

Southern Alberta Resource Economics Centre

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SAREC Report 2010-14

**Water Use Technical and Economic Efficiency
in Southern Alberta Irrigated Agriculture**

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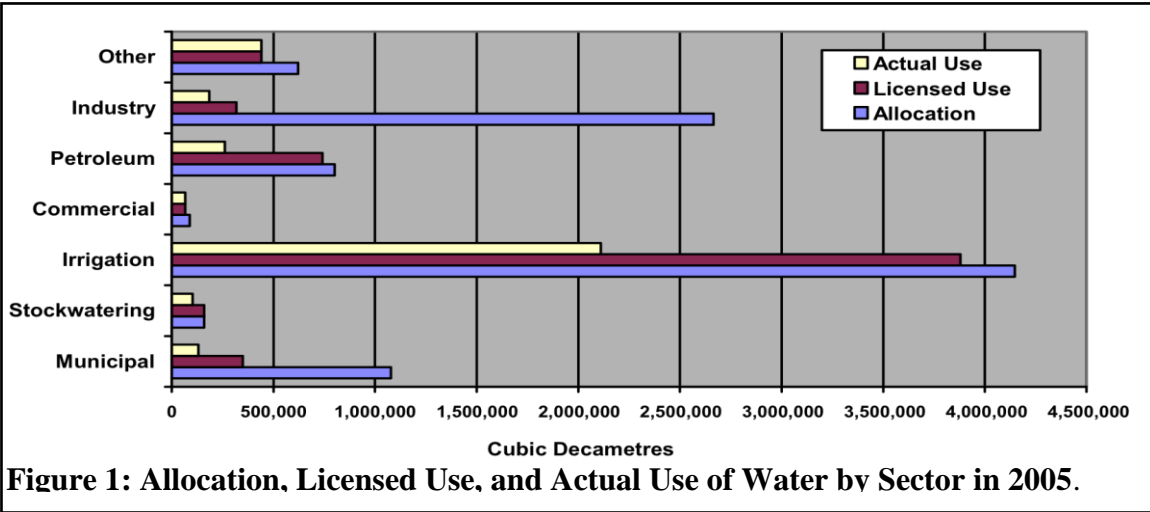
Water Use Technical and Economic Efficiency in Southern Alberta Irrigated Agriculture

Abstract

In this study, water use technical efficiency and three types of water use economic efficiency are estimated for the four river sub-basins that encompass the 13 irrigation districts in southern Alberta for five years: 2004 – 2008. The average level of water use technical efficiency over the five-year period varied from 3.5 – 6.2 metric tonnes/dam³. The gross economic value of crop production per unit of water used varied from \$345- \$592/dam³. The net economic value of crop production per unit of water used varied from \$163-\$268/dam³. Another measure of water use economic efficiency was defined as the marginal increase in net value of crop production under irrigation over what it would have been under dry land conditions; that measurement varied from \$130-199/dam³.

1 Introduction and Background

There are competing uses for water as economic and population growth continues in Alberta (AENV, 2008a; AENV, 2007). Many have seen a need for reform of how water in Alberta is managed so that water is allocated as efficiently as possible as water supplies diminish, conflict increases, and aquatic ecosystem health becomes increasingly threatened (Bjornlund, 2010). The government of Alberta is committed to sustainable management of water as written in the *Water Act* (2000) and in the *Water for Life Strategy* (AENV, 2003a). Within the WFL strategy there is a commitment to improving the efficiency of water use and assisting in allocation of water to its most beneficial purpose (AENV, 2008b). Presently, water used for irrigation has the largest allocation of water in Alberta (Figure 1). Irrigation accounts for over 75% of the allocation in some river sub-basins in southern Alberta (Bjornlund et al., 2007; Grinder, 2010). As such, irrigation users face pressure to increase their level of water use efficiency to allow for water to be reallocated to other uses.



Source: Alberta Environment, 2007 (p. iv)

There are various methods to calculate water use efficiency (WUE). The literature shows that estimated level of WUE depends partly on the method used to calculate it, which, in turn, depends on available data and scope of measurement (farm or basin level) (Du et al., 2010; Webber et al., 2006; El-Rahman, 2009; Seckler et al., 2003). Two general measurement paradigms appear in the literature with respect to WUE; one can be described as classical efficiency (CE) based methods, the second as neoclassical efficiency (NE) based methods. Debate still exists as to which methods are most appropriate (Seckler et al., 2003; Billi et al., 2007). The need for more integration of WUE assessment methods is also apparent due to the increasingly holistic nature of examining WUE, and the development of larger scale water management plans like those of the WFL strategy in Alberta (Haie and Keller, 2008).

The main objectives of this study are to (1) describe and examine different methods of estimating WUE; and (2) estimate technical and economic water efficiencies in the irrigated area of Southern Alberta over the period 2004-2008.

2 Methods for Estimating Water Use Efficiency

There are several different methods to estimate WUE (Du et al., 2010; Webber et al., 2006; El-Rahman, 2009; Seckler et al., 2003). Use of Neo-classical (NE) and Classical (CE) concepts of efficiency in the literature create a “Water-Efficiency-Paradox,” where each produces useful results (Seckler et al., 2003, Willardson et al., 1994). Seckler et al. (2003) point out that there is still debate and confusion over the use of efficiency even after over two decades of using both NE and CE measures. Billi et al. (2007) suggest the use of two main categories to assess WUE. The first is the hydrological/engineering (technical) approach and the second is the economic/institutional approach. The first looks at the yield per unit of water input or diversion needed to achieve required evapotranspiration, and the second looks at social gains from reallocation of water to alternate uses (Billi et al., 2007). Other measures look at the yield of crops for the amount of water needed (Klein et al., 2010; Tollefson and Harrington, 2005; Evans and Sadler, 2008; Katerji et al., 2008). These concepts are explored further in the following sections.

2.1 Classical Efficiency

Classical efficiency (CE) is defined as the net evapotranspiration per unit of diverted water needed to satisfy the water requirements of the plants (equation [1a]) (Seckler et al., 2003; Haie and Keller, 2008). This definition is expanded to equation [1b] to obtain the efficiency of crops grown per unit of water needed for evapotranspiration (Du et al., 2010; Mueller et al., 2005; Keller and Keller, 1995; Mostafazadeh-Fard et al., 2010).

$CE = NET/DIV$	<p>Where NET = $E_t - P_e$, and E_t = Evapotranspiration requirements of Crop [1a] P_e = Effective Precipitation DIV = Diversion of water for irrigation.</p>
$CE = WUE_{ET} = \frac{Y}{ET}$	<p>where, Y = Yield (Kg or MT) [1b] ET = Water used in Evapotranspiration (m^3 or Dam^3)</p>

The equations above use effective precipitation, which is the portion of precipitation contributing to the growth of the plants. The CE considers any water not absorbed by the plants for biomass growth as lost (Seckler et al., 2003; Haie and Keller, 2008). This loss can be from

anywhere in the conveyance system or when delivered. Only the water used for evapotranspiration is considered useful (Seckler et al., 2003; Haie and Keller, 2008).

2.2. Neoclassical Efficiency and Effective Efficiency

Neoclassical WUE involves a more “top down” approach that considers the river basin level efficiency rather than the farm level as in CE (Seckler et al., 2003). Neoclassical WUE considers return flows and recycled water used by other users in the efficiency calculation whereas CE does not (Seckler et al., 2003). The equations for efficiency in the neoclassical sense are derived from those above to account for return flows to get the Net Efficiency (NE) shown in equation [1c] (Seckler et al. 2003).

$$NE = CE + Er(1 - CE) \quad \text{Where } Er = \text{percentage available for recovery, reuse, recycling} \quad [1c]$$

1 - CE = classical inefficiency, water not used for meeting
evapotranspiration needs of plants

Similar to the NE is Effective Efficiency (EE) that was developed to account for aspects like pollution. It has the form shown in equation [1d] (Haie and Keller, 2008; Seckler et al., 2003).

$$EE = \frac{NET}{I - O/R} \quad \text{Where } NET = \text{net evapotranspiration, } I = \text{inflows, } O = \text{Outflows,} \quad [1d]$$

R = percent usable return flow

The value for (R) in equation [1d] represents the amount needed to dilute pollutants from the outflow (O) so that the water is usable somewhere else in the system (Haie and Keller, 2008). The NE and EE then are able to better show the effective water use on a basin-wide basis as return flows can be used by others depending on the level of pollutants. Seckler et al. (2003) note some key points in the use of CE vs. NE or EE including:

- CE has an important role to play in assessing the project or farm level efficiency where NE would not be suitable.
- Judgments are part of choosing the measure of efficiency used and must be stated for beneficial and non-beneficial flows. In CE the distinction is clear, but in NE or EE the beneficial flows are harder to pinpoint.

2.3 Other Calculations of Efficiency

Other indicators of WUE, such as those used by Agriculture and Agri-Food Canada (Lefevbre et al. (2005) and the Organization for Economic Cooperation and development (OECD, 2001), consist of a combination of Water Use Technical Efficiency (WUTE), as shown in equation [1e], and Water Use Economic Efficiency (WUEE), shown in equation [1f] (Tollefson and Harrington, 2005). These calculations of efficiency are similar to the CE with the value for evapotranspiration being substituted by the precipitation and irrigation water applied. There are inherent weaknesses in using equations [1e] to [1h] below in that water “lost” to other parts of the hydrological system or reused elsewhere are not counted as they would be in equations based on the NE or EE (Seckler et al., 2003; Haie and Keller, 2008).

$WUTE = \frac{\text{Yield}}{(P_e + I + SW)}$	Where P_e = Effective precipitation (rainfall) I = Irrigation water applied [1e] SW = soil water depletion during growing season Yield is in Metric Tones (MT)
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$WUEE \text{ (Gross)} = \frac{CRVAL}{(P_e + I + SW)}$	$CRVAL$ = Crop revenue in dollars I = Irrigation Water Applied [1f] P_e = Effective Precipitation. SW = soil water depletion during growing season
Also,	
$WUEE \text{ (net)} = \frac{CRVAL - \text{Total Variable Costs}}{(P_e + I + SW)}$	[1g]

Equation [1g] can be used to find the marginal WUTE ($\Delta WUTE$) by taking the difference between the net revenue from irrigating and that from dry land farming, as shown by equation [1h].

$\Delta WUEE = \frac{\text{Net Revenues from Irrigation} - \text{Net Revenues from Dryland}}{\text{Irrigation Water Applied}}$	[1h]
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2.4 Water Use Efficiency Calculation Methods

The above discussion of WUE demonstrates a number of different methods that have been used to calculate the measure. The literature shows the choice of method used depends on factors such as:

- Scope and scale of the measurement being done, such as farm/project level or basin level;

- Availability of data on aspects like evapotranspiration needs of crop species, biomass harvested, water used/diverted (and recovered for NE or EE), precipitation data and crops chosen for study;
- For economic analysis, data are needed on the value of crops produced per unit biomass, impacts on society through aspects such as farm level income, basin level income, multiplier effects, and opportunity costs of alternate uses of water such as industry.

There is a need for improvement in understanding water management and efficiency as water resources become increasingly scarce (Evans and Sadler, 2008; Seckler et al., 2003; Haie and Keller, 2008). Water management is becoming more integrated and holistic and looking at water efficiency from the project or farm level is no longer adequate to ensure water is used and allocated effectively (Haie and Keller, 2008; AENV, 2008a; Seckler et al., 2003). As such, movement to efficiency calculations that can take farm/project level efficiencies and integrate them into calculations of basin level efficiencies is needed. Calculations of basin level efficiencies also require data on the water used by non-agricultural uses such as domestic, industrial, and environmental goods and services, including recreation and amenity use.

3 Water Use Efficiency of Southern Alberta River Sub-basins

3.1 Study Region and Background

The South Saskatchewan River Basin (SSRB) (Figure 2) in southern Alberta is home to close to half of Alberta's population (AENV, 2007). The SSRB includes an important portion of Alberta's agricultural activity, as shown in the cultivation intensity map in Figure 3 where the coloured regions show areas of agricultural activity, and the orange and red regions represent the regions with the highest level of agricultural activity (AARD, 2005). The Bow and Oldman River sub-basins have over 75% of the water allocated for irrigation and the Red Deer and South Saskatchewan River sub-basins have less than 25% of the water allocated for irrigation (Figure 4).

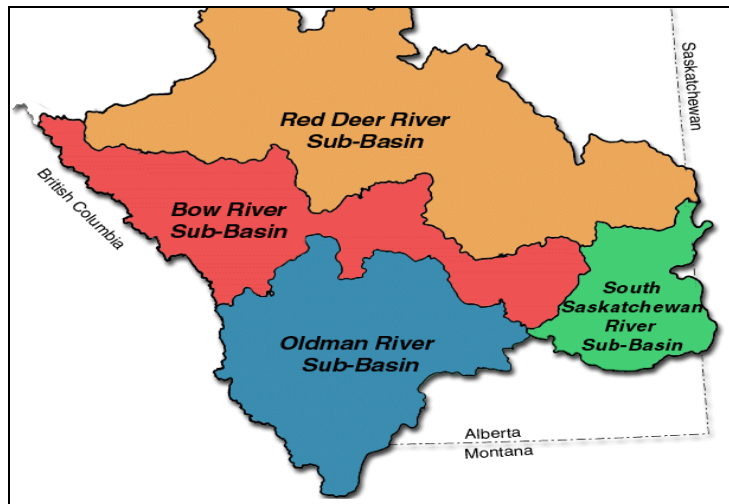


Figure 2: Sub-Basins of South Saskatchewan River Basin. Source: AENV, 2003a.

Irrigation in southern Alberta consists of a mixture of technologies that range from pivot sprinklers, wheel move sprinklers, gravitational applications, and other methods (AENV, 2009). Pivot sprinklers are the most common irrigation technology used in Southern Alberta with 69.7% overall usage (AENV, 2009). Wheel move sprinklers are used on 17% of farms, gravitational (surface) systems on 12.5%, and other methods on 0.8% of operations. Application efficiencies of these delivery systems vary and are calculated as the ratio of water delivered to the field to the amount available to the crops or the stored soil moisture level divided by the farm diversion

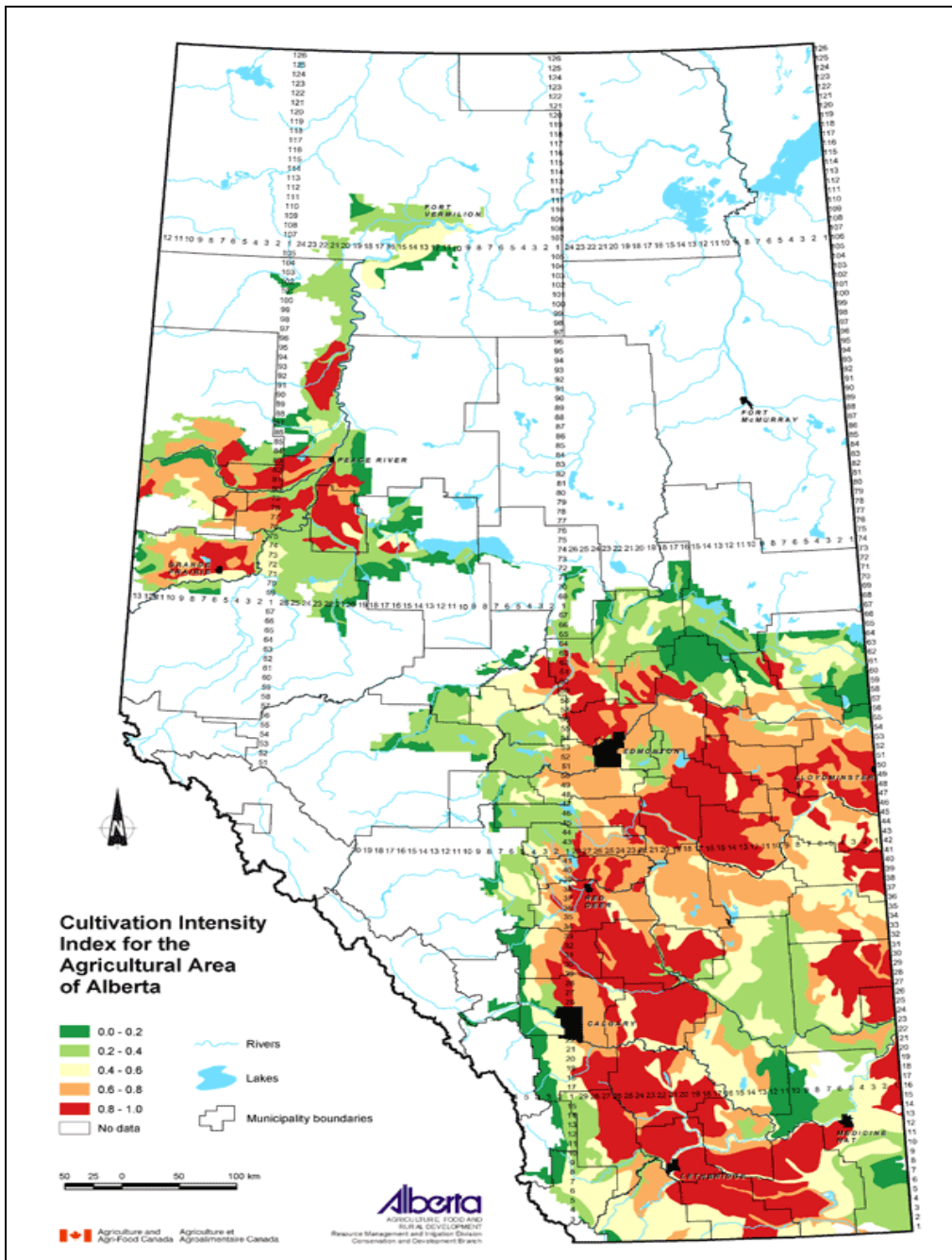


Figure 3: Cultivation Intensity for Alberta Showing Regions with Highest Level of Agricultural Activity. Source: AENV, 2005.

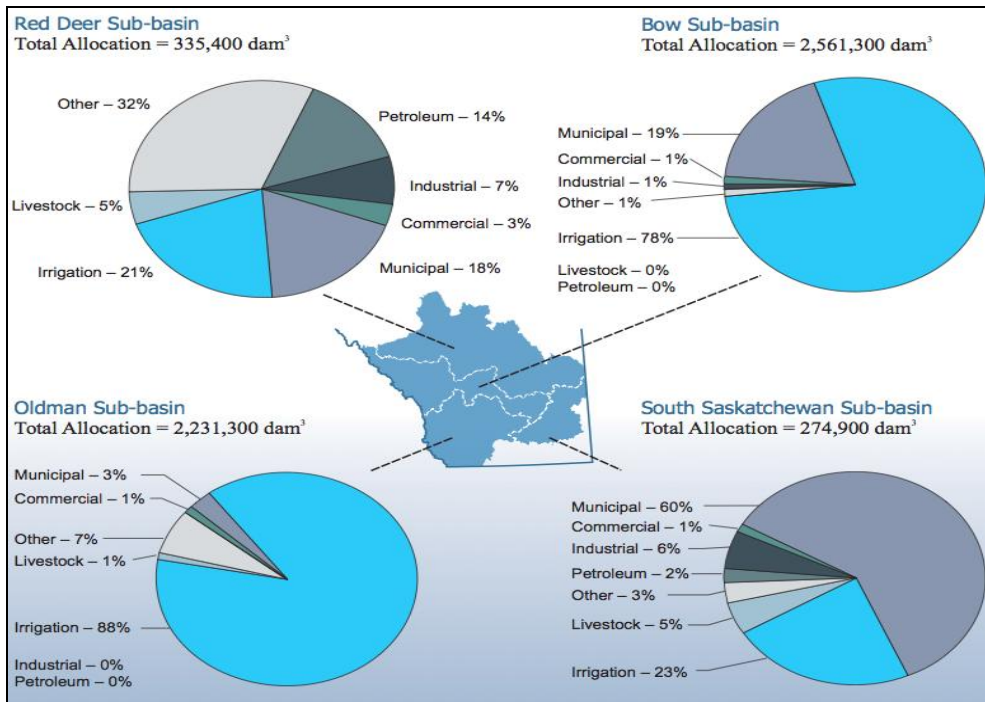


Figure 4: Distribution of Surface Water Allocations in Sub-Basins of the SSRB.

Source: Grinder, 2010: SSRB in Alberta: Water Supply Study Summary (p.9)

amount (Rogers et al., 1997; IWMSC, 2002a). The typical application efficiencies for the different systems used in Alberta are: surface or undeveloped 30%, developed 65%; wheel move sprinklers 68% (hand move wheel roll 65%); high pressure centre pivots 74%; low pressure centre pivots 80% (IWMSC, 2002a). The application efficiency is at the farm level only and does not apply to the sub-basin level.

There are 13 irrigation districts in the SSRB (Figure 5) as well as numerous private irrigation projects. This study considers the water use in just the irrigation districts, which account for about 83% of total irrigation in the region.

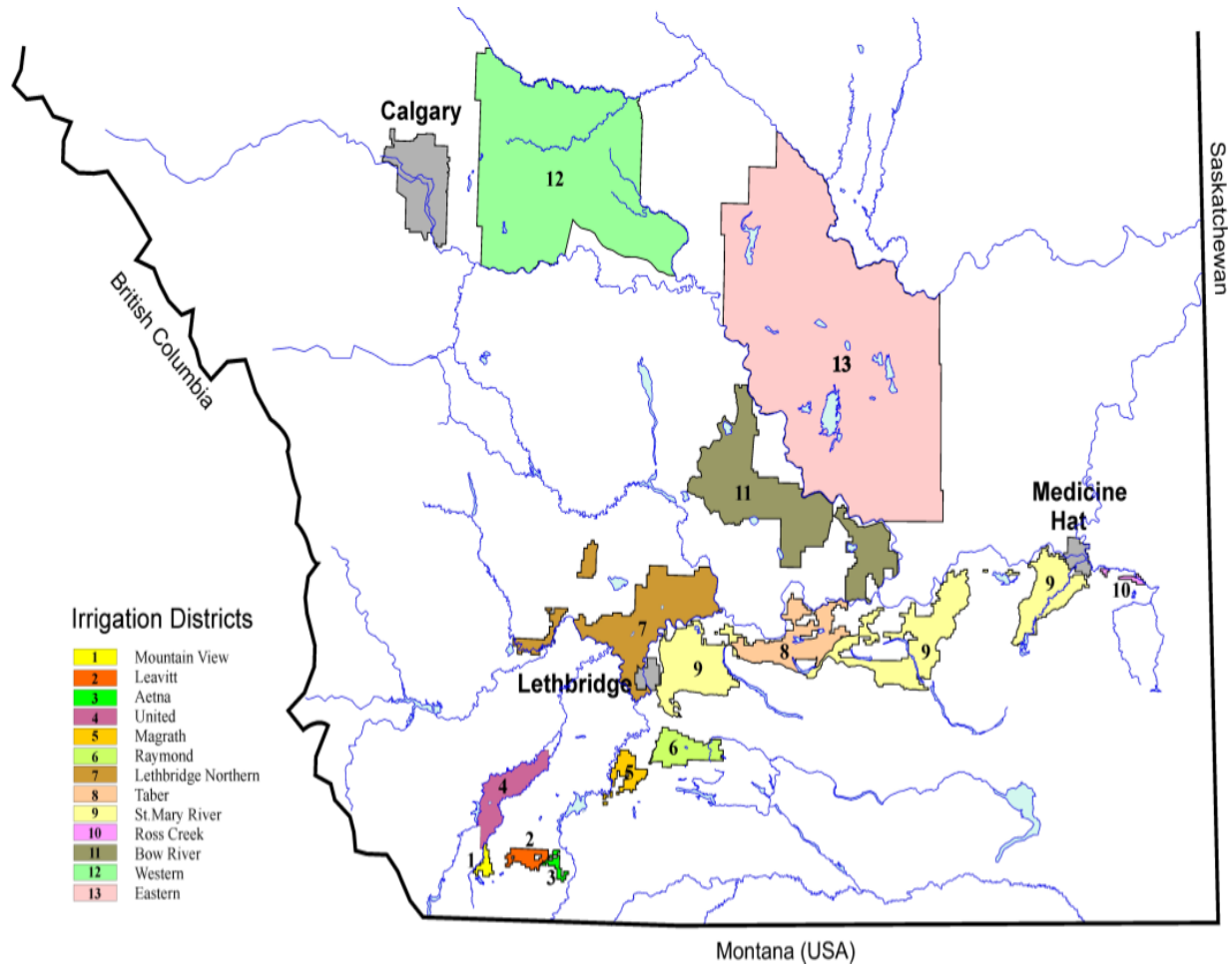


Figure 5: Irrigation Districts in South Saskatchewan River Basin. Source: AARD Website (2010b)

3.2 Data and Methods of Calculation

Four different definitions of water use efficiency are used in this study. Calculations are made of Water Use technical Efficiency (WUTE) and three definitions of Water Use Economic Efficiency: WUEE (Gross), WUEE (Net), and WUEE (Marginal). Calculations are made of these four measures for each year of a five-year period, 2004-2008 for each of the four river sub-basins in Southern Alberta. The WUTE is calculated using a variant of equation [1e]: biomass of the irrigated crops, obtained as the product of yields and acreages, is divided by the net water diverted to get the biomass per unit of water used (Mt/Dam³). Gross revenues of the irrigated crops, obtained as the product of the biomass and average crop prices, are divided by the net water diverted (a variant of equation [1f]) to obtain WUEE (Gross). For WUEE (Net), net income (gross income less variable costs of production) is divided by the net water

diverted. For WUEE (Marginal), equation [1h] is used where the net revenue from dryland crop production is subtracted from net revenue under irrigation and then divided by the units of water used. All Water Use Economic Efficiency measures result in a benefit of the irrigation water in dollars (\$/dam³).

The scope of this research is the sub-basin level in Southern Alberta. It does not address water loss in the conveyance system that might affect efficiency of water use on the farm and / or subbasin.

The denominators of all water use efficiency measures require the net diversions of water for each year over the five-year period. However, complete data on water diversions were available for only nine of the districts (Nitschelm, 2010):

- Aetna Irrigation District (AID),
- Bow River Irrigation District (BRID),
- Eastern Irrigation District (EID),
- Lethbridge Northern Irrigation District (LNID),
- Magrath Irrigation District (MID),
- Mountain View Irrigation District (MVID)
- Raymond Irrigation District (RID),
- St. Mary River Irrigation District (SMRID),
- Taber Irrigation District (TID)

To obtain estimates of net diversions for irrigation districts where data were missing, the following procedures were used:

- The net diversions for the WID were calculated using the gross diversions reported in AARD (2009, p. 10) and the 1997-2000 four-year return flow average value of 56% for the WID from IWMSC (2002a, p. 79).
- The LID return flows were estimated to be equivalent to the gross diversions and the return flow percentage from the adjacent AID.
- The return flows and net diversions of the UID were estimated using the gross diversions and the percentage return flow from SMRID (Nitschelm, 2010).
- The values for the RCID were set at zero due to the low level of diversions of this district, which has a negligible effect on sub-basin level calculations.

Gross diversions, return flows (some estimated, as explained above) and net diversions for each of the 13 irrigation districts for the five-year period are shown in Table 1. Some irrigation districts operate in more than one sub-basin (Table 2). The calculation of net diversions for each of the four sub-basins was obtained by summing the proportions of net diversions for each of the irrigation districts in each sub-basin (Table 3). The net diverted water in each sub-basin is that amount that was sent through irrigation works and applied to the crops and becomes the denominator in each of the water use efficiency measures.

In a previous study, Yan et al. (2010) estimated the total weight of biomass that was harvested, gross farming revenues, and net farming revenues (above total variable costs) of irrigated cropping activities undertaken in the four sub-basins during the years 2004-2008. The total biomass of crops produced on irrigated land was derived from the 2000-2004 average yields in metric tonnes for each of the major irrigated crops multiplied by the irrigated crop area in hectares for those years. These data are presented in the first column of Table 4 and are the numerators in the calculation of WUTE.

The second column in Table 4 is the calculation of gross revenues of all major irrigated crops grown in each of the sub-basins during the years 2004-2008. These were obtained by multiplying number of hectares planted to each of the major crops by its average yield and by its average farm-level price (Yan et al., 2010). This column provides the numerator for the calculation of WUEE (Gross).

The third column of Table 4 is the calculation of net revenues of all major irrigated crops grown in each of the sub-basins during the years 2004-2008. These were obtained by subtracting the variable costs of production from the gross revenues. This column provides the numerators for the calculation of WUEE (Net).

Table 1: Water Diversions to Alberta Irrigation Districts (cubic decametre or dam³)

Irrigation districts	Diversions	2004	2005	2006	2007	2008
AID	Gross diversion	4,243	4,934	4,540	3,990	4,421
	Return flow	1,895	2,339	2,529	1,479	2,302
	Net diversion	2,349	2,595	2,012	2,511	2,119
BRID	Gross diversion	284,709	225,504	259,945	316,410	293,569
	Return flow	69,161	111,061	62,464	58,027	63,310
	Net diversion	215,547	114,442	197,482	258,384	230,259
EID	Gross diversion	514,818	392,247	413,475	515,386	504,987
	Return flow	98,075	127,049	93,286	102,934	120,190
	Net diversion	416,743	265,199	320,190	412,452	384,797
LNID	Gross diversion	205,098	165,395	204,452	290,275	220,485
	Return flow	32,169	46,378	49,232	N/A	55,121
	Net diversion	172,929	119,017	155,220	290,275	165,364
MID	Gross diversion	15,284	10,927	17,409	22,496	15,615
	Return flow	5,115	4,437	5,112	5,173	4,137
	Net diversion	10,169	6,491	12,298	17,323	11,478
MVID	Gross diversion	3,281	2,550	4,918	4,441	3,218
	Return flow	900	1,129	1,164	1,394	1,409
	Net diversion	2,381	1,421	3,753	3,047	1,810
RID	Gross diversion	34,814	33,361	45,699	58,371	42,368
	Return flow	12,163	18,780	18,045	27,489	20,698
	Net diversion	22,650	14,581	27,655	30,881	21,670
SMRID	Gross diversion	453,305	390,027	412,106	486,855	470,203
	Return flow	33,933	87,830	40,810	24,725	41,593
	Net diversion	419,371	302,197	371,297	462,130	428,610
TID	Gross diversion	79,435	89,411	101,698	124,467	104,132
	Return flow	11,607	28,946	25,840	19,858	20,339
	Net diversion	67,828	60,465	75,858	104,609	83,793
LID	Gross diversion	6,692	7,701	6,588	7,808	7,881
	Return flow	4,386	3,172	4,289	2,442	4,065
	Net diversion	2,305	4,529	2,299	5,366	3,816
RCID	Gross diversion	34,814	33,361	45,699	58,371	42,368
	Return flow	0	0	0	0	0
	Net diversion	34,814	33,361	45,699	58,371	42,368
UID	Gross diversion	26,643	16,920	25,151	39,226	25,970
	Return flow	1,994	3,810	2,491	1,992	2,297
	Net diversion	24,649	13,110	22,660	37,234	23,673
WID	Gross diversion	140,617	148,615	88,811	83,877	104,846
	Return flow	78,745	83,224	49,734	46,971	58,714
	Net diversion	61,871	65,391	39,077	36,906	46,132

Notes: Except for LID, RCID, UID, and WID, all data are obtained from Jennifer Nitschelm, Alberta Agriculture and Rural Development, Lethbridge. Gross diversions for those four irrigation districts were taken from AARD (2009, pp. 10). Return flows for LID are estimated using the ratio of gross and return flows of the adjacent AID. Return flows for RCID are assumed to be zero. Return flows from UID were estimated using the ratio of gross and return flows of SMRID. Return flows for WID were estimated using the 1997-2000 average return flow of 56% (IWMSC, 2002a, p.79).

Table 2: Geographic Distribution of Irrigation Districts in the Four Sub-Basins of the SSRB

Sub-Basins	Constituent Irrigation Districts
Bow River	(45% of EID) + (55% of WID) + (52% of BRID)
Oldman River	AID + LID + LNID + MID + MVID + RID + TID + UID + (48% of BRID) + (40% of SMRID)
Red Deer River	(52% of EID) + (45% of WID)
South Sask. River	RCID + (60% of SMRID) + (3% of EID)

Source: Yan et al. (2010), p. 6.

Table 3: Net Diversions of Water (dam³) for the Sub-Basins, 2004-2008

Year	Sub-Basins			
	Bow	Oldman	Red Deer	S. Sask.
2004	333,518	573,941	244,453	298,822
2005	214,730	393,337	167,264	222,548
2006	268,163	542,554	184,011	277,974
2007	340,128	504,285	230,992	347,887
2008	318,142	591,643	220,768	310,956

Source: Calculated using data in Tables 1 and 2.

Yan et al. (2010) also calculated the expected net revenues that would have been obtained if the irrigated area in the four sub-basins had no access to supplementary water but, instead, had to rely on rainfall for crop growth. To obtain these, they assumed that the dryland cropping pattern that prevailed during the years 2004-2008 in areas adjacent to the irrigated region would apply in the absence of irrigation. Dryland yields were multiplied by the appropriate areas in each sub-basin and by farm-level prices to obtain gross revenues from producing dryland crops. The total variable costs of production were subtracted from the gross dryland revenues to obtain estimated net revenues under dryland conditions¹. Finally, the estimated net revenues under dryland conditions (column 4 in Table 4) were subtracted from the net revenues under irrigated conditions (column 3 in Table 4) to obtain the marginal revenues from

¹ Unlike the irrigated crop production costs, which are available only at the average level for all soil types, dryland crop production costs are available by brown, dark-brown, and black soil types for each crop. Using the percentage composition of soils in each sub-basin as weights, the total variable costs of production for dryland crops in each sub-basin was calculated as the weighted average of the production costs in brown, dark-brown, and black soils and then used for net revenue calculations.

irrigation (column 5 in Table 4). These are the values that become the numerator in the calculation of WUEE (Marginal).

Table 4. Biomass and Revenues for the Sub-Basins, 2004-2008

Year	Sub-Basins	Biomass of irrigated crops (MT)	Gross revenues of irrigated crops (mill \$)	Net revenues of irrigated crops (mill \$)	Net revenues of dryland crops (mill \$)	Marginal revenues (mill \$)
		(1)	(2)	(3)	(4)	(5) =(3)-(4)
2004	Bow	1,168,684	106.792	49.211	5.735	43.476
	Oldman	3,134,680	281.251	140.238	32.584	107.654
	Red Deer	767,720	64.990	32.352	6.459	25.893
	S. Sask	1,004,429	111.784	51.870	6.763	45.108
2005	Bow	1,160,257	115.420	52.808	-0.092	52.899
	Oldman	3,207,185	279.433	134.690	15.772	118.919
	Red Deer	735,073	67.943	33.228	2.360	30.867
	S. Sask	1,024,869	117.049	55.476	3.141	52.335
2006	Bow	1,159,959	106.857	42.755	0.669	42.086
	Oldman	3,283,402	284.496	127.406	13.323	114.083
	Red Deer	713,124	62.550	28.245	2.290	25.955
	S. Sask	990,024	107.949	45.831	0.057	45.775
2007	Bow	1,135,814	118.502	47.577	8.441	39.136
	Oldman	3,230,662	310.010	128.590	26.744	101.846
	Red Deer	732,195	71.203	32.660	5.984	26.676
	S. Sask	1,008,802	120.765	48.564	3.685	44.879
2008	Bow	989,729	153.201	66.972	14.238	52.734
	Oldman	2,916,678	369.755	157.095	52.462	104.633
	Red Deer	648,666	89.412	42.299	11.484	30.815
	S. Sask	885,956	160.313	70.183	14.691	55.492

Source: Compiled from Yan et al. (2010), various tables.

3.3 Results

Results for the WUTE shown in Table 5 were calculated using data in Table 3 and column (1) of Table 4. Over the five-year period, the average WUTE was 3.937 MT/dam³ for the Bow River, 6.201 MT/dam³ for the Oldman River, 3.504 MT/dam³ for the Red Deer River, and 3.455 MT/dam³ for the South Saskatchewan River sub-basins over the 2004-2008 period. The average WUTE was much higher for the Oldman than it was in the other sub-basins. The cropped area was larger in the Oldman River sub-basin than in the other sub-basins. Also, the 2000-2004 average yields in the Oldman River sub-basin were higher than in the other sub-

basins for major crops barley, CPS wheat, durum, oats, and soft wheat (Yan et al., 2010, p. 25). The combination of the larger cropped area with the higher yields was the largest factor driving the higher value of WUTE in the Oldman River sub-basin.

Table 5: Water Use Technical Efficiency (WUTE) for the Sub-Basins (Mt/dam³), 2004-2008

Year	Sub-Basins			
	Bow	Oldman	Red Deer	S. Sask.
2004	3.504	5.462	3.141	3.361
2005	5.403	8.154	4.395	4.605
2006	4.326	6.052	3.875	3.562
2007	3.339	6.406	3.170	2.900
2008	3.111	4.930	2.938	2.849
Mean	3.937	6.201	3.504	3.455
Std. dev.	0.939	1.229	0.611	0.710

Source: Calculated using data in Table 3 and column (1) of Table 4.

There was significant variation in calculated values of WUTE throughout the five-year period. The standard deviation of WUTE was the highest at 1.109 Mt/dam³ in the Oldman River sub-basin and lowest in the Red Deer River sub-basin. Two factors caused this variation. First the cropping pattern changed, which had effects on the numerator. More importantly, the denominator (net water diverted) changed markedly from year-to-year (Table 3).

Results for the WUEE (Gross) shown in Table 6 were calculated using data in Table 3 and column (2) of Table 4. The average calculated WUEE (Gross) was \$417.23/dam³ in the Bow River, \$592.91/dam³ in the Oldman River, \$345.05/dam³ in the Red Deer River, and \$430.21/dam³ in the South Saskatchewan River sub-basins. The highest WUEE (Gross) occurred in 2005 with the value on the Oldman River sub-basin being \$710.41 that year. In every year, the WUEE (Gross) was higher in the Oldman River sub-basin than it was in any of the other sub-basins. The use of higher efficiency equipment in the Oldman River sub-basin is a factor in this higher average WUEE (Gross). The irrigation districts that use more than 50% of the more efficient high and low pressure pivot systems mostly operate in the Oldman River sub-basin: BRID (78.2%), LNID (68.1%), RID (61%), SMRID (81.9%), TID (74.3%), and UID (68%) (AARD, 2009). Only four irrigation districts that are located somewhat in the

Oldman River sub-basin have less than 50% pivot systems: AID (15.8%), LID (19.5%), MID (45.4%), and MVID (0%) (AARD, 2009). The irrigation districts that use more than 50% pivot systems in the Bow River sub-basin are EID (58%), WID (55.7%), and BRID (78.2%). The irrigation districts that use more than 50% pivot systems in the Red Deer River sub-basin are the EID and WID. The irrigation districts that use more than 50% pivot systems in the South Saskatchewan River sub-basin are the SMRID and EID (AARD, 2009). As noted above, there is some overlap between sub-basins for some irrigation districts (Table 2).

Table 6: Water Use Economic Efficiency (Gross) for the Sub-Basins (\$/dam³), 2004-2008

Year	Sub-Basins			
	Bow	Oldman	Red Deer	S. Sask.
2004	320.20	490.03	265.86	374.08
2005	537.51	710.41	406.20	525.95
2006	398.48	524.36	339.92	388.34
2007	348.40	614.75	308.25	347.14
2008	481.55	624.96	405.00	515.55
Mean	417.23	592.91	345.05	430.21
Std. dev.	90.978	87.455	61.209	84.043

Source: Calculated using data in Table 3 and column (2) of Table 4.

Results for the WUEE (Net) shown in Table 7 were calculated using data in Table 3 and column (3) of Table 4. The average calculated WUEE (Net) was \$180.66/dam³ in the Bow River sub-basin, \$268.42/dam³ in the Oldman River sub-basin, \$163.50/ dam³ in the Red Deer River sub-basin, and \$190.61/ dam³ in the South Saskatchewan River sub-basin. The WUEE (Net) was highest in the Oldman River sub-basin in each year of the study period. The Oldman River sub-basin consists mainly of highly productive dark brown and brown soils (Yan et al., 2010). Cropping in these soils typically incur lower input costs than do the black soils. Crop prices, input cost variability, and the amount of precipitation in a given year also affect the WUEE (Net).

Table 7: Water Use Economic Efficiency (Net) for the Sub-Basins (\$/dam³), 2004-2008

Year	Sub-Basins			
	Bow	Oldman	Red Deer	S. Sask.
2004	147.55	244.34	132.35	173.58
2005	245.93	342.43	198.66	249.28

2006	159.44	234.83	153.50	164.88
2007	139.88	255.00	141.39	139.60
2008	210.51	265.52	191.60	225.70
Mean	180.66	268.42	163.50	190.61
Std. dev.	45.717	42.937	29.938	45.352

Source: Calculated using data in Table 3 and column (3) of Table 4.

Finally, the results for the WUEE (Marginal) shown in Table 8 were calculated using data in Table 3 and column (5) of Table 4. The average calculated value was \$162.89/ dam³ in the Bow River, \$215.80/ dam³ in the Oldman River, \$137.32/ dam³ in the Red Deer River, and \$171.65/ dam³ in the South Saskatchewan River sub-basins. The WUEE (Marginal) was highest during the 2005 growing season and the Oldman River sub-basin had the highest WUEE (Marginal) throughout the study period. Variability of WUEE (Marginal) was highest in the Bow River sub-basin and lowest in the Red Deer River sub-basin. The results for Δ MUEE show that the largest benefit per unit of irrigation water is in the Oldman.

Table 8: Water Use Economic Efficiency (Marginal) for the Sub-Basins (\$/dam³), 2004-2008

Year	River Sub-Basins			
	Bow	Oldman	Red Deer	S. Sask.
2004	130.36	187.57	105.92	150.95
2005	246.35	302.33	184.54	235.16
2006	156.94	210.27	141.05	164.67
2007	115.06	201.96	115.48	129.00
2008	165.76	176.85	139.58	178.46
Mean	162.89	215.80	137.32	171.65
Std. dev.	50.881	50.060	30.461	39.925

Source: Calculated using data in Table 3 and column (5) of Table 4.

One of the questions that one could pose is how closely does the technical water use efficiency reflect economic water use efficiency. This issue was examined using bivariate correlation, and results are shown in Table 9. The WUTE and WUEE (Gross) are not close for any of the sub-basins. Thus, technical efficiency does not reflect economic efficiency at the sub-basin level. The degree of association between WUEE (Net) and WUTE was slightly higher than that for WUEE (Gross), but still not very high. The Red Deer sub-basin consistently had a higher

degree of association between the technical and economic efficiency measures than did the other three sub-basins. This suggests that technical efficiency does not closely reflect changes in the economic welfare of producers in these sub-basins.

Table 9: Bivariate Correlations between Water Use Technical Efficiency and Water Use Economic Efficiency Measures, by Sub-basins

Sub-basin	Correlation between WUTE and WUEE (Gross)	Correlation between WUTE and WUEE (Net)	Correlation between WUTE and WUEE (Marginal)
Bow	0.583	0.591	0.839*
Oldman	0.650	0.797	0.965**
Red Deer	0.399	0.415	0.817*
South Sask	0.441	0.569	0.827*

Notes: N = 5; * = significant at 10% level; ** = significant at 1% level.

4 Conclusion

Southern Alberta is an area with highly developed irrigation infrastructure and multiple irrigation districts. Each irrigation district uses different combinations of irrigation infrastructure to deliver water to fields. In this study, an attempt was made to calculate different measures of water use efficiency over a five-year period in four separate river sub-basins. It appears that the benefits of irrigation are highest in the Oldman River sub-basin, regardless of the measure used. This was a result of particular cropping patterns (with associated yields), equipment used and harvested area. Results from this study demonstrate that measurements of water use efficiency are not straight-forward and interpretation of calculated values of water use efficiency need to consider factors such as crops grown, output prices, input prices, methods of irrigation and amount of net water used to irrigate, which tends to vary greatly from one year to the next.

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