent to 49 percent of natural base flows. Winter flows are still relative high. The biggest difference is in the summer months. Recall that irrigation growth is quite large in terms of MCM per year. This increase in consumption takes place almost entirely in the summer. Compounding this is a decrease in the anticipated summer flows under climate change. Together, both place pressure on summer flows.

The results are similar for the Bow River though to a smaller degree. Consumption rises by 25 percent while water supply falls by 10 per year. The Bow is characterized by a very sharp summer peak (see Figure 11.4 above). Consumption is spread out over the summer. Hence the pressure on net flows occurs in the early summer and late summer but not mid-summer. On an annual basis, flows fall from 78 to 59 percent of natural base flows.

The results for the Oldman River are similar but different. As in the other basins, consumption grows by 30 percent while water supply falls by 4 percent. Winter flows tend to be higher under climate change so that adjusted flows in the winter are higher than we would see under the current regime. The critical period occurs in the late summer as flows fall while irrigation demand stays high.

For the South Saskatchewan River, summer flows are still low relative to natural base flows. However, as noted above, these results are probably skewed by Lake Diefenbaker.

11.6.5 Worst Case Monthly Flow

We can also consider the worst case scenario on a monthly basis. The following shows the change in consumption under the high growth scenario and the change in water supply under the driest climate scenario (ECHA21a).

Consumption rises in all months in all basins. Again, it rises more in the summer than in the winter due to irrigation growth. Natural flows generally fall in each month in each basin. The exception is the Oldman River which has slightly higher winter flows (January through April) and the SSR with slightly higher flow in February. On average, climate change is twice that of the increase in demand. In this respect, the dry scenario has a greater impact on water availability than even the highest of the growth scenarios.

For the SSRB as a whole the rise in demand is about half of the fall in supply. However, the fall in autumn flows is much larger than the rise in demand. The rise in summer demand is smaller than the fall in supply but only by about 50 percent. This makes overall mitigation easier. For the Red Deer River, the fall in summer water supplies is up to three times larger than the rise in demands. This makes mitigation harder, but given the level of irrigation consumption, not impossible. For the Bow River, the summer fall in water supply is up to five times larger than the rise in demand. This is more pronounced in the mid summer. For the Oldman River, the summer fall in water supply is also up to eight times larger than the rise in demand. This is more pronounced in the late summer.

The effect of a dry climate and high growth is generally similar to that under the average climate and medium growth: adjusted flows fall, particularly in the summer. However the degree is much stronger. In this case, all the basins see summer flows fall below the 50 percent threshold. This is acute in all sub-basins. The Red Deer River is exceptional as flows fall below 50 percent in virtually all months.

	RD		**BR**		**OR**		**SSR**		**SSRB**	
	CON	FLOW	CON	FLOW	CON	FLOW	CON	FLOW	CON	FLOW
January	3.0	-5	7.0	-10	1.6	14	4.6	-25	16.2	-25
February	3.0	-5	7.0	-3	1.6	31	4.6	7	16.2	7
March	3.0	-15	7.0	5	1.6	6	4.6	-9	16.2	-9
April	3.0	-49	7.2	15	1.7	3	4.6	-21	16.5	-21
May	42.7	-47	54.3	-70	27.7	-243	29.1	-66	153.7	-66
June	40.4	-87	59.5	-200	30.4	-255	31.6	-185	161.9	-185
July	41.1	-112	60.4	-312	30.5	-131	31.7	-227	163.6	-227
August	41.9	-83	60.2	-182	30.4	-90	31.7	-183	164.3	-183
September	30.3	-59	40.6	-89	19.9	-56	21.8	-145	112.6	-145
October	3.0	-44	7.3	-60	1.7	-39	4.6	-148	16.6	-148
November	3.0	-18	7.1	-25	1.6	-2	4.6	-127	16.3	-127
December	3.0	-8	7.0	-8	1.6	16	4.6	-93	16.2	-93
ANNUAL	**217**	**-535**	**325**	**-747**	**150**	**-460**	**178**	**-1386**	**870**	**-1386**

Table 11.17 *Changes in Supply and Demand under Dry Climate and High Growth (MCM per month)*

	RD	as fraction of BASE	BR	as fraction of BASE	OR	as fraction of BASE	SSR	as fraction of BASE
January	7.2	0.41	50.6	0.70	67.5	1.17	589.4	0.92
February	5.8	0.35	60.7	0.81	92.4	1.41	528.3	0.96
March	43.8	0.68	127.4	0.96	128.0	1.02	471.5	0.93
April	245.2	0.82	193.7	1.02	209.5	1.00	450.2	0.90
May	32.9	0.15	153.1	0.35	389.7	0.53	-158.7	-0.34
June	81.2	0.27	549.5	0.56	636.6	0.64	-59.8	-0.08
July	47.2	0.16	205.2	0.27	233.2	0.49	-105.3	-0.15
August	-46.7	-0.27	49.8	0.11	-5.4	-0.03	-375.4	-0.91
September	-37.3	-0.32	62.0	0.20	8.0	0.06	-209.7	-0.63
October	43.7	0.47	160.0	0.69	88.8	0.68	220.4	0.56
November	22.4	0.48	86.4	0.71	95.9	0.94	302.8	0.66
December	8.4	0.39	48.4	0.71	81.1	1.19	433.6	0.78
ANNUAL	454	0.27	1747	0.45	2025	0.62	2087	0.33

Table 11.18 *Monthly Flow under Driest Scenario and High Growth (MCM per month)*

11.6 Conclusion

The implication of the above analysis supports the fear that significant climate change can alter water resources in the SSRB and make current water consumption practices unsustainable from an ecological perspective. However, the current data and projections do not *predict* ecological collapse. Nor does the data suggest that current projections in economic and population growth are unsustainable. Rather, the data suggests that we may face a serious problem. The analysis does imply that, if current human consumption is close to ecological limits, then climate change can make current consumption unsustainable. Alternately, if consumption does not change to accommodate a potential fall in water supplies, then we may see extreme water stresses and potential ecological collapses in the SSRB. However, nothing is inevitable given our current understanding of the effects of climate and anticipated growth in water demands. What our analysis does tell us is that we need to consider both climate change and human demand growth as potential problems that need to be dealt with as we move into the future.

The climate scenarios provide a wide band of possible outcomes. The climate may be getting wetter, at least in the foothills of the Rockies, or drier. On average, the scenarios point to a drier climate with significant drying in the prairies. This reduces both net basin supply of water and annual streamflows.

Combined with climate change is an anticipated rise in consumption and withdrawals by humans. Because of the nature of current SSRB demands, most of this growth is likely to come from irrigation. This growth can occur despite the fact that there is no anticipated increase in the licensed allocations of water in Alberta. Irrigation demand will come from more intensive use of licenses as operators expand acreage and reduce runoff. Further, irrigation demand will remain the dominant human consumption sector despite the fact that non-irrigation demands is expected to double over the next forty years. In general, growth in non-irrigation demands would not be the primary source of water stress (though it could push us pass ecological limits). Current and potential future demands are small relative to basin water supplies. Growth in non-irrigation demand, though large in terms of current non-irrigation demand, is still quite small relative to the effect of potential climate change. The net effect of climate change and non-irrigation demand, though of some concern, is probably within the capacity of the current ecosystem to sustain or to accommodate.

The growth in irrigation subsequently implies that most of the increase in demand will take place in the summer where water stresses are already emerging. Current irrigation is large relative to basin water supplies. Changes in irrigation in the future, even if they are small relative to current demand, would still account for a lot of water.

The relative magnitudes of the two effects, climate change and growth in demand, are both important. The potential fall in water supplies is about equal to anticipated increase in all consumption demands by humans in the SSRB as a whole. In other words, as far as water resources are concerned, climate change is of about of equal importance as economic and population growth in the basin. Further, the scale of current human consumption is about four times the anticipated fall in supply. Since non-irrigation demand is small, this implies that current and future irrigation consumption is also four times the potential change in supply. The effect of irrigation growth is of similar magnitude to anticipated change in climate. Both are large relative to available water and anticipated changes can have large ecological impacts. In a worst case climate scenario, even current irrigation demands are likely too high to preserve ecological integrity. However, if the average of the climate scenarios emerges, and irrigation growth is not too strong, then the river systems would likely experience increased water stress but perhaps not at catastrophic levels.

The effects of irrigation also have cascading effects downstream. For instance, under the driest climate scenario, water flows in late summer at St. Louis could be less than 50 percent of natural flows despite the fact that the Saskatchewan portion of the SSRB has little irrigation. This suggests that watershed managers need to account for these downstream effects in managing water withdrawals.

The large size of irrigation demand, however, also offers some flexibility. To the extent that irrigation demands are so large, there is no reason to think that non-irrigation demands cannot be met in the future. If climate change requires a reduction in human demands, irrigation consumption can be made to take the full reduction while leaving non-irrigation demands to grow unabated. This also suggests that mitigation of climate change, to preserve current water flows, is possible. Whether it is desirable, or warranted, is not established. More work needs to be done in this area before any conclusions about the advisability of mitigation can be made.

This analysis also shows that annual data will tend to hide critical issues associated with monthly flows. Monthly variations in streamflow and consumption demand matter. What might appear as a non-critical annual flow hides the possibility that summer flows can be significantly lower than current natural flows. This is partly because consumption demands are concentrated in the summer as are water supply losses. The climate scenarios also tend to maintain or increase winter flows. The implication of this analysis is that the combination of consumption growth and average climate change will tend to worsen the summer flow regime. Current activities are already perceived to place pressure on water resources in the summer months. The future is likely to make this worse. However, high growth in non-irrigation sectors is not anticipated to be a significant factor though it might have strong marginal effects. Rather, strong irrigation demand growth is more important since the current scale of irrigation is already large.

Whether we cross critical ecological thresholds depends on what those thresholds are. We simply do not have enough information at this time to identify thresholds. This is important since mitigation is possible, but we cannot establish at this point whether it is desirable. The cost of mitigation can be estimated from current data but the benefits of mitigation can not. So even though we could offset the fall in supply by reducing irrigation there is no clear evidence to suggest that we should.

Also important is the ability of reservoir capacity and management to accommodate the mismatch between consumption demand and water supply. This is not yet modeled. Consumption demand is very high in the summer and low in the winter. This is also true of natural flows but not to such a great degree. Hence demand is a proportionally larger amount of natural flows in the summer than in the winter. Reservoir storage can offset this by transferring water from one month to another. On the other hand, much of the benefit derived from reservoirs is the capacity to generate hydro-electricity. This is most valuable in the winter months when demand is highest. Hence reservoir managers tend to want to reduce summer flows so as to increase winter releases. That tradeoff and tension between power production and streamflow maintenance is made worse by climate change and economic growth. As we do not model reservoir management we cannot say more about this.

One possible solution is the building of reservoir to preserve in-stream flow since reservoirs might be able to “transfer” winter flows to meet late summer irrigation needs. However, under the driest scenarios, there may be too little water available to effect sufficient “transfers”.

Our analysis, however, is quite coarse. More research is justified given the lack of detail in the spatial analysis as well as the lack of certainty in climate projections. In particular, the irrigation sector, and how it changes in the face of climate change, will also be critical to our understanding of future consequences.

References:

Joel F. Bruneau, 2004. *Value of Water in the South Saskatchewan River Basin,* report to the Climate Change and Impact Fund of Natural Resources Canada.

Joel F. Bruneau, 2006. *South Saskatchewan River Basin Water Withdrawal Forecasts and Scenarios*, report to the Climate Change and Impact Fund of Natural Resources Canada.

Greater Vancouver Water District Operations and Maintenance Department, 2004. *GVRD Water Consumption Statistics, April 2004*.

IPCC-TGCIA, 1999. Guidelines on the use of scenario data for climate impact and adaptation assessment. Prepared by Carter, T.R., M. Hulme and M. Lal, Intergovernmental Panel on Climate Change, Task Group on Scenarios for Climate Impact Assessment. Available at http://ipcc-ddc.cru.uea.ac.uk/guidelines/guidelines_home.html. Accessed June 2004.

Irrigation Water Management Study Committee, 2002. *South Saskatchewan River Basin: Irrigation in the 21st Century, Volume 1: Summary Report*. Alberta Irrigation Projects Association. Lethbridge, Alberta.

Suren Kulshreshtha and Wayne Thompson, 2004. *South Saskatchewan River Basin Input-Output, Employment and Water Use Model: Technical Documentation*,

Jessika Töyrä, Alain Pietronrio and Barrie Bonsal, 2005. Evaluation of GCM Simulated Climate over the Canadian Prairie Provinces. Canadian Water Resources Journal 30(3): 245-262.

12 Impact of Economic Development on Water Resources in the SSRB under Climate Change: *A Tale of Three Cities*

The purpose of this section is to identify, using broad strokes, the potential risks and challenges facing human and aquatic communities in the South Saskatchewan River Basin (SSRB). The focus here is on three cities: Calgary, Lethbridge, and Saskatoon, illustrating how the challenge of adapting to climate change induced water supply change is likely to impact the SSRB sub-basins in different ways. These cities differ in many ways, including growth potential, reliance on water resources, and location in the watershed. This case study approach allows us to identify a spectrum of different experiences, opportunities, and risks.

Our primary focus is to identify the extent and magnitude of potential water shortages (or gains) at these three locations that may emerge in the next forty years. We do this by first identifying changes in the hydrology of the basin under a suite of climate change scenarios that capture trends in global warming. This establishes the supply side for water. We then add socio-economic growth scenarios (the demand side) to the climate change scenarios to get a total impact on available water resources. These two components, supply and demand, are then brought together to assess the risks and challenges that climate change and economic growth create. Under this approach, climate change impacts are viewed as a competing demand.

Our results suggest that climate change, though quite large, need not constrain economic growth in any of these three cities. Furthermore, growth in non-irrigation demands is unlikely to create significant additional stresses on water resources. This is because current non-irrigation demand is still a small fraction of total available water in the SSRB. Irrigation activities, on the other hand, consume a significant fraction of available water, such that irrigation growth, combined with climate change, may prove unsustainable from an ecological perspective. Importantly, the impacts and challenges faced by these cities are quite distinct. This observation makes watershed management more difficult as it must accommodate these spatially-differentiated experiences.

12.1 Introduction

The following demonstration of a dove-tailed physical and socioeconomic science approach reflects on the risks and challenges facing three prairie cities in the South Saskatchewan River Basin (SSRB) given anticipated climate change and potential economic growth. The approach taken here brings together the supply and demand for water in a simple, straight-forward method that can be easily understood. Our intention is to provide analysis as a guide to understanding the challenges and opportunities that climate change brings to the Prairies.

We look at three of the largest cities in the SSRB: Calgary, Lethbridge, and Saskatoon. These cities were selected to provide a spectrum of experiences that reflect the influences of climate change on water resources as well as economic and population growth potentials. We focused on a small sample of communities to sharply illustrate the range of opportunities, constraints and concerns that are likely to emerge under climate change even in a geographically-constrained area.

To do so we consider three primary driving factors. First are the hydrological impacts of climate change that might occur in the SSRB. These impacts result from possible changes to temperature, precipitation, and resulting evapotranspiration (evaporation from water bodies and soil as well as transpiration from plants). The second driver is growth in human activities that create demand for water resources. Growth can come from expansion of population, increases in economic activities, and/or increases in *per capita* water use. A third driver, minimum instream flow needs (IFN) for ecological sustainability, is also important and included in our analysis.

Our primary focus is to identify the extent and magnitude of potential water shortages (or gains) relevant to the three cities as may emerge in the next forty years. We do this by first identifying changes in the hydrology of the basin under a suite of climate change scenarios that capture trends in global warming. This is the supply side for water. We then add socio-economic growth scenarios (the demand side) to the climate change scenarios to get a total impact on water resources. We then bring these two components (supply and demand) together and look at the net change in (naturalized) instream flows that could emerge.

12.2 The Case Studies: Three Cities

Calgary is the largest of the three cities with a *Census of Canada* 2001 population of 878,866 followed by Saskatoon (196,811) and Lethbridge (77,304). Each has a different economic focus. Calgary is a large metropolitan city that is the centre for business headquarters in the petro-chemical industry and is a major service centre for Alberta. Lethbridge lies in the heart of Alberta's irrigation districts and has intensive livestock operations. Saskatoon is Saskatchewan's largest city with its largest university. It is also a headquarters for the province's mining industry.

These differences are partly reflected in their water use characteristics. Table 12.1 shows that Calgary and Saskatoon are very similar in terms of their water use intensity. Lethbridge has much higher livestock activities in the area, as reflected in higher *per capita* non-irrigation consumption.

The second difference in demands comes from irrigation activities across the SSRB (see Table 12.2). If we directly compare the three relevant river sub-basins, we see that the Oldman River has much higher irrigation activity. Irrigation acreages are more than 10 times higher on a *per capita* basis than in either the Bow or South Saskatchewan (Saskatchewan portion) sub-basins. Water withdrawals *per capita* from irrigation are also much higher. The result is that total withdrawal, from all sources, is highest in the Oldman River sub-basin despite the small population. On a *per capita* basis, both water withdrawals and water consumption are about ten times higher in the Oldman River sub-basin than in either the Bow or the Saskatchewan-SSR.

	Calgary	**Lethbridge**	**Saskatoon**
Sub-Basin Population (1996)	873,268	103,250	200,405
Per Capita Withdrawals[1] (m^3/year)	219	379	272
Local Sub-Basin Area (km^2)	5,616	12,057	28,429
Population Density (pop/km^2)	155	8.6	7.0
Equivalent Cattle[2] per capita	0.29	3.47	0.38

[1] Based on non-irrigation demands (household, commercial, industrial, livestock, and power generation) for 1996.

[2] Equivalent Cattle is calculated by dividing total livestock water usage by water use coefficient for cattle (23.36 m^3 per head per year)

Table 12.1 *Sub-Basin Characteristics*
Sources: Bruneau (2006) and Bruneau and Toth (2006)

1996 IRRIGATION	**Bow River**	**Oldman River**	**SSR (Sask-portion)**
Human Population (1996)	878,388	152,030	244,933
Area Irrigated (ha)	106,322	209,144	21,102
Irrigation Density (ha/pop)	0.12	1.38	0.09
Total Non-Irrigation Withdrawals (MCM)	196	64	94
Total Irrigation Water Withdrawals (MCM)	613	932	68
Total Per Capita Withdrawals: Irrigation and non-irrigation (m^3 per person per year)	921	6,551	661
Total Irrigation Consumption[1] (MCM)	421	776	47
Total Non-Irrigation Consumption[1] (MCM)	55	26	24
Total Per Capita Consumption[1]: Irrigation and non-irrigation (m^3 per person per year)	542	5,275	290

[1] Consumption is equal to withdrawals less runoff.

Table 12.2 *Irrigation and Non-Irrigation Activities in SSRB Sub-Basins, 1996.*
Source: Bruneau and Toth (2006)

The cities' location in the watershed is critical to water stress. Calgary is in the foothills of the Rocky Mountains so it is close to the headwaters of both the Bow and Elbow rivers. This means that most of the irrigation withdrawals are downstream of their intake so do not directly impact upon water availability in the city. However, due to Alberta's priority water allocation rights, a large portion of the water that comes through Calgary is already allocated to downstream users.

Lethbridge, on the other hand, is situated below the confluence of the St Mary and Oldman rivers and is in the heart of the irrigation districts. It could be considered as having a "mid-stream" location. Water availability is directly affected by irrigation draws and affected indirectly through induced agricultural-based economic activities. Like Calgary, much of the water passing through Lethbridge is already allocated to downstream users, primarily irrigation districts.

In terms of flow, Saskatoon is on the South Saskatchewan River below Lake Diefenbaker and below the confluences of the Oldman, Bow, and Red Deer Rivers. As such, it is downstream of virtually all the water-related activities in the SSRB, and additionally above the important Qu'Appelle Valley diversion of water to Regina. All upstream water takings affect water availability in Saskatoon. However, this diversification of supply source also provides less variability at Saskatoon. Furthermore, storage in Lake Diefenbaker creates a significant supply buffer for Saskatoon.

12.3 Hydrological Implications

Hydrologic data for the current water regime comes from Pietroniro and Toth (2006). Row 1 of Table 12.3 shows the naturalized streamflows at Calgary, Lethbridge, and Saskatoon averaged for the 1961-1990 period. These we converted this into an equivalent quantities of water per year in million cubic meters (MCM).

Our methodological sequence is as follows. We first take the estimated water consumption from all local and upstream activities to determine the share of water used up by human activities for each city. This provides the benchmark for economic growth. It also allows us to compare consumption and withdrawals to water availability. For Calgary, virtually all the water consumed is from non-irrigation activities and takes place in and around the city. (The irrigation that does take place on the Bow River is almost all downstream of Calgary). For 1996, total water consumption from all sources accounts for about 1.9 percent of available water at Calgary (based on the average *supply* for the 1961-90 period). Total municipal withdrawal for 2001 was 179 million cubic meters (MCM), about 6.2 percent of the average annual flow. Actual municipal consumption is smaller at about 1.5 percent of annual average flows.

This smaller municipal consumption has two implications. First, as long as climate change is not too severe, then water consumption in Calgary is unlikely to be directly limited by water availability. Secondly, the small consumption means that conservation efforts in Calgary can only offset a small climate change. Large climate change effects would simply overwhelm the ability of Calgary to mitigate decreases in water supply.

	Calgary (Bow River)	**Lethbridge (Oldman River)**	**Saskatoon (South Sask)**
Annual Naturalized Flow (MCM per year)	2,853	3,286	6,445
Upstream Non-irrigation Consumption 1996	52	16	155
Upstream Irrigation Consumption 1996	1	310	1928
Upstream Consumption as a share of base flow	1.9%	9.9%	32.3%
Total Municipal Withdrawals[1]	179	18	47
City consumption as a share of natural flow	6.2%	0.5%	0.7%

[1] Total municipal withdrawals taken from the Municipal Use database, 2001, Environment Canada.

Table 12.3 *Naturalized Flows 1961-90 and Water Use in 1996 (MCM per year)*

This circumstance is quite different in Lethbridge due to the large irrigation capacity in the area. Approximately 40% of the irrigation withdrawals from irrigation districts in the Oldman River sub-basin take place upstream of Lethbridge. In total, this irrigation consumption upstream of the city is about twenty times the non-irrigation consumption. On average, about 9.9 percent of the available water is permanently removed at or above Lethbridge. The city itself, however, absorbs only 0.5 percent of available water (in 2001). This suggests that the Lethbridge area is at greater risk of climate change but also has a greater capacity to mitigate decreases in water supply.

At Saskatoon, there is a tremendous flow of water accumulated from the upstream sub-basins. However, Saskatoon is at the bottom end of the river so we need to account for virtually all of the water consumption activities in the SSRB. Doing so shows that water flows at Saskatoon are about 32.3 percent lower than the naturalized flows would generate. The city of Saskatoon, however, withdrew about 47 MCM in 2001. This is only 0.2 percent of the natural flow at Saskatoon on an average year. Hence Saskatoon is in greater risk of climate change than the other two cities but has little independent ability to mitigate. Mitigation would have to incorporate the entire SSRB.

12.4 Economic Growth and Population: Scenario Implications

The primary source for non-irrigation scenarios comes from Alberta Environment's (2002) *South Saskatchewan River Basin Non-Irrigation Water Use Forecasts* (also known as the *Hydroconsult Report*). The primary source for irrigation scenarios comes from the Irrigation Water Management Study Committee (2002), *South Saskatchewan River Basin: Irrigation in the 21st Century, Volume 1: Summary*

Report. The following economic and population growth scenarios are described more fully in Bruneau (2006). For illustration here, we take medium growth scenarios for 2046 as our basis for analysis.

	Calgary	**Lethbridge**	**Saskatoon**
Human Population (1996)	873,268	103,250	200,405
Annualized growth rate (%)	1.73%	0.89%	0.75%
Human Population (2046)	2,058,570	161,141	299,682
Upstream Non-Irrigation Consumption 1996 (MCM/year)	52	14.71	155
Annualized growth rate (%)	1.47%	1.01%	1.41%
Upstream Non-Irrigation Consumption 2046 (MCM/year)	108	24.31	313
as share of 1961-90 water flow	4.5%	0.76%	2.76%
Upstream Irrigation Consumption 1996 (MCM/year)	1	310	1,928
Annualized growth rate (%)	0%	0.34%	0.41%
Upstream Irrigation Consumption 2046 (MCM/year)	1	368	2,368
as share of 1961-90 water flow	0.03%	11.2%	36.7%
Total Consumption in 2046 as share of 1961-90 water flow	4.5%	11.9%	41.6%

Table 12.4 *Population and Economic Growth Projections, 2046*
Sources: Bruneau (2006) and Bruneau and Toth (2006)

Population is expected to grow fastest in Calgary with an annualized compounding growth rate of around 1.7 percent per year. This implies that Calgary and the surrounding area will likely top 2 million people by 2046. Lethbridge and Saskatoon will grow slower but still generates, over 50 years, a net increase of about 50 percent. Growth in water consumption will reflect population growth as well as expansion in livestock and commercial/industrial activities. Though Calgary grows faster in population, it grows more slowly than Saskatoon in terms of water consumption. Overall, SSRB water consumption could grow by 1.4 percent per year which would double consumption by 2046.

Irrigation consumption, the largest consumptive use, will grow slower than non-irrigation consumption. Alberta has no plans to create new irrigation licenses so consumption growth comes from changes in on-farm practices (expanded acreage and changes in crop choices, application technologies and intensities, runoff capture, and water conservation/trading). For Saskatchewan, we assume the same level of expansion as in the Oldman River districts of 23 percent in gross diversions and 32 percent in area. This is much less than the possible expansion identified by Parsons (2005) but reflects Alberta Irrigation's assessment of reasonable expansion parameters based on market forces. Despite the slow growth in irrigation, the magnitudes of the changes are very large. For instance, irrigation consumption could rise by 440 MCM. This is a 23 percent rise but is almost three times the increase in non-irrigation consumption which is anticipated to rise by 158 MCM by 2046.

Despite high anticipated growth in non-irrigation demand across the SSRB, this demand will only absorb a small fraction of available water resources. That is, all SSRB non-irrigation demand in 2046 would still only consume less than 3 percent of the water that is currently in the SSRB. Even in Calgary, non-irrigation consumption is under 5 percent of current flows. Irrigation demand, however, will still be the largest component of demand and the potential increase in consumption would take out another 6.8 percent of current available water. Hence the rise in irrigation demand, though small relative to current activity, is larger than the total anticipated consumption from all non-irrigation activities in 2046.

12.5 Future Hydrology under Selected Scenarios

Pietroniro and Toth (2006) provide hydrological data for the SSRB using three climate models under with two different CO_2 emission scenarios. Each scenario results in slightly different precipitation, temperature, and evapotranspiration patterns across the sub-basins. Pietroniro and Toth interpret the results as offering an envelope of possibilities and do not impute any probability to a particular scenario. They interpret the unweighted average as a measure of central tendency only. Detailed description on the model selection process and hydrographic calibration can be found in Pietroniro and Toth (2006).

Table 12.5 below shows the current naturalized flow and potential future flows for the three cities. For each city there is a potential for either an increase in available water or a large decrease. The average scenario shows a decline of almost 10 percent at Calgary, 3.5 percent at Lethbridge, and 8.5 percent at Saskatoon. The worst case scenario has decreases of 19, 13 and 22 percent respectively.

ANNUAL FLOW (MCM)	**Calgary**	**Lethbridge**	**Saskatoon**
hydrographic station	BH004	AD007	HG001
ANNUAL NATURALIZED FLOWS (1961-1990)	2,853	3,286	6,445
AVERAGE SCENARIO	2,577	3,172	5,900
AVERAGE GAIN/LOSS	-276	-114	-546
as a fraction of BASE FLOW	-9.7%	-3.5%	-8.5%
MAXIMUM FLOW	0	+227	+540
as a fraction of BASE FLOW	0.0%	6.9%	8.4%
MINIMUM FLOW	-535	-448	-1,420
as a fraction of BASE FLOW	-18.7%	-13.6%	-22.0%

Table 12.5 *Annual Flow (MCM) from Climate Change Scenarios*
Source: Pietroniro and Toth (2006)

We can now compare these average changes to the increases in consumption from economics growth. For Calgary, the average of the climate change scenarios implies a reduction in water of 276 MCM per year. Human consumptive growth will rise by about 56 MCM. Hence climate change effects are about 5 times larger than the human growth effects at Calgary. Furthermore, the change in water due to climate is more than twice the total human consumptive water use at, or upstream, of Calgary. This means that it is not possible for changes in consumptive uses in Calgary to fully mitigate the effects of climate change. They simply do not consume enough water to make that much difference.

ANNUAL FLOW (MCM)	**Calgary**	**Lethbridge**	**Saskatoon**
hydrographic station	BH004	AD007	HG001
ANNUAL NATURALIZED FLOWS (1961-1990)	2,853	3,286	6,445
AVERAGE SCENARIO	2,577	3,172	5,900
AVERAGE GAIN/LOSS	-276	-114	-546
Upstream Consumption 1996 (MCM/year)	53	325	2083
Upstream Consumption 2046 (MCM/year)	109	392	2681
Change in Consumption	+56	+67	+598
Total Consumption in 2046 as share of 1961-90 water flow	4.5%	12.33%	23.63%
Net 2046 flow as a share of BASE FLOW	86.5%	84.6%	49.9%

Table 12.6 *Economic Growth and Climate Change 2046*

In Lethbridge, climate change effects are about twice the human growth effect. Total human consumption, on the other hand, is about 3 to 4 times the climate change effect. Further, most of this consumptive use is in irrigation. Hence, it may be possible for irrigators in the Lethbridge area to offset the effects of climate change. However, since net flow falls to about 85 percent of the base regime, it is not obvious that such an adjustment is required (at least on an average, annual basis).

For Saskatoon climate change reduces net flows by 546 MCM per year. The total effect of growth in all upstream areas is slightly larger at 598 MCM under the medium growth scenario used. Hence climate change effects are of similar magnitude to human consumptive growth for the SSRB as a whole. Importantly, the total human consumptive use by 2046 is about 5 times the climate-induced change. This suggests, as in the Lethbridge case, that adjustments in the SSRB are possible to offset climate-induced effects. The question is whether the total effect of the two reduces net flows to such an extent that we run the risk of crossing a critical ecological threshold. That the net flows would fall, on an annual basis, to around 50 percent suggests we would be close, if not past, such a threshold.

12.6 Conclusions

Each of the cities in our case study analysis consumes only a small share of available water resources from the SSRB. The majority of human consumption derives from irrigation activities. Most population and economic growth will be located in the larger cities with Calgary having the faster growth. The implication is that population and economic growth in cities will not, directly, create significant increases in water stress even under climate change. The anticipated rise in consumption is small relative to the available water supply now and in the future. Rather, growth- induced water stress will come from the higher consumptive use sectors, like irrigation. Like it or not, irrigation is simply the largest consumptive use in the SSRB and will likely continue to be so.

The net effect of climate change is, overall, no larger than the anticipated growth in human consumption. Furthermore, total human consumption of water is about 5 times larger than the anticipated average effect of climate change. This suggests that changes in consumptive use could offset the average climate effect. Whether we need to is not yet established. Although we may not cross ecological thresholds, we are certainly getting closer to them. Whether, and how, we would change consumptive activities is left to extension of the baseline work performed here under the initial phase of the SSRB study.

An important insight from this analysis is that each city, and indeed each sub-basin, has a different hydrology and a different growth potential. The impacts of climate change are not uniform. Any watershed management scheme will have to account for these differences. The advantage of the SSRB is that these differences also allow for the diversification of risks and adaptation activities.

References:

Joel F. Bruneau, 2006. *South Saskatchewan River Basin Water Withdrawal Forecasts and Scenarios*, report to the Climate Change Impact and Adaptation Program.

Joel F. Bruneau and Brenda Toth, 2006. *Impact of Economic Development on Water Resources in the South Saskatchewan River Basin under Climate Change*, report to the Climate Change Impact and Adaptation Program.

Hydroconsult EN3 Services Ltd., 2002. *South Saskatchewan River Basin Non-Irrigation Water Use Forecasts,* prepared for Alberta Environment

Irrigation Water Management Study Committee, 2002. *South Saskatchewan River Basin: Irrigation in the 21st Century, Volume 1: Summary Report*.

Graham F. Parsons, 2005. *A presentation to the Saskatchewan Agrivision Conference on Water: Mainstream of the Economy*, North Battleford, November 4th, 2005.

Al Pietroniro and Brenda Toth, 2006. *Water Availability under Climate Change in the SSRB*, report to the Climate Change Impact and Adaptation Program.

13 Conclusions and Extensions

13.1 Summary of the Results

The aim of this co-team effort was to complete an integrated physical and social science analysis of climate-induced water supply impacts on key water use sectors in the South Saskatchewan River Basin. The physical team used down-scaled climate scenarios from selected general circulation models (GCMs) to project surface water supply in the SSRB under climate change. The hydrological implications under climate change were then determined for the SSRB sub-basins and coupled with selected socioeconomic scenarios. The socioeconomic team proceeded in tandem. We defined the watershed boundaries as well as the stakeholders reliant upon the watershed's surface water supply. The SSRB overall has striking regional limitations, with its cold continental position creating relatively dry, rain-shadow conditions. The physical characteristics of the SSRB and its sub-basins were studied, noting factors that not only link climate and water supply (position, landscape, precipitation, runoff and drainage), but also influence population settlement and economic activity. Essentially, the physical geography of the SSRB as an expansive, inter-provincial basin with close to 150,000 square kilometers of drainage area leads logically to sub-basin analysis of water supply impacts and adaptation; the four SSRB sub-basins have between 25,000 and 48,000 square kilometers each, offering significant differentiation as well as internal variation. The relative geographic position of these sub-basins is also significant. In terms of annual precipitation, the SSRB sub-basin variation is notable, ranging from 200 to 500 mm. Generally, spring snowmelt in the Rockies provides the majority of surface water supply, with heavy spring and early summer rains recharging soil moisture and groundwater reserves, and to a decreasing extent downstream, glacier melt contributes to instream flows.

Human activity evolving under these varied sub-basin conditions has taken on distinctive patterns given resource availability, proximity to markets, production prospects, and infrastructure development. Other dimensions of economic geography, such as settlement, agriculture, industry and recreational activity, reflect the SSRB's internal eco-regional distinctions: the Cordillera, foothills and Great Plains. Across the SSRB, three main agricultural land uses persist, for cropland, grassland and forage. Water control, capture, storage and diversion within the SSRB is well-engineered and closely monitored; water allocation and recycling must not only serve municipal, irrigation, commercial and industrial needs, but also preserve both recreational and critical instream and riparian ecological contributions. Two features of this managed system are of particular note. First, the largest water body within the SSRB is a constructed reservoir, Lake Diefenbaker, covering about 430 km^2, whereas most of the SSRB rivers flow in deeply defined channels, fed by alpine sources and a relatively narrow contributing area along the valleys. Secondly, the Qu'Appelle Valley Dam and diversion supply water to the cities of Moose Jaw and Regina and mining operations east of the watershed. Within the SSRB boundaries, a considerable portion of the land has internal drainage and does not contribute overland runoff to the main rivers. Only about 85,000 separate wetlands remain, covering about 500,000 hectares in total. Most of these are in Saskatchewan, within the shared South Saskatchewan sub-basin, and less than one acre in size. However, about 60% of the SSRB wetlands' gross area overall is in the Red Deer sub-basin, where wetlands are three acres on average.

The socioeconomic method used here considers the vulnerability of key stakeholders under the prolonged and gradual exposure of climate change. Such an exposure over the given 50 year period (1996 to 2046) mirrors the duration and temporal characteristics of impacts projected under global climate models. This approach favours the identification and measurement of adaptation options and sensitivities through economic and institutional means. The socioeconomic team has always maintained nonetheless that regional climate models, with their recognition of short-term oscillations, could provide a sharper lens for viewing sub-basin challenges. Across the SSRB, the impacts of human-induced climate change are likely to interact with shorter-term historic weather and hydrological patterns or related natural hazards (such as the ENSO phenomena or droughts and floods, respectively). The vulnerability model applied here considers how human and ecological components are subject to direct environmental exposures and, to some extent, also indirect social response, as result in both immediate and lagged *net* sensitivity overall. The resilience of groups or communities in terms of their collective ability to cope and sometimes even benefit from repeated or continuing exposures, reflects the perceived options, learning capacity, suitability of support programs, and relevant policies and institutional arrangements. The decision to focus on SSRB sub-basin variation when gauging vulnerability considers as well that provincial distinctions also impact on stakeholder resilience: Alberta and Saskatchewan are notably different in terms of population numbers and concentration, the associated advantages of scale, accumulated and anticipated collective wealth, and other variations due to political and economic heritage.

Water use patterns within the SSRB were comprehensively studied for the base year of 1996 on both a basin-wide and sub-basin basis. These water use patterns assume a *status quo* baseline if projected forward because any significant adjustments made to physical structure (i.e. infrastructure) or policy and practice (i.e. water allocation or pricing schemes) would create both immediate and ripple effects upon direct human production and related sector activity, and possibly shift water use expectations. Similarly, historic water use patterns reflected past expectations and technologically-constrained response to extreme circumstances such as drought. The evolution of various regional water management bodies was very significant, and these developments were summarized in Chapter 6. In many respects, resource management benefits from both forward planning and reflection upon past successes and failures. The end-to-end exercise modeled here lays the groundwork for repeated and expanded analysis, set within an institutional and legal framework.

The effectiveness of debate over water supply impacts is often eroded by the lack of clear distinctions between use, intake, demand, and requirements and consumption. A taxonomy of water use was set out and applied here: *water use* is associated with resource *utilization* (for both withdrawal and non-withdrawal (*in-situ*) use), *water intake* captures the amount of water physically applied for a certain need, *water demand* reflects the economically-defined amount of water people are willing to pay for (or forego in terms of alternative purchases), a *water requirement* is the quantity of water needed to maintain or sustain an activity, and *water consumption* is the actual amount of water lost or consumed during a production process. For this last distinction, water consumption is key to understanding the prospects of *virtual water trade*, where water resources are transformed through production into export crops or other commodities and not returned to the source. Any future application of the exercise demonstrated here will likely benefit from the efforts of both the physical and socioeconomic teams who have fine-tuned definitions, reconciled data and methodologies, and queried and provided feedback to data assimilators and providers.

The socioeconomic team used a layered economic analysis approach. First of all, the foundation for regional policy analysis and specific infrastructure decisions was established through a framework for input-output economic impact assessment. Secondly, an economic efficiency approach was used to study water usage and pricing schemes, determine water average values and net values, and gauge sensitivities and thresholds in terms of options available, sector planning horizons, and decision trade-off criteria. As justified above, the study focus moved more so towards the sub-basin analysis of vulnerabilities under climate change. The input-output model (IOM) nevertheless retains valuable potential for use and this work is being pursued ongoing by the socioeconomic team. Preparing the IOM framework, Chapter 7 reflects on the overall structure of the Saskatchewan and Alberta SSRB economies while observing that water use by agriculture remains predominant with irrigation withdrawals at 82% and further livestock use at 2%. On a regional, provincial and basin-wide basis, constraints on available water supply under climate change can lead to changes in the allocation of water to agriculture or any other sector, with direct and indirect impacts upon all sectors.

Applying the IO model, Chapter 7 estimates employment coefficients in 1999 for worker employment per $1,000 of production output. It observes the divergent provincial employment contributions of agriculture (with Saskatchewan's agriculture far more influential), but notes that the support activities for both agriculture and forestry, and fishing, hunting and trapping as well, are all very important province-wide. Given all of these activities are very reliant upon adequate water supply and quality, it can be concluded that changes in water supply (both surface and groundwater sources combined) are likely to have wide-spread impacts upon community welfare in both of these provinces. Within the provincial portions of the SSRB, Saskatchewan's employment contribution from irrigated farming was especially important and almost twice that of Alberta. In Saskatchewan, beef farm and non-commercial farm employment coefficients were 72% higher, with those in combination farming (+51%) and hog farming (+27%) reflecting Saskatchewan's greater reliance of employment in the agricultural sector. In Alberta, the non-agricultural and manufacturing employment coefficients revealed a more diverse economy, notably less vulnerable to reduced water supply withdrawal, with the significantly important construction and paper sectors contributing 13-15% more in terms of employment benefits, with primary metal manufacturing, mining, oil and gas extraction, and non-metallic metal manufacturing contributing more so to Alberta's employment.

An assessment of gross employment in the SSRB basin and its Saskatchewan and Albertan portions has also been documented. About 80% (roughly 900 thousand) of the SSRB region's 1.1 million labour force works within Alberta with 20% (about 215 thousand) in Saskatchewan's SSRB. Despite this pronounced difference in the size of economy and labour force, there are only a few discernible sectoral distinctions. Both provinces employ over half of their workers in service industries, with the top five of the *Ten Top Employing Industrie*s in both provinces categorized as service industries. The retail sector, for the SSRB overall, is the largest employer of workers, ranking first for Alberta and as second in Saskatchewan, with the latter's health care and social services sector topping its Ten Top list. In Saskatchewan, grain farming ranked in sixth position as an employer, whereas in Alberta's SSRB, agriculture was not a significant employer on an aggregate basis.

In terms of surface water withdrawal and gross domestic project (GDP), the redistributive benefits of the provinces' direct employment, secondary impacts and taxation on primary, secondary and tertiary production warrant examination. As Chapter 7 demonstrates, a specified shortage of surface withdrawal water, used for a key sector such as irrigation, can be applied as a scenario to calculate direct, indirect and total output impacts within the SSRB region. In terms of GDP and its influence upon provincial policy, the provincial sensitivities and responses are likely to differ. Gross production values in Alberta in the primary, secondary and tertiary classes are five, eight and six times those of Saskatchewan, respectively. The SSRB basin overall produces $141 billion in economic goods and services, of which roughly half or $69 billion is estimated as total GDP; of the $141 billion gross production, Alberta's activity was roughly five times that of Saskatchewan, yielding almost $118 billion compared to Saskatchewan's $23 billion. Alberta's relative strength in non-primary production and lesser reliance upon agricultural employment suggests that the overall economy in that province's SSRB portion is less vulnerable to water supply changes. Water quality impacts, related to water recycling, water and energy efficiency, and other municipal, commercial and industrial standards, are likely to be more so an issue for Alberta. If viewed under the full water cycle, water supply and quality issues could combine under reduced mid-season streamflows to encroach on thresholds and threaten ecological integrity.

In Chapter 8, the socioeconomic team determined water use by key stakeholders in the SSRB and its divisions. Across the SSRB as a whole, agriculture was the dominant water withdrawal activity in 1996, drawing 86.5% of water supply. Basin-wide municipal, thermal and industrial uses drew far lesser proportions, at 8.7%, 3.0%, and 1.8%, respectively. Within the provincial SSRB portions, the pattern of water use was quite distinctive. Alberta's SSRB withdrawal for agriculture is far larger than that of

Saskatchewan's SSRB, at 87.9% compared to 56.3%. This divergence of water withdrawal use was reflected in further sub-basin divisions. Agricultural water use was particularly high in Alberta's Oldman and Red Deer river basins, at 96.6% and 91.4% respectively. The proportional use by agriculture in the Bow river basin was less, at 78.3%, due in large part to Calgary's stronger municipal demands at 19.7%. The remaining sub-basin, the South Saskatchewan Basin (with its area mostly in Saskatchewan but shared with eastern Alberta) had the lowest agricultural water withdrawal at 76.8%. So, whereas Saskatchewan's SSRB portion realizes far greater contributions from agricultural use in terms of gross revenues and employment benefits as reported above, its water withdrawal portions for agriculture are far less. In the provincially-shared SSRB, water withdrawal usage for thermal electricity production is relatively large at 11.3%. Chapter 8 provided considerable detail on the key water use sectors, for agricultural irrigation and livestock watering, hydropower and thermal power generation, hydroelectricity, domestic, and industrial mining and manufacturing use. The concentration of national parks and provincial recreational areas in the SSRB Alberta foothills, where instream (*in situ*) recreation is regionally and nationally recognized, offers multiple and often concurrent activities which pose challenges for measurement through non-market valuation.

In Chapter 8, the research team documented the SSRB and sub-basin 1996 populations which revealed pronounced differences by sub-basin. Of the SSRB's overall 1.4 million population, Alberta's Bow River basin, including Calgary, had the highest population at close to 830 thousand, with a very small rural population of 2,000. The South Saskatchewan basin, including Saskatoon, was second largest in population with about 283,000 residents, 17,000 of which were rural. The populations of the Red Deer and Oldman river basins were almost balanced, at 124,000 and 118,000 respectively, with almost three times the rural population (14,000) reported in the Red Deer basin. Given the continuing trend towards urbanization, and concerns about rural versus urban welfare, the team also reported population growth which occurred between 1996 and 2001. Urban communities around Calgary had the greatest growth, followed by the Red Deer and Oldman centres, with the growth in Saskatchewan urban communities hardly changing at all. Rural community change was also stronger in Alberta, at 7.0%, compared to Saskatchewan at 1.7, within the 5.0% overall rural growth within the SSRB.

Chapter 9 used a standard economic efficiency approach to determine socioeconomic water values, sensitivities, and thresholds in terms of sector-specific options and their limitations. The economic input value of water by sector and its overall sector value were estimated, noting that these values are always influenced by geographic position and vary dramatically across sectors. Saskatchewan is likely to retain an agricultural emphasis benefiting from further expansion and technological improvements, whereas Alberta now has its water supply applied to full capacity, with little opportunity for gains through technical efficiency and the need for both water trading now apparent along with restrictions on new water licenses. There are both cautionary and optimistic premises associated with water trading. On one side, it is likely that the reallocation of unused portions of existing licenses will be redirected to higher value or more profitable use, and this could compromise the ecological *buffer* offered through sub-optimal use. On the other side, analyses performed by the SSRB team's collaborator, Alberta Research Council (Weber, 2005), suggest that water trading might help protect ecological integrity. This is an area which deserves more analytical attention, particularly within the full water cycle capture of both water supply and water quality.

In summary of the dove-tailed exercise, irrigation demand is likely to continue as the overwhelming water withdrawal use with even marginal expansion very significant under climate change. A more active precipitation cycle is expected under climate change, with hotter, drier summers and otherwise wetter conditions, testing the ingenuity of both farmers and water planners. The accelerated spring snowmelt is likely to contribute most to the SSRB's river water supplies, with glacier contributions playing a rapidly diminishing role, particularly downstream. However, there is still a significant risk of decreased surface water availability in the basin. The average change in overall surface water availability across the SSRB could be as high as -8.4%. Within the SSRB sub-basins, decreased flows could be as high as -10% (Bow), -4% (Oldman), -13% (Red Deer), and -8.5% (South Saskatchewan at Diefenbaker Lake).

Demand for water from non-irrigation sources is anticipated to double by 2046. This increased demand will be driven by significant population growth, increased livestock, industrial and mining production, and increased thermal power generation. However, total consumption by non-irrigation users in 1996 was only 1.9% of available water supply (based on the 1961-90 water regime). The implication is that non-irrigation water demand would not be a significant risk to water supply resources in the SSRB even if there was a doubling in this non-irrigation demand. On the other hand, irrigation demand is already very large with its potential expansion proportionally significant under climate change scenarios. In 1996, which was slightly drier than normal, irrigation diversions accounted for 31% of available surface water (based on the 1961-90 water regime). We can expect some growth in net diversions despite improvements in water use efficiency since return flows are likely to fall over time and the increasing use of tradable permits will likely decrease under-utilized license allocations.

Working together, the physical and socioeconomic teams found that actual water consumption will be less of an issue than the timing and quality of flows returning after water withdrawals. The SSRB is served by a sophisticated water management system with controlled water storage and redistribution. In light of these observations, the original focus of the SSRB project solely on surface water supply was too limited. There are indications that climate change and its associated hydrology will affect water quality, groundwater depletion and recharge; as such, many aspects of the full water cycle are likely to have significant socioeconomic impacts, especially for human and ecological health, and rural populations in particular. The SSRB case of a basin shared between two provinces has proven to be particularly illuminating. The fact that the South Saskatchewan River flows downstream into Manitoba, a province with furthermore striking differences in terms of climate, other eco-regional characteristics and settlement patterns (primarily within the Red River basin) makes the task of assessing Prairie-wide instream flows and their terms of apportionment very challenging.

13.2 Implications for Project Scope as Given

At the outset, the socioeconomic study was focused on aggregate stakeholder impacts and economy-wide redistributive impacts associated with changes in water supply. The framework necessary for this aggregate analysis was developed in Chapter 7 in preparation for immediate policy extension work. This policy extension work was not funded. The regional input-output "snapshot", despite its assumptions and limitations as noted, remains useful for political, economic and trade deliberations. It can be used, for a given reduction of water supply, to assess direct and indirect sector impacts associated with specific input decisions, for example, regarding water infrastructure, transportation networks, processing capacities, and production standards. There are data limitations, nevertheless, which make it difficult to assess these redistributive effects on a sub-basin or more refined basis. The SSRB stakeholders consulted during this study often expressed concern about the regional and often more abrupt and less flexible challenges of international trade and inflation on input prices; the aggregate approach thus retains much potential. In general many stakeholders said they were far less concerned about adapting to gradual climate change.

If further work reveals that climate change is more likely to result in extreme events, such as unseasonal weather conditions, drought, floods, and windstorms, stakeholder receptivity to research which explores adaptation and mitigation options might be heightened. The SSRB advisory committee maintained that considerable research has already been done on drought, and that this work should only be documented rather than duplicated. Other types of extreme events might be best viewed under the full water cycle, considering both water supply and quality; threshold sensitivities of instream flora and fauna, as well as instream consumptive activities by humans, are impacted by the force, timing and quality of the flows.

13.3 Recommendations for Extension

The following opportunities for policy extension were identified. Some of this extension work has already been undertaken and discussed with potential collaborators.

13.3.1 Extension Opportunities

Five areas for policy extension, with collaborators confirmed and funding prospects identified, are:

- Irrigation Water Use and Agricultural Land Use
- Water Use and Technological Change
- Legal and Institutional Analysis of Water Trading, Water Access and First Nation's Issues
- Climate Change and Extreme Events
- Surface Water Supply and the Full Water Cycle

1. Irrigation Water Use and Agricultural Land Use

This extension builds upon the SSRB socioeconomic database, applying its GIS-configurations to related *Census of Canada*, Agriculture and Agri-Food Canada (AAFC) and Environment Canada information. The *Census of Agriculture*, in particular, contains useful information about tillage practices, crop choice, irrigated area, and the types of irrigation, all of which could be used with the SSRB results reported here to fine-tune calculations of the amount, timing and quality of surface water return under climate change. These data could also be combined with SSRB results to investigate the sensitivity of small versus large scale operators (or other characteristics, such as tenure). Given AAFC is already collaborating with the physical science team on the use of environmental indicators, the SSRB socioeconomic results could also be linked to consider the costs of agricultural water quality input and treatment under climate change. Environment Canada's eco-regional and eco-district configurations have already been reconciled with *Census of Agriculture* divisions (by AAFC), so irrigation and other land use variables could be coupled with the SSRB socioeconomic *Census of Canada* data to examine direct and indirect social impacts.

2. Water Use and Technological Change

This extension builds upon the taxonomy of water use applied here. In particular, industrial water use is an area where data gaps existed and updated survey work offers immediate opportunities for analysis. Such work is already being pursued by Joel Bruneau and Michel Villeneuve (Environment Canada). Under potential climate change, the quantity and costs of water use, intake, consumption, requirements and demand, as well as the costs of water quality standards, recycling and reuse, could benefit from analysis under the economic frameworks applied here, testing theories of technological change. The economic frameworks used here could also link sector-based technological improvements with benefits both locally and regionally. A broader social science lens could also be applied to examine the receptivity of stakeholders and the public to water use changes (i.e. wastewater or differential water use).

3. Institutional and Legal Analysis of Water Trading, Water Access and First Nation's Issues

This extension builds upon the policy linkages already examined by the SSRB team's collaborators, the Saskatchewan Research Council (SRC) and the Centre for the Study of Agriculture, Law and the Environment (CSALE). This work (see Section 2.5 and Appendix P) reflects on SSRB water research gaps, relevant legal structures and limitations, and prospects for water markets in light of water access and rights issues. These extensions could dove-tail with water market research and institutional adaptation issues, extending linkages forged with the Alberta Research Council (Marian Weber) and the SSHRC-MCRI (University of Regina) team. Comparative, institutional analysis could provide insights into the applicability and success of formal water markets and other systems for allocation and regulation. For socioeconomic adaptation, there are always institutional, legal and political factors that influence: market transactions; response options, barriers and flexibility; resource use and non-use expectations; public opinion, participation and lobbying; and policy response. Behavioural dynamics also impact on an individual or collective stakeholder's perceptions of the options and costs of adaptation, avenues for recourse, *net* vulnerability remaining during or after adverse conditions, and satisfaction with government policies.

4. Climate Change and Extreme Events

This extension considers regional and sub-regional variations under regional climate models (RCMs). These further dynamics could be coupled with the SSRB socioeconomic sensitivities already determined. For example, the role of short-term oscillations (i.e. ENSO phenomena) and combined impacts of longer-term climate change and extreme events could be assessed in terms of stakeholder impacts. The costs of mitigating damage under extreme events might, some argue, be better viewed under the higher resolution RCMs; an analysis of results at the nodal water supply (sub-sub-basin) level might aid in this comparison. Using the SSRB end-to-end approach an additional sub-set of physical scenarios could be incorporated at the front end, for the selected GCM envelopes, but with RCM variations. A modified socioeconomic approach would likely be required to embrace advancements in decision and risk analysis, more suitable for agent-based response and specific infrastructure decisions. The use of insurance and disaster relief programs could also be viewed under this expanded lens. During the SSRB consultations, stakeholders have made it clear that concerns about their competitiveness *relative* to other producers (regionally, continentally and globally) exceed those about gradual climate change. Accordingly, an assessment of the impacts of climate change and extreme events in the SSRB and beyond, in terms of both productivity and profitability, are welcomed. This extension would grant insights into prospects for both bulk water trading and *virtual water trading* in light of emergency response, humanitarian needs generally, or economic opportunities otherwise.

5. Surface Water Supply and the Full Water Cycle

The study terms of the SSRB project did not support examination of the full water cycle, as necessary to link both water quantity and quality, and surface water and groundwater. These linkages are essential. The SSRB literature search both generally and on commissioned components (see Appendix X, on drought) prepared for this extension. The expansion of the SSRB terms will support a broader analysis on ecosystem impacts, in particular on the meshed contributions of instream flows and riparian zones with non-contributing SSRB areas and wetland habitats. Alberta Environment has already undertaken detailed work on instream flows and this work needs to be reconciled with more effort within Saskatchewan. The question of whether or not the inter-provincial 50% apportionment rules would meet the requirements for minimum instream flows under potential climate change, without additional infrastructure or capacity for additional mid-season release, might be addressed.