



AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
<http://ageconsearch.umn.edu>
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

**Policy Instruments and Agricultural Water Allocation
in the Bow River Basin of Southern Alberta**

Lixia He
Research Associate
Alberta Ingenuity Centre for Water Research and
Department of Economics
University of Calgary
Calgary, Alberta, Canada T2N 1N4
Email: lixiahe@gmail.com
Telephone: (301) 560-4389
Facsimile: (403) 282-5262

Theodore M. Horbulyk
Associate Professor
Department of Economics
University of Calgary
Calgary, Alberta, Canada T2N 1N4
Email: horbulyk@ucalgary.ca
Telephone/Fax: (403) 220-4604

***Selected Paper prepared for presentation at the American Agricultural Economics Association
Annual Meeting; Long Beach, CA; July 23-26, 2006***

Copyright 2006 by Lixia He and Theodore M. Horbulyk. All rights reserved. Readers may make verbatim copies of this document for non-commercial purposes by any means, provided that this copyright notice appears on all such copies.

Abstract

In Southern Alberta, agriculture is the largest water user. Thirteen irrigation districts plus numerous private irrigators hold licenses to withdraw more than 75% of the available surface water. Water use decisions made by farmers in irrigation districts have significant impacts on the productivity of water use and on environmental outcomes (instream flow needs) throughout the South Saskatchewan River Basin (SSRB), especially during periods of drought.

The objective of this paper is to investigate the current and alternative water allocation strategies and their effects on crop choices with a focus on the irrigation districts in the Bow River Sub-basin of the SSRB. A mathematical programming model is developed to optimize economic returns from crop production, subject to specified restrictions imposed by water supply, institutional and hydrological conditions, production technology and land characteristics. Positive Mathematical Programming is used for model calibration with data from 2002-2003 provided by Alberta Agriculture Food and Rural Development. This research provides an explicit framework for the design and comparison of water policy options in Southern Alberta. The findings provide information to address the twin objectives of increasing the productivity of agricultural water use and meeting the environmental flow requirements of the Bow River Basin.

Keywords: Irrigation; Instream flow requirements; Positive Mathematical Programming

JEL Classification: Q15, Q25, Q28

Policy Instruments and Agricultural Water Allocation in the Bow River Basin of Southern Alberta

1. Introduction

Many economic instruments and incentives have been studied and applied in numerous countries to encourage water conservation and reallocation. However, defining and choosing effective policy options that meet economic objectives and environmental goals remains a challenge to planners and policy makers. In many countries, agriculture is the largest water user, and in regions where water is scarce, irrigation water is often the focus of policy action. Producers who depend on irrigation may respond to policy decisions in ways that have complex effects on water quantity, quality, and on the economy as a whole.

In the semi-arid, southern half of the Canadian province of Alberta, increasing demand for water to meet population growth, industrial use, municipal needs, irrigation demand, and climate change have drastically altered the historical equilibrium between water demand and supply. Southern Alberta is home to nearly 60% of the provincial population and almost all of the irrigated land yet Southern Alberta has less than 20% of the province's average annual surface water supply.

The South Saskatchewan River Basin is composed of the sub-basins of four main river systems: the Bow River Sub-Basin, the Oldman River Sub-Basin, the Red Deer River Sub-Basin, and the South Saskatchewan River Sub-Basin. Under an inter-provincial water sharing agreement, half of the annual water accumulation in the Alberta portion of the SSRB must be allowed to pass to downstream provinces, Saskatchewan and Manitoba. Within Alberta, a system of tradable, appropriative water rights is used to help allocate water between consumptive uses and instream flow needs, such as the support of aquatic flora and fauna and riparian ecosystems.

Some water use decisions made by farmers in irrigation districts have significant impacts on the productivity of water use and on instream flow uses throughout SSRB, especially during low flow periods. Recently, several policy instruments have received much local attention: water pricing, development of off-stream storage capacity, and short-term trading of water rights (Horbulyk and Lo, 1998; Mahan *et al.*, 2002; Alberta Environment, 2003; Horbulyk, 2005). However, the compound effect of these policies on diverse users at the sub-watershed level makes it crucial to understand their interaction and to identify opportunities for coordination of these policy options to realize efficient irrigation water management.

The objective of this paper is to investigate current and alternative water allocation strategies and their effects on crop choices with a focus on the irrigation districts in the Bow River Basin of the SSRB. The specific questions addressed are:

- What are the critical water-induced stresses for the predominant crops? Can adjusting cropping location or encouraging short-term trading of water entitlements alleviate these stresses?
- What are the impacts of different water policies on the existing cropping systems?
- How much does social welfare in irrigation districts change under alternative water allocation strategies?

The paper is organized as follows. There is an overview of water consumption across economic sectors and identification of selected policy issues in the Bow River Basin and its legislated irrigation districts. These include issues of water allocation transfers (especially within the agriculture sector and within individual irrigation districts), off-stream storage systems, expansion of irrigated land area and environment protection. The methodology of mathematical programming is shown to integrate examination of these issues and allows one to simulate

decision making and policy analysis at the irrigation district level first, then for the entire Bow River Basin. A general modeling framework for the Bow River Basin and a specific mathematical programming model for three irrigation districts are presented. Numerical results are followed by conclusions and policy implications.

2. Bow River Basin and Irrigation Districts

The Bow River is the largest tributary of the South Saskatchewan River System. It contributes nearly 43 percent of the 9,500 million cubic meters of average annual combined flows that form the South Saskatchewan River (BRBC, 2005). The Bow River Basin (BRB) is situated south of the Red Deer River Basin and north of the Oldman River Basin. Below the confluence with the Oldman River, the basin is known as the South Saskatchewan River Sub-basin. The Bow River Sub-basin receives surface water flows from two main tributaries, the Bow and Elbow Rivers, and from numerous smaller tributaries (Figure 1).

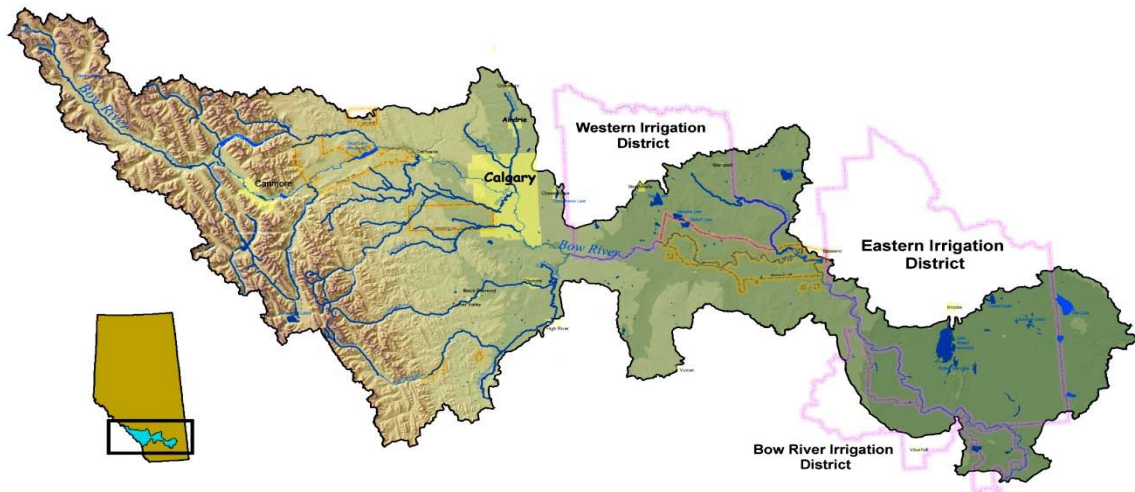


Figure 1: Bow River Sub-Basin in Alberta, Canada (Source: <http://www.urbanswm.ab.ca/>).

The main consumptive users of river water are the City of Calgary, industry (including oilfield injection, oil and gas plants, food processing, and aggregate washing) and agriculture. Upstream of Calgary, there is a network of hydropower facilities in the upper Bow River basin,

extending from Banff to Calgary. There are 11 generating stations with one storage reservoir on the Bow and five on other tributaries. Public water managers control main-stem river flows and withdrawals to provide for minimum instream flow needs, although the adequacy of these levels is the subject of considerable popular debate. Reservoirs along the river system are used for recreational and tourist activities. About 1.12 million people live in the Bow River watershed, with more than 80% of them resident in Calgary. Compared to historical values, residential and recreational use of water from the Bow River has impacted the river's rate of flow, water quality, fish populations, and aquatic plant communities. The human population of the basin is expected to grow by about 50% to 1.65 million by 2030, which could impose further stresses on the Bow River (Hydroconsult, 2002).

Since the late 1800s, irrigated agriculture has depended upon the Bow River network. Agriculture is the largest water consumer in the three primary irrigation districts: the Bow River Irrigation District (BRID), the Western Irrigation District (WID), and the Eastern Irrigation District (EID). The livestock industry and domestic water supply for the rural population also depend on surface water withdrawal from Bow River, with relatively limited reliance on groundwater.

Despite limited rainfall, the Bow River Basin is well suited for irrigated agriculture, with more frost-free days than most parts of the province, good soils for growing a variety of crops, and little potential for water erosion in most parts of the basin due to the adoption of conservation tillage, reductions in summer fallow area and prudent crop rotation (AAFC, 2000, p. 68). The BRID, WID and EID are licensed to withdraw almost 1,700 Million m³ (gross diversion) of water annually from the Bow. Water allocation licenses for agriculture are essentially fixed upper limits, while the actual volume of water used by the irrigation districts

varies considerably from year to year. Figure 2 depicts the change of diversion over 28 years in these three irrigation districts. The observed variation of annual irrigation water diversion from the Bow River is mainly due to variation in precipitation and temperature during the growing season. For example, in a normal year like 1997, the total volume of water diverted by irrigation districts was about 68% of the licensed volume. These irrigation districts diverted about 84% of their licensed allocation in the extremely hot summer of 1988 whereas only 40% of the allocation was diverted in the wet summer of 1993 (AAFC, 2000).

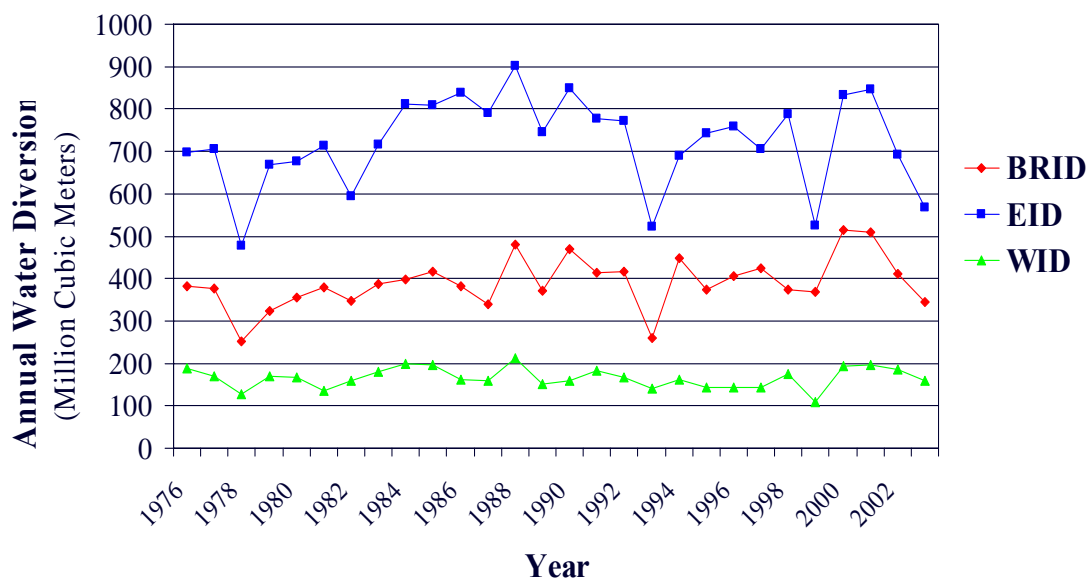


Figure 2: Record of Water Diversion for Irrigation Use
Source: (AAFRD, 2004)

Not surprisingly, within the boundaries of the legislated irrigation districts, irrigated agricultural production predominates, and only very small portions of land that are irrigable with existing works are cultivated on a dryland basis. The principal limit to the expansion of irrigated land in each district is security of additional water supply. The major crops grown in the three irrigation districts are cereals, forages and oilseeds.

Much effort has been made by irrigation district managers and crop producers to improve irrigation efficiency at the head works, distribution and farm levels. In the late 1970s and early 1980s, seepage losses were a substantial factor, with about 18% of irrigated lands in the Bow River Basin affected by salinity and water logging. Since then, many canals have been lined and pipelines have been installed to reduce seepage and evaporation. Other initiatives by the farmers and the districts have been to reduce return flows¹ to make more efficient use of diverted water, to decrease canal maintenance costs, to improve water quality in the larger river basin, and to improve public perception of their management practices (BRBC, 2005).

Alberta has been described as “... a global leader in irrigation technology and management ...” (Klassen, 2002). Rehabilitation of canals is 57% complete in the BRID and seepage losses are now estimated to be only 2.2%. In the EID, rehabilitation is about 32% complete and seepage losses are estimated at 2.6%. The WID has a longer conveyance system compared to the area being irrigated, and only 18-20% of its 1200 km of canals has been rehabilitated. Seepage losses have been reduced to 6.8% of its licensed volume (BRBC, 2005). Most farmers have switched to low pressure, drop tube, center pivot sprinklers that are far more technically efficient than the surface (flood) irrigation or wheel-move systems used in the past. As estimated for 2003, the irrigation efficiency was 69% for BRID, 64% for EID, and 57% for WID.²

Conflicts among irrigators, recreationists and environmental groups may occur in a drought year, when the irrigation districts have limits placed on their diversions to make water available for non-crop uses. In drought years, such as 2001 and 2002, the irrigation districts

¹ Return flow is the surplus water returned to a river system through natural drainage of irrigation diversions. Recent studies show irrigation return flow to be largely a factor of infrastructure characteristics, on-farm irrigation methods and district management.

² Authors’ calculation for 2003. Values represent the weighted average of published efficiency estimates based on the area of irrigated land covered by each type of irrigation technology in each irrigation district. The proportion of land irrigated with each method is used as the weight for calculation. The principal irrigation methods applied in these irrigation district estimates are pivot, wheel move, gravity, and micro.

limited their water withdrawal to meet the minimum instream flow needs and to meet the inter-provincial flow apportionment agreement. These adjustments constrain crop production in the irrigation districts and may trigger water transfers within or among districts under the existing legislation. Many stakeholders also believe that monetary incentive policies will promote the wise use of water, and that greater investment in off-stream storage capacity would be a beneficial strategy for irrigation districts to reduce their production risk in drought periods.

3. Research methodology

3.1 Conceptual framework

In Alberta, three categories of models have been used frequently to analyze water policy: economic optimization models, simulation models (physical and economic), and combined optimization and simulation models. Recent economic optimization models of water use and transfers on a larger “basin scale” for the SSRB include Horbulyk and Lo (1998), Mahan *et al.* (2002) and Cutlac and Horbulyk (2004). These models use economic optimization algorithms that reallocate water use according to its social or private marginal value. They show the economically optimized uses of water across sectors of the economy and across sub-basins with appropriate calibration, although they are at a very high level of aggregation or abstraction. Simulation models in use at the basin level are the Water User Analysis Model (WUAM) (Environment Canada, 1994) and Water Resources Management Model (WRMM) (Alberta Environment, 2002). WUAM describes aspects of the SSRB across Alberta and Saskatchewan, while WRMM looks at only the Alberta portion of the SSRB. Both of these models employ information on physical infrastructure, hydrology, and the priority of licences. A model that combines economic optimization analysis with simulation is the Farm Financial Impact and Risk Model (FFIRM) (AAFRD, 2002a). This model uses the Irrigation District Model (IDM)

(AAFRD, 2002b) and the WRMM in an iterative fashion to simulate irrigation water demand and supply in order to provide economic analysis, such as testing the risks and impacts of water supply deficits on income at the representative farm level across the basin. The advantage of this simulation model that contains economic parameters is that it can help policy makers and analysts to think not only in terms of physical or climate conditions that can affect water users' consumption behavior, but also allow them to see the interaction between human behavior and natural/physical settings with respect to water availability. However, this farm-level modeling approach is hampered by the difficulty in combining the economic model and hydrological simulation model iteratively in the same platform.

The modeling approach taken here builds on these simulation and optimization models. Figure 3 gives the conceptual model framework for the entire Bow River Basin and the interactions among agriculture and other water consumers, including effects on water demand,

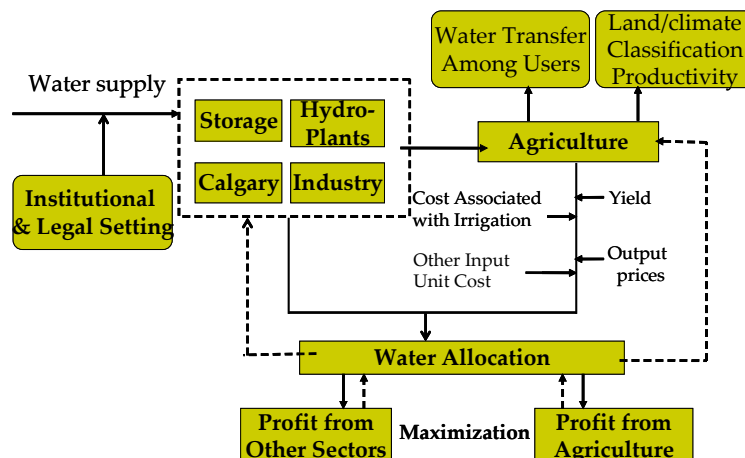


Figure 3: Bow River Sub-Basin Model

return flow, and social welfare.

This model of decision-making within each irrigation season simulates the production, market (considering output price) and environmental conditions faced by irrigation districts in the Bow River watershed. The objective function allocates expected seasonal water supplies to maximize economic returns (producers' surplus plus any water fees) subject to a specific set of hydrological, technological and institutional constraints. The hydrological constraints describe surface flow in the river channel, precipitation, soil moisture and local water storage options. The technological constraints include diverse irrigation methods and water application efficiencies, water application rates and other input factor intensities along with corresponding crop yields. The institutional and legal constraints reflect the assignment of water rights (including the terms of licensed access to divert surface water for irrigation) and allowable uses. There are important linkages between the combination of these constraints and the resulting potential for water re-allocation among users and mitigating any external cost that is generated.

Figure 4 depicts the model framework for the agricultural sector. Surface water is diverted to three irrigation districts according to their licenses and irrigated acreage. Temporary transfers of water entitlements are allowed among irrigation districts; however, this serves as an optional feature in the model that can be turned on and off according to the policy under analysis. Surplus water can be returned back to rivers or pumped into off-stream storage. Irrigation water demand is defined by crop mix decisions in each irrigation district where the production that can maximize the producers' surplus is constrained by water availability, input costs, output price, and production technologies.

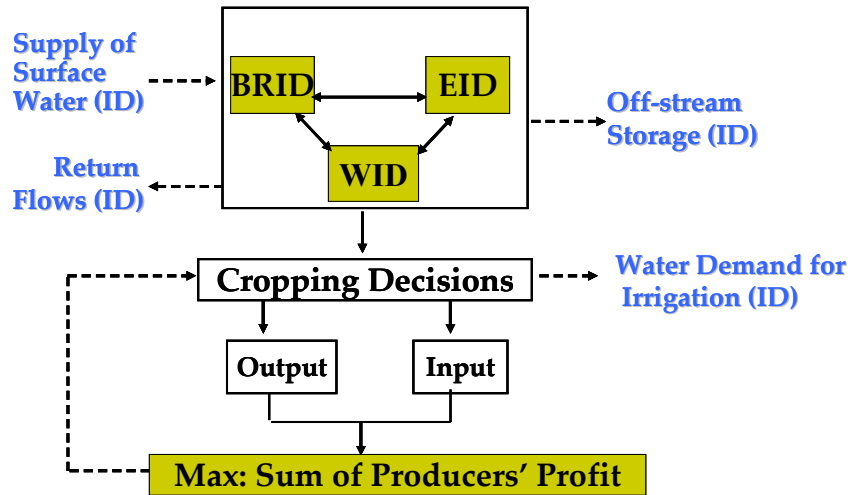


Figure 4: Irrigation District Model of Bow River Basin
(ID means irrigation district)

3.2 The Data and Mathematical Programming

Based on the model framework in Figure 4, a mathematical programming model is developed to optimize the welfare generated from surface water use in the irrigation districts in the Bow River Basin, subject to constraints such as water supply (surface water from precipitation and the Bow River), institutional and legal requirements (surface water license caps, instream flow requirements and downstream water apportionment agreements), production technology, and land classification (irrigated land, non-irrigated land, and dry land that has the potential to become irrigated land). The model allows decision-making at the district level in each irrigation season and allocates expected seasonal water supplies to maximize producers' surplus subject to a specific set of social, physical, and technological constraints.

Data from 2002-2003 were used with the 2003 cropping pattern as the base activity level. Data on irrigation practices, input costs, yields levels, and water requirements for irrigated crops were collected by AAFRD from BRID, EID and WID (AAFRD, 2004). Although the model takes into account effective rainfall, it may overestimate the true irrigation requirement because

it does not consider water use from stored soil moisture. Table 1 describes some of the main characteristics of each irrigation district and the producers' surplus level under the 2003 water supply conditions. The WID is located upstream of both BID and EID and holds 11% of the total irrigation water rights in the Basin. The BRID and EID have adjoining and overlapping access and return flow to the Bow River.

Table 1: Main Characteristics of Three Irrigation Districts (WID, EID and BRID)

	Crop Pattern		Irrigation Demand	Licensed Water Right	Annual Diversion	Return Flow Rate ³
	% of area		Million m ³	Million m ³	Million m ³	%
Bow River Irrigation District	Cereal	36	141.76	554.87	345	0.33
	Forage	32	113.41			
	Specialty crops	20	76.85			
	Oilseed	12	41.04			
Eastern Irrigation District	Cereal	24	148.98	939.58	566.83	0.28
	Forage	64	332.33			
	Specialty crops	7	52.71			
	Oilseed	5	38.39			
Western Irrigation District	Cereal	24	45.34	197.78	158.69	0.42
	Forage	65	97.17			
	Specialty crops	6	7.31			
	Oilseed	5	16.44			

Source: AAFRD (2003)

** return flow rate is the average percentage of annual diversion that returns to the river channel.*

The Positive Mathematical Programming (PMP) approach is used for model calibration. PMP is an approach developed to incorporate both marginal and average cost and revenue information into a regional optimization model. This approach allows precise calibrations in acreage, production and prices (Howitt, 1995). Traditional regional models have relied on average production information, but not marginal conditions. However, marginal conditions are key determinants of the short-run and long-run equilibria. Risk, requirements for crop rotation, exogenous government programs, and other resource constraints can influence the marginal costs and revenues among crops. Not all farms enterprises have the same, average set of conditions,

and therefore the marginal cost and revenue curves do not coincide with the average cost and revenue curves. Consequently, one observes a diversity of crop activities in a region instead of an “average” or homogeneous pattern that sees all firms only produce the same crops. PMP can integrate the marginal value of resources (derived from shadow prices) to augment the average cost and revenue information and calibrate a regional model to a baseline condition. This allows the model to predict a more diverse set of activities than would be possible with a simple linear framework.

The PMP approach is now widely used as a calibration method for the specification of programming models designed for policy analysis (Heckelei, 2002). Heckelei and Britz (2000) apply PMP in the Common Agricultural Policy Regional Impact Analysis programming model. Johnson *et al.* (2003) use PMP to calibrate observable individual farm-level parameters using profit maximization as their objective function. The Central Valley Production Model is a PMP-calibrated model developed by the California Department of Water Resource (DWR). This CVP Model was tested with out-of-sample predictions of regional crop acreage changes during a recent drought period. The CVPM predictions for crop acreage with three contract crops (sugar beets, tomatoes, and subtropical orchard) had a 14-23% error while the remaining nine crops had prediction errors below 7%. Regional crop acreage was predicted for eleven regions and all regions had crop acreage prediction errors below six percent (Howitt, 2005, p. 64). An extended and improved version of CVPM covering the entire State of California, re-named California Agricultural Model (CALAG), is also calibrated using PMP (DWR, 1997).

The standard PMP approach is applied in three steps. First, one adds calibration constraints to a dual problem which bind the activity level to observed base year data and solves the problem to get the marginal value of the calibration constraints. Second, one uses the

marginal values from calibration constraints to estimate the parameters of a quadratic cost function of output quantities. In the third step, one specifies a nonlinear objective function using the calibrated parameters and removes the calibration constraints to reproduce the base year activity level to check if the model calibrates.

The calibration of the mathematical programming model can be compactly written as equations (1) through (9) below, where the choice variable, A , refers to crop cultivation areas:

Maximize:

$$\sum_d \sum_{xc} \sum_l A_{d,xc,l} Y_{d,xc,l} P_{xc} - \sum_i \sum_{xc} \sum_l \sum_d c_{i,xc,l} A_{d,xc,l} - \sum_d \sum_{xc} A_{d,xc,l} Q_{d,xc} VMP_w \quad (1)$$

Subject to:

$$\sum_{xc} A_{d,xc,l} \leq \overline{L_{d,l}} \quad (2)$$

$$\sum_{xc} Q_{d,xc} = \sum_{xc} ETA_{d,xc} - S_d - precipitation(d) \quad (3)$$

$$\sum_{xc} Q_{d,xc} \leq withdrawal(d) - \sum_{dd} T_{d,dd} + \sum_{dd} T_{d,dd} \quad (4)$$

$$withdrawal(d) \leq WR_d \quad (5)$$

$$\sum_{dd} T_{d,dd} \leq WR(d) \quad (6)$$

$$T_{d,dd} * T_{dd,d} = 0 \quad (7)$$

$$ETA_{d,xc} = \overline{ETA_{d,xc}} \quad (8)$$

$$A_{d,xc,l} \leq \overline{A_{d,xc,l}} \quad [\lambda_{d,xc,l}] \quad (9)$$

Where:

A	Cultivation area
\overline{A}	Cultivation area in base year
Y	Yield

a_0, a_1, a_2	Coefficient of yield response function (for actual yield)
C	Unit cost of input
d, dd	Irrigation district
ETA	Actual crop evapotranspiration or consumptive use
ETP	Potential crop water use when water is not limiting
I	Input factor items
kay	Crop water use coefficient
L	Land type and irrigation system
\bar{L}	Total available land
P	Prices of output
$precipitation$	Precipitation
Q	Irrigation requirement
r	Input quantity
S	Soil moisture
T	Water for trading
VMP	Value of marginal productivity of input
W	Water price
$withdrawal$	Withdrawal from river
WR	Licensed accessible water
xc	Crop types
YM	Maximum yield

Equation (1), the objective function, maximizes the combined sum of crop production profit of all irrigation districts under the constraints of land (equation (2)), water (equation (3)), and the water trading opportunity (equation (7)). Equation (3) is the quadratic yield function for irrigated crops. Equation (4) states the irrigation water requirement after subtracting the available rainfall and soil moisture. Withdrawal /diversion/ transfer of surface water cannot

exceed the limit of the licensed water right by an irrigation district ((5) and (6)). Equation (7) indicates that the trades are unidirectional—a buyer from another district cannot sell water back to the same irrigation district contemporaneously. Equations (8) and (9) are PMP calibration constraints on acreage and actual water application, which will force the model to produce results close to the base level.

The cost function can be derived from the above setting. The general formula of this cost function is specified as: $C_{d,x,l}^* = \mathbf{d}'\mathbf{A} + \frac{1}{2}\mathbf{A}'\mathbf{\Gamma}\mathbf{A}$; where \mathbf{d} is the vector of parameters associated with the linear term which can be the same as the average cost in a linear programming problem, and $\mathbf{\Gamma}$ is an n by n symmetric, positive semi-definite matrix of parameters associated with the quadratic term. Let $q_{d,x,l}$ be the n diagonal elements of $\mathbf{\Gamma}$. It can then be calculated

$$\tau_{d,x,l} = \frac{\lambda_{d,x,l}}{A_{d,x,l}} \text{ for this problem.}$$

The final objective function is:

$$\text{Maximize: } \sum_d \sum_{xc} \sum_l A_{d,x,l} Y_{d,x,l} P_{xc} - \sum_i \sum_{xc} \sum_l \sum_d c_i r_{i,x,l} A_{d,x,l} - \sum_d \sum_{xc} A_{d,x,l} Q_{d,x} VMP_w - 0.5 * \tau_{d,x,l} A_{d,x,l}^2 \quad (10)$$

The constraint equations (8) and (9) are relaxed in the new objective function after model calibration.

4. Policy Scenarios to Reduce the Water Demand and Model Results

As long-term (2011 to 2014) goals, Alberta's "Water for Life" Strategy states "water is managed and allocated to support sustainable economic development and the strategic priorities of the province; the overall efficiency and productivity of water use in Alberta has improved by 30% from 2005 levels by 2015" (Alberta Environment, 2003). Rather than coping or responding to a future water supply shortage, the government seeks proactively to reduce water demand and to achieve optimal reallocation through economic instruments and other policy tools.

This highlights questions about the possible allocative and welfare impacts of pricing water or of short-term water trading among users? To assess these impacts, the base case water supplies are retained and new policies are treated as an alternative to water supply reductions. With the optimizing model used here, one can predict the water users' best response to alternative policy regimes. The result yields a new level and distribution of producers' surplus and government's revenue from water and irrigated land under each policy scenario. One result of the alternative policies may be to change the agents' objectives or constraints in a manner that provides an irrigation district with incentive to alter its crop mix or irrigation intensity, thereby changing related estimates of social welfare for the basin.

Scenario 1: Water Pricing

Higher water prices will encourage farmers to move to higher valued crops only if there is a direct relationship between the price changes and the water volume received (Perry, 1996). When the irrigation charges are area-based, water has a marginal cost of zero, and its price will not induce the farmer to save water or move to high value products. This is generally the case in the Bow River Basin. Although water consumers in Alberta have to pay for some of the fixed costs of water management and water infrastructure, at the margin, water is literally free for major users in Alberta (Carpay, 2003). Irrigation water charges are not based on a volumetric measure but on the acreage that is irrigated (Table 2).

Higher volumetric charges can encourage an appreciable change in crop mix only if producers perceive water costs to be significant in relation to gross margin. If marginal water charges are a very small fraction of net revenues earned, they will have no significant allocative effects. This appears to be the case in the study area according to Figure 5.

Table 2: Irrigation Districts (BRID, EID, WID) Annual Water Rates (\$/acre/year)

Year	BRID	EID	WID
2000	14.5	7.5	\$16.25 + pressure surcharge*
2001	14.5	7.5	\$16.25 + pressure surcharge
2002	14.5	7.5	\$16.25 + pressure surcharge
2003	15.0	7.5**	\$16.25 + pressure surcharge
2004	14.5*	7.5	\$16.25 + pressure surcharge

Source: AAFRD, 2005.

* An additional levy is charged for areas serviced by a pressure pipeline.

** The Eastern Irrigation District waived the irrigation rate for irrigated acres in 2003.

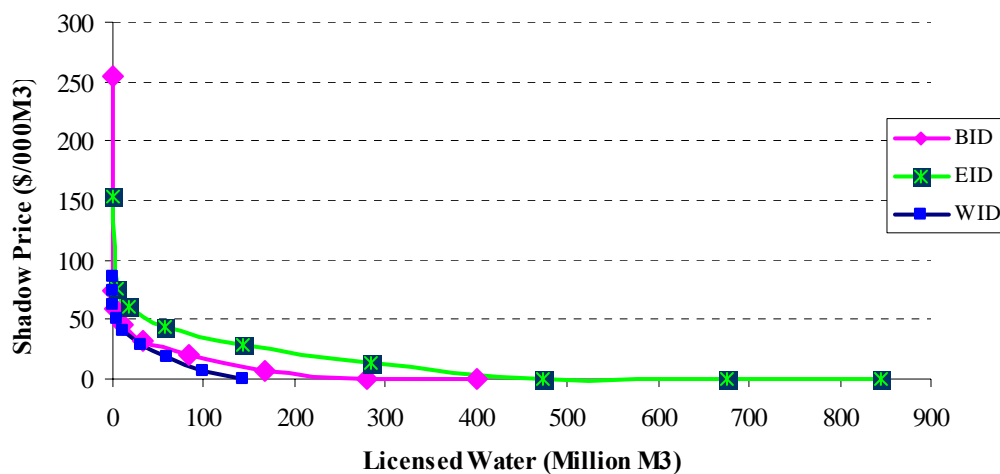


Figure 5: Estimated Water Shadow Prices of Irrigation Districts

Figure 5 shows that the shadow prices are very small until the licensed water usage drops substantially in these irrigation districts. The rather flat lines imply that the elasticity of water demand is low. A relatively high water price level is a prerequisite to have impacts on water use behavior. In this specific scenario, the results are based on a weighted average of shadow prices for the three irrigation districts, “as if” in a season where they face a 30% shortage of water relative to the 2003 level.

Scenario 2: Short-term trading among irrigation districts

Surface water in this basin is managed according to the principle of historical priority of rights, or “first in time, first in right.” The earliest licensee is entitled to receive the entire quantity of water in the license before the next licensee can receive any water at all, and so on. Water transfer is a reallocation of water among water licensees and may serve as an alternative to enforcing this priority system in times of drought or insufficient flows. Senior water licenses can be transferred to junior users, in an effort to provide water to those who need it most at that point in time. These transfers can happen as an impersonal market transaction or through some form of cooperation or voluntary sharing arrangement.

Legislation in Alberta provides for the transfer of an allocation of water held under a license from one parcel of land to another, whether owned by the same or another licensee. There are two basic types of transfer in Alberta: permanent transfers and temporary transfers; that is, part or all of the allocation of water can be transferred on a permanent or temporary basis. In an irrigation district, irrigation water can be transferred among or within irrigation districts under legislation that is distinct from that governing transfers among other individuals or (private) licensees. Temporary transfers of irrigation water within an irrigation district are administratively very simple, and there is some evidence to suggest this market has been active (Chinn, 2004). Nevertheless, the utilization of formal irrigation water markets in Alberta has been limited. High transaction costs could be one factor that impedes market activity for formal transfers. Smoothing the transfer processes and administrative procedures could encourage trading behavior by an irrigation district that values water more than another. Figure 6 illustrates the amount of water that might be able to be traded among irrigation districts when there is a water shortage and the transaction cost of trading water is zero. Using these base data, it appears



Figure 6: Purchases and Sales of Water at Different Water Withdrawal Levels

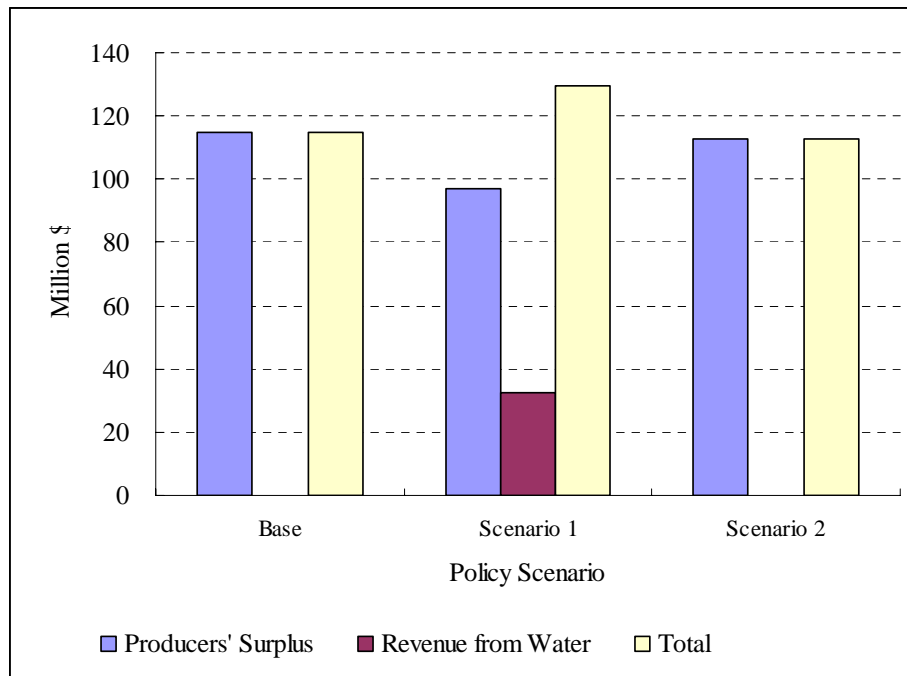


Figure 7: Social Welfare Changes Under Two Policy Scenarios

that the EID is most likely to be the irrigation district to sell water to other irrigation districts when facing a shortage. Recall, this district historically has the largest volume of licensed water among these three irrigation districts.

Figure 7 compares the welfare changes under two policy scenarios. Scenario 1 (water pricing) results in a reduction in producers' surplus, but government can capture this as revenue from priced water. The total level of related economic welfare is higher than the base level. In Scenario 2 (short-term water trading), the aggregate welfare does not change much from the base level, even when facing a 30% reduction in allowable water diversions for irrigation district use.

Short-term water trading may also achieve the same kind of cropping pattern as water pricing does. Table 3 gives the change of cropping mix in three irrigation districts measured from the base level to those achieved in the water pricing scenario and the short-term trading scenario. In the water-pricing scenario, the water shadow price associated with water constraints at 70% of the 2003 water withdrawal level was used, and this same 30% water shortfall is applied to trading scenario. Table 3 shows that all irrigation districts reduce their irrigated area. The direction and magnitude of changes are the same under these two policy scenarios.

Table 3: Cropping Area Change from the Base Level under two Policy Scenarios

	Scenario 1			Scenario 2		
	BID	EID	WID	BID	EID	WID
Cereal	-19.97%	-19.33%	-15.45%	-19.88%	-19.23%	-15.38%
Forage	-20.10%	-19.42%	-19.47%	-20.00%	-19.33%	-19.38%
Specialty crops	-13.58%	-10.57%	-11.04%	-13.52%	-10.52%	-10.99%
Oilseed	-28.27%	-25.18%	-17.11%	-28.18%	-25.10%	-17.02%

5. Conclusions

This paper employs a mathematical programming model to analyze alternative water policies that may be relevant to water allocation in the Bow River Sub-basin of the South Saskatchewan River. Two policies (water pricing and short-term water trading) are analyzed for a situation where water supplies are 30% below typical flow rates. In the water-pricing scenario, producers' surplus decreases and government revenue increases, where the gains in government revenue outweigh losses in producer surplus and generate an overall increase in social welfare. In the water-trading scenario, changes in producers' surplus are negligible. In both scenarios, production of cereal, forage, specialty crops and oilseeds decreased by similar magnitudes.

Much remains to be done in these and related analyses of water policy in the SSRB. A better understanding of the physical, technological, institutional and economic dynamics affecting water consumption and replenishment will require more detailed data. For example, a better understanding of crop response functions at the regional level would be useful for understanding the impact of changes in water allocation on agricultural production. Additionally, risk could be incorporated into the mathematical programming model by including rainfall and weather probabilities. To examine the effects on long-term decision-making, the mathematical program could be made dynamic with complete multi-year data sets.

References

- Agriculture and Agri-Food Canada. (AAFC) (2000). Environmental Sustainability of Canadian Agriculture: Report of the Agri-Environmental Indicator Project. Ottawa: AAFC. Available online at: <http://www.agr.gc.ca/policy/environment/pdfs/aei/fullreport.pdf>
- Alberta. Legislative Assembly. (2000). *Irrigation Districts Act*. Edmonton: Queen's Printer for Alberta. Available online at: [http://www1.agric.gov.ab.ca/\\$department/deptdocs.nsf/all/acts6476?opendocument#text](http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/acts6476?opendocument#text)

- Alberta Agriculture, Food and Rural Development (AAFRD). (2002a). *Farm Financial Impact and Risk Model (FFIRM)*. Edmonton: AAFRD.
- Alberta Agriculture, Food and Rural Development (AAFRD) (2002b). *Irrigation District Model (IDM)*. Edmonton: AAFRD.
- Alberta Agriculture, Food and Rural Development (AAFRD) (2003). *Annual Irrigation Diversion*. Available online at:
[www1.agric.gov.ab.ca/\\$department/deptdocs.nsf/all/irr8782](http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/irr8782).
- Alberta Agriculture, Food and Rural Development (AAFRD). (2004). *Record of Water Diversion for Irrigation Use*. Lethbridge, Alberta: AAFRD Irrigation Branch.
- Alberta Agriculture, Food and Rural Development (AAFRD) (2005). *Irrigation in Alberta: Facts and Figures for the Year 2004*. Edmonton: AAFRD. Available online at:
www.agric.ab.ca
- Alberta Environment (2002). *Water Resources Management Model (WRMM)*. Edmonton: Alberta Environment. Available online at:
www3.gov.ab.ca/env/water/regions/ssrb/wrmmoutput/WRMM/index.asp
- Alberta Environment (2003). *Water for Life: Alberta's Strategy for Sustainability*. Edmonton: Alberta Environment.
- Bow River Basin Water Council (BRBC) (2005). *Nurture, Renew, Protect: A Report on the State of Bow River Basin*. Calgary: BRBC. Available online at:
<http://www.brbc.ab.ca/issues2.asp>
- Carpay, J. (2003). *Water Conservation without Tax Increases*. Edmonton: Canadian Taxpayers Federation. Available online at:
[http://www.taxpayer.com/pdf/Water_conservation_without_tax_increases_\(May_30_2003\).pdf](http://www.taxpayer.com/pdf/Water_conservation_without_tax_increases_(May_30_2003).pdf)
- Chinn, W.. (2004). "Sharing Water in Times of Shortage: A Case Study." Presented to "Confronting Water Scarcity Conference," Lethbridge, Alberta, July 15th.
- Cutlac, M.I., and Horbulyk, T.M. (2004). "Water Allocation Alternative for the South Saskatchewan River Basin: Optimization Modeling for Improved Policy Choices." Presented to "57th Canada Water Resources Association Annual Congress," June 16-18, Montreal.
- Department of Water Resource (DWR) (1997). *The Central Valley Production Model (CVPM)*. Sacramento: California Department of Water Resources.
- Environment Canada (1994). *Water Use Analysis Model (WUAM)*. Ottawa: Environment Canada.

- Heckelei, T. (2002). 'Calibration and Estimation of Programming Models for Agricultural Supply Analysis', Habilitation Thesis, Bonn: University of Bonn.
- Heckelei, T. and Britz, W. (2000). "Positive Mathematical Programming with Multiple Data Points: A Cross-Sectional Estimation Procedure," *Cahiers d'Economie et Sociologie Rurales* (No.57) 28-50.
- Horbulyk, T.M. (2005). Markets, Policy and the Allocation of Water Resources Among Sectors: Constraints and Opportunities. *Canadian Water Resources Journal*. 30(1): 55-64.
- Horbulyk, T.M. and L.J. Lo (1998). Welfare Gains from Potential Water Markets in Alberta, Canada, in K.W. Easter, M.W. Rosegrant and A. Dinar, (eds.) *Markets for Water: Potential and Performance*. Boston: Kluwer Academic, 241-257.
- Howitt, R. (1995), "Positive Mathematical Programming," *American Journal of Agricultural Economics*, May: 329-342.
- Howitt, R. (2005). "Agricultural and Environmental Policy Models: Calibration, Estimation and Optimization". Davis: UC Davis. Available online at:
<http://www.agecon.ucdavis.edu/aredepart/facultydocs/howitt/master.pdf>
- Hydroconsult. 2002. *South Saskatchewan River Basin Non-irrigation Water Use Forecast*. Prepared for Alberta Environment.
- Johnson, M., Masters, W. and Preckel, P. (2003), 'Diffusion and Spillover of New Technology: A Heterogeneous-Agent Model for Cassava in West Africa'. Available online at:
www.agecon.purdue.edu/staff/masters/JohnsonMastersPreckelHeterogeneousAgModel.pdf
- Klassen, S. (2002). *Water in Alberta: Workshop and Think Tank*. Burnaby, BC: Simon Fraser University.
- Mahan, R.C., Horbulyk, T.M., and Rowse, J.G. (2002). "Market Mechanisms and the Efficient Allocation of Surface Water Resources in Southern Alberta," *Socio-Economic Planning Sciences: The International Journal of Public Sector Decision Making*. 36(1): 25-49.
- Perry, C.J. (1996). "Alternative Approaches to Cost Sharing for Water Service to Agriculture in Egypt," IIMI Research Report No. 2, Colombo, Sri Lanka: IIMI.

* * *