Value of Irrigation Water for Drought Proofing in the South Saskatchewan River Basin (Alberta)

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Abstract: Typically, the value of irrigation water is recognized for enhancing producer income and reducing rural poverty through its primary use—crop production. However, in this study an additional benefit to producers from irrigation is explored—reducing variability in farm income due to extreme weather events (droughts). This benefit is estimated for the Alberta portion of the South Saskatchewan River Basin (SSRB). Benefits from irrigation during a drought year were measured as the difference between producer surpluses from irrigated and dryland production systems, in a drought year, excluding the value of water for irrigated crop production in a non-drought year. This value was expressed per unit of water applied to irrigation. Short-run value estimates ranged from \$37 per dam^3 in the Bow River sub-basin, to about \$42 per dam^3 in the Oldman River sub-basin. These results suggest that water used for irrigation provides additional benefits beyond enhanced producer income in crop production. Thus, it is an effective drought mitigation strategy, and provides a successful adaptation to occurrence of extreme events (droughts) under climate change.

Resumé : En général, la valeur de l'eau d'irrigation est reconnue en ce qu'elle accroît les revenus des producteurs et réduit la pauvreté en milieu rural grâce à son principal usage : les cultures agricoles. Cependant, dans la présente étude nous nous penchons sur un avantage supplémentaire que l'irrigation offre aux producteurs, soit la réduction du caractère variable des revenus d'agriculture attribuable aux phénomènes météorologiques extrêmes (sécheresses). Cet avantage est estimé pour la portion de l'Alberta du bassin de la rivière Saskatchewan Sud. Les avantages découlant de l'irrigation au cours d'une année de sécheresse ont été mesurés en tant que différence entre les surplus des producteurs tirés des systèmes de production en milieu irrigué et aride, au cours d'une année de sécheresse, à l'exclusion de la valeur de l'eau pour les cultures agricoles en milieu irrigué au cours d'une année de non sécheresse. Cette valeur a été exprimée par unité d'eau appliquée à l'irrigation. Les estimations de valeur sur une courte période allaient de 37 \$ par dam3 dans le sous-bassin de la rivière Bow à environ 42 \$ par dam3 dans le sous-bassin de la rivière Oldman. Ces résultats tendent à indiquer que l'eau servant à l'irrigation procure des avantages supplémentaires qui vont au-delà de l'accroissement des revenus des producteurs dans le domaine des cultures agricoles. Il s'agit donc d'une stratégie efficace d'atténuation des effets de la sécheresse, qui permet de bien s'adapter aux événements extrêmes (sécheresses) pouvant se produire en raison du changement climatique.

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Introduction

Application of water for irrigating crops results in other benefits to producers than just enhanced income from crop production. In this paper, irrigation benefits are extended to another direct benefit to producers from adopting irrigated production technology. These benefits arise during period of water scarcity—soil moisture deficits, which affect the crop production adversely.

Droughts are a common phenomenon on the prairies. Besides the prairie-wide drought of the 1930s, several droughts have been observed during 1984, 1985, 2001 and 2002 (Wheaton *et al.,* 2005). Through reduced crop production, these droughts can generate a large adverse impact on the producers and through that on the regional economy, and rural communities.

The hydrologist's definition of drought concerns a lengthy period of time with below mean monthly or annual streamflows (Dracup and Kendall, 1990). For determining the amount of water available for irrigation, such a definition is appropriate. However, in the context of crop production, drought definition needs to be modified to an agricultural drought. An agricultural drought is defined in terms of below mean monthly (or crop season) precipitation leading to lack of soil moisture available for crops. Under these conditions, crop growth suffers and creates many adverse impacts on the producers, and through that many downstream impacts on the economy.

During a drought period, the farm business could be affected in one of two ways. First, due to the lack of soil moisture, crop production may be reduced. Depending on the severity of drought, some of the cultivated area may have lower yields or a total crop failure (no production at all). This results in lost revenue. Secondly, through a shortage of forage during drought, some adjustments may be made in the livestock enterprises on the farm. In this study, however, livestock impacts were excluded for two reasons. The first reason is that the relationship between irrigation and livestock (beef cattle) enterprise on the same farm is not well understood. Furthermore, forage in irrigated areas is frequently sold to neighbouring dryland farms, which distorts the relationship between irrigation and beef cattle enterprise. The second reason for excluding livestock impacts was a general lack of data on livestock water use for the various sub-basins. Even though the Oldman and Bow River basins document stockwatering license allocations, there was poor data on actual stock water use. A recent study by Alberta Environment (2007) also acknowledged this shortfall. Irrigation specialists acknowledge that a yet unknown portion of irrigation water was being used for stockwatering. Some producers use water for their livestock, from a small part of the water originally diverted for irrigation, by storing it in dugouts. Others use runoff water stored in dugouts. Alternatively, they may even use part of their farm domestic water sources, groundwater sources or their exempt water allocation for stockwatering at times. Because the proportion of irrigation water used for stockwatering could not be clearly identified, this study focussed only on the crop production impacts of irrigation water, with respect to drought proofing (or drought mitigation).

The primary objective of this paper is to estimate the additional value of irrigation water through drought mitigation/drought proofing the farm business. This value is determined on a net basis, i.e., over and above that of water used for crop production. In this paper, the methodology of valuation of drought period benefits is described, starting first with a conceptual framework, and following it by methodology and results. The last section includes major conclusions of the study.

Conceptual Framework

The conceptual benefit of using irrigation as a drought-proofing measure on a farm, relative to a dryland farm, is illustrated in Figure 1. The figure plots crop yield against soil moisture availability under a dryland/irrigated production system. The lower crop yield line, *0K*, represents crop production function under dryland farming when no supplementary water is added. Let us now impose a drought during this period. The moisture availability is now reduced to $0Q_1$ and this affects crop yields which are reduced from *0b* to *0a* units.

Under supplementary irrigation, farmers' production function would be *0L*, and if Q_1Q_2 quantity of water is added as supplementary irrigation, crop yield would increase from *0a* to *0c*. This increase in the yield of *bc* units is the value of irrigation water, which is the direct value of irrigation for crop production.

Let us now revisit the same farm with irrigation under a drought condition. The first effect on the irrigated farm will be that the crop yield would not be reduced to *0a* units. This is the first set of benefits in terms of drought mitigation on this farm, shown as Y_1 in Figure 1. However, in addition, there is also a second benefit, which is discussed in three steps. First we consider that droughts are caused by "disruptions to an expected precipitation pattern and can be intensified by anomalously high temperatures that increase evaporation" (Environment Canada, 2004). Secondly, we consider that higher temperatures, among other factors, help increase evapotranspiration (ET). Thirdly, we consider that greater ET helps increase crop growth, when moisture and nutrients are not constrained, supported by an empirical crop production function developed for the SSRB (Heikkila *et al.,* 2002). This shall be the production function we use to estimate the irrigation-crop production relationship, with changes to ET (Heikkila *et al.,* 2002). Stated differently, the beneficial effects of warmer temperatures increases slightly, when water availability is included (Mendolsohn and Dinar, 2003). Under the above assumptions, under drought conditions, there may be an additional shift in the production function to *0M*. Thus, one may hypothesize an additional gain of *cd* units of crop yield under these conditions. Total gain in yield will be a sum of *ab* and *cd* units (or alternatively sum of Y_1 and Y_2 in Figure 1). This sum, if converted into producer surplus, would be the additional benefit of irrigation water during a drought period. The following section will discuss how producer surplus is estimated.

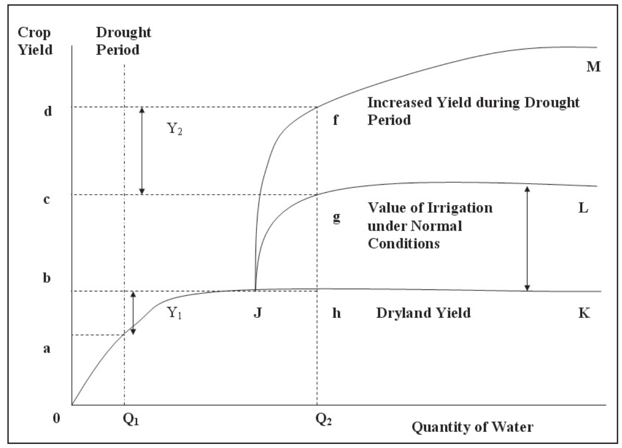

Figure 1. Drought mitigation for crop production through irrigation.

Methodology

Following the conceptual framework, as shown in Figure 1, drought mitigation benefit for crop production is composed of two parts. Part one is the distance *ab* in Figure 1 (equal to distance Y_1 units), and part two is the distance *cd* in the same figure (equal to the distance Y_2). These two changes were estimated separately.

The Y_1 benefit (or producer surplus) was calculated by subtracting drought-year crop yields from non-drought year crops yields under dryland production systems. In this study, mean crop yields between drought years 2001 and 2002, on dryland were assumed 'drought year crop yields', and mean crop yields on dryland, between non-drought years 1999 and 2000 were assumed 'non-drought year crop yields'. These mean crop yields were multiplied by price to derive gross revenue (ten-year average crop prices were used to even out price variability over time). Gross revenue minus costs provides net revenue. The difference between drought year gross revenue and non-drought year gross revenue was assumed to be similar to the difference between drought year net revenue and non-drought year net revenue, in the dryland. This is because input use in a dryland production system was assumed to change little between a drought and non-drought year. Based on Kulshreshtha and Marleau (2005), cost of production for various crops was not assumed to be changed under drought conditions. Data for crop yields for the above periods were obtained from Wittrock (2005); Sobool *et al.* (2004); and Alberta Agriculture, Food and Rural Development [AAFRD] (2003; 2005). The ten-year annualized crop prices between 1994 and 2003 were derived from AAFRD (2003).

The Y_2 benefit (or producer surplus) was calculated by subtracting non-drought year crop yield when irrigation was applied, from drought year crop yield, also when irrigation was applied. Both situations were simulated using an empirical irrigation-crop production function developed for the SSRB by Heikkila *et al.* (2002). It would help to introduce this model and its calibration, before continuing with the estimation of Y_2.

The irrigation-crop (input-output) function is shown in Equation 1.

$$Y_a = K_{ay}.[A_0 + \{A_1.(ET_a/ET_p)\} + \{A_2.(ET_a/ET_p)^2\}].Y_m \quad (1)$$

where Y_a = actual yield from each crop under prevailing water supply conditions (kg/ha); Y_m = maximum yield attainable from each crop where inputs are not limiting (kg/ha); ET_a = actual evapotranspiration; ET_p = potential evapotranspiration; K_{ay}, A_0, A_1 and A_2 are crop specific coefficients.

The crop and sub-basin specific coefficients (K_{ay}, A_0, A_1 *and* A_2) were obtained from Heikkila *et al.* (2002). They are constant through time. The variable ET_a was assumed to be the crop moisture requirement, to be satisfied by a combination of precipitation and irrigation. ET_a, ET_p, and precipitation change through time. ET_a, ET_p, and precipitation are specific to crop and sub-basin, because each crop has a different growing period that also influenced by the sub-basin it is cultivated on. As a result the three variables are referred to as effective precipitation, ET_a, ET_p. The difference between effective ET_a and precipitation helps determine crop and sub-basin specific crop moisture requirement.

Data on effective precipitation, ET_a and ET_p, for each crop on each sub-basin was provided by Chinn (*personal communication,* 2005). Chinn provided a historic average (from 1928 to 1995) for each of the above three variables in three separate data sets. The first set contained the historic (1928-1995) average of each year's mean effective precipitation, ET_a and ET_p values, for each crop and each sub-basin. The second data set contained a historic average of each year's maximum effective precipitation, ET_a and ET_p values by crop and sub-basin. The third set contained a historic average of each year's minimum effective precipitation, ET_a and ET_p values, by crop and sub-basin.

To estimate crop moisture requirements (effective ET_a minus precipitation) under drought, the model was calibrated with average historic maximum ET_a and ET_p but, average historic minimum precipitation. Similarly, irrigation requirements under non-drought conditions were estimated by calibrating the model with average historic mean ET_a, ET_p and precipitation.

The irrigation requirement would generally be greater than the crop moisture requirement, depending on different types of irrigation technology being adopted in each sub-basin and the application efficiency of each type of technology (or, how much water that was applied actually reached the roots of the crop). Estimation of irrigation requirement for a sub-basin required that the crop moisture requirement (calculated above) be first multiplied by the percentage of each crop group under different irrigation technologies, and second divided by the on-farm irrigation system efficiency. The greater the efficiency, the less water lost as wastage. Efficiency values ranged from a low of 20% for gravity to a high of 75% under pivot. A matrix of the proportion of each irrigation technology being used by different crop groups was provided by Chinn (*personal communication,* 2005). The application efficiency of each type of technology can be found in Heikkila *et al.* (2002).

In addition to irrigation requirement, the model simulated crop yields under the above drought and non-drought assumptions. The product of simulated crop yields and crop prices provided gross revenues. Again, 10-year average prices were used. Gross revenues (yields) were greater when irrigation was provided under drought years compared with non-drought because greater drought temperatures combined with irrigation were growth conducive. However, because more irrigation water is needed in a drought period, irrigation costs are also higher than under normal weather conditions.

The costs of irrigation in a drought year over a non-drought year considered only the marginal (incremental costs of irrigation). These costs differ only by irrigation technology, and not necessarily by crops grown (Heikilla *et al.,* 2002). The marginal costs with each additional unit of water applied include labour, repair and maintenance, and energy costs (Table 1). When irrigation was applied across a sub-basin, the marginal cost was estimated by first weighting the costs on Table 1 by the respective proportion of irrigation technologies adopted in the sub-basin, and then multiplying it by the incremental volume of irrigation water applied. The marginal cost shown on Table 1 was assumed to remain constant across the entire range of water application.

The difference between above estimated gross returns and irrigation costs, are called net returns. The difference in net returns between drought and non-drought conditions, gives the producer surplus denoted by Y_2, by crop and sub-basin.

Total producer surplus under drought period is the sum of the above two producer surpluses—Y_1 and Y_2. The sum of the two producer surpluses, divided by volume of water used, provides value of water during a drought period. This is the short-run value of irrigation water in drought mitigation, or alternatively called additional value of irrigation during a drought year. The volume of irrigation water used for Alberta was obtained from Beaulieu *et al.* (2007). This study

Table 1. Marginal cost of irrigation by system.

System	Labour Cost ($/mm/ha)	Repair and Maintenance ($/mm/ha)	Energy Cost ($/mm/ha)
Gravity-Flood	0.101	0.0065	0.000
Gravity-Developed	0.079	0.0200	0.000
Gravity-Controlled	0.045	0.0490	0.037
Sprinkler-Hand-move, Solid set or Wheel move	0.067	0.0570	0.195
Sprinkler-Pivot-High pressure	0.022	0.1090	0.220
Sprinkler-Pivot-Low pressure	0.022	0.1110	0.160
Sprinkler-volume gun, traveler	0.045	0.0840	0.350
Micro	0.027	0.1850	0.067

Source: Heikkila *et al.,* 2002.

reported an average water use of 5.809 dam^3 per ha. No sub-basin or crop specific estimates were available in this study. Since droughts only occur occasionally, in the long run this value will be different. Over the long run, producers explore a host of other options to respond to drought. They may substitute other inputs like more labour or energy to maintain or improve the effective distribution of water, respectively. They could invest in water conserving technology, change cropping patterns, or choose more drought-resistant crops. They could move out of farming and into other sectors like tourism, for example. These medium or long-term adaptations reduce the reliance of water for drought-proofing crops. As a result short-run value of irrigation water in drought-proofing crops, as calculated, may be an upper-bound on the value of drought proofing, when we consider the aforesaid adaptation possibilities.

Results

Since estimation of yield differences requires knowledge of water production function, this estimation was limited to seven crops. This is because the function developed by Heikkila *et al.* (2002), provided coefficients for only these seven crops. However, these seven crops comprised approximately 90% of irrigated cropping extent in the Alberta portion of the SSRB. They are shown in Table 2.

Conforming to the conceptual framework, the value of water during a drought period was estimated

Table 2. Value of irrigation water for crop production* under drought period, value for Y_1, Alberta.

Particulars	HRS** Wheat	Barley	Canola	Dry Bean	Potato	Tame Hay	Alfalfa
Dryland Avg. Yield (kg/ha)	2,791	3,255	1,513	1,233	37,660	5,622	9,950
Dryland Drought Year Yield (kg/ha)	1,782	2,313	1,121	549	37,346	3,793	6,714
Yield Difference (kg/ha)	1,009	941	392	684	314	1,829	3,237
Gross Return difference ~ Net Return Difference, or producer surplus in $/ha	$168	$112	$135	$371	$52	$144	$308

* These values are applied to all four sub-basins in Alberta.

** Hard Red Spring.

in two parts—estimation of Y_1 and Y_2 benefits. A regionally disaggregated analysis was undertaken, because the sub-basin specific crop mix, precipitation and evapotranspiration effects are different.

Results for the Y_1 benefit during a drought period are shown in Table 2. These values reflect the change in the producer surplus when dryland crop yields were affected by the drought, but irrigated yields were unaffected. In Alberta, these returns ranged from $52/ha for potatoes to $371/ha for dry beans.

Y_2 benefit was estimated on a sub-basin basis. These values reflected additional returns to producer by irrigating a crop during a drought period. These values for the Red Deer River sub-basin are shown in Table 3. Potatoes had the highest return ($469 per ha). On the other hand, tame hay had the lowest net return. This is because the high cost of irrigation, in the case of tame hay, exceeded the yield advantage under drought conditions. Results for the Oldman River, Bow River and SSRB-Alberta sub-basins are shown in Tables 4, 5 and 6, respectively. Compared to Red Deer River sub-basin, most of these estimated producer surplus values were similar, with potatoes generating the highest and the tame hay the lowest value.

The estimates of producer surplus by crop were multiplied by their respective irrigated extents and aggregated to arrive at a producer surplus by sub-basin. These values are shown in Table 7. Finally the producer surplus by each sub-basin was divided by the total volume of water allocated (5.809 dam^3 per ha) for each of the four sub-basins. The short-run value of water for drought mitigation was estimated to range from $217 to $245 per ha. When divided by the quantity of water used for irrigation, this amounts range from $37 to $42 per dam^3, for the Bow River and Oldman River basins, respectively. For the entire Alberta portion of the SSRB irrigation provided an additional net returns of $236 per ha. Considering the total irrigated area in the Basin of 504,373 ha, this translates into an income of $119.4 million during a drought year.

Summary and Conclusions

This paper discussed the value of irrigation water in mitigating drought impacts on farm business. Scope of this analysis was limited to crop production. The value of irrigation water during a drought period was divided into two parts. Part one was the difference between the value of dryland yields under normal weather conditions and those under drought periods. The second part was enhanced production of the crop

Table 3. Value of irrigation water for crop production under drought period, value for Y_2, Red Deer River sub-basin, Alberta.

Particulars	HRSWheat	Barley	Canola	Dry Bean	Potato	Tame Hay	Alfalfa
Irrigated Yields during a Drought Year in kg/ha	4,270	6,325	3,249	2,660	37,322	4,398	14,230
Irrigated Average Period Yields in kg/ha	3,673	5,382	2,936	2,252	34,057	4,243	12,876
Yield Difference (kg/ha)	597	943	313	408	3,266	155	1,355
Producer Surplus or Net Return Difference ($/ha)	$36	$54	$49	$158	$469	-$54	$51
Irrigated crop extent (ha)	8,241	18,556	8,012	3,260	2,900	23,299	30,574
Total net return in $	$296,676	$1,002,024	$392,588	$515,080	$1,360,100	($-1,258,146)	$1,559,274

Table 4. Value of irrigation water for crop production under drought period, value for Y_2, for Oldman River sub-basin, Alberta.

Particulars	HRS Wheat	Barley	Canola	Dry Beans	Potato	Tame Hay	Alfalfa
Irrigated Yields during a Drought Year in kg/ha	4,282	6,317	3,256	2,757	37,510	4,418	14,139
Irrigated Average Period Yields in kg/ha	3,649	5,321	2,924	2,285	34,122	4,202	12,829
Yield Difference (kg/ha)	633	996	332	472	3,388	216	1,310
Producer Surplus or Net Return Difference ($/ha)	$31	$43	$43	$195	$488	-$44	$61
Irrigated crop extent (ha)	13,833	49,784	15,150	9,209	9,815	30,395	38,735
Total net return in $	$428,823	$2,140,712	$651,450	$1,795,755	$4,789,720	($-1,337,380)	$2,362,835

Table 5. Value of irrigation water for crop production under drought period, value for Y_2, for Bow River sub-basin, Alberta.

Particulars	Hrs Wheat	Barley	Canola	Dry Bean	Potato	Tame Hay	Alfalfa
Irrigated Yields during a Drought Year in kg/ha	4,193	6,218	3,209	2,796	37,561	4,400	14,139
Irrigated Average Period Yields in kg/ha	3,719	5,447	2,959	2,301	34,430	4,253	13,081
Yield Difference (kg/ha)	474	771	250	495	3,131	147	1,058
Producer Surplus or Net Return Difference ($/ha)	$25	$41	$36	$209	$455	-$45	$36
Irrigated crop extent (ha)	4,645	13,319	3,584	479	540	16,736	21,677
Total net return in $	$116,125	$546,079	$129,024	$100,111	$245,700	($-753,120)	$780,372

Table 6. Value of irrigation water for crop production under drought period, value for Y_2, for SSRB-Alberta.

Particulars	HRS Wheat	Barley	Canola	Dry Bean	Potato	Tame Hay	Alfalfa
Irrigated Yields during a Drought Year in kg/ha	4,200	6,173	3,190	2,666	37,731	4,439	14,459
Irrigated Average Period Yields in kg/ha	3,781	5,528	2,991	2,385	34,996	4,276	13,210
Yield Difference (kg/ha)	418	645	199	282	2,735	163	1,249
Producer Surplus or Net Return Difference ($/ha)	$12	$24	$16	$100	$378	-$59	$36
Irrigated crop extent (ha)	8,022	17,492	9,311	6,755	4,633	11,802	17,199
Total net return in $	$96,264	$419,808	$148,976	$675,500	$1,751,274	($-696,318)	$619,164

Table 7. Weighted drought mitigation benefit by sub-basin.

Sub-Basin	Short Run Value ($/ha)	Short Run Value ($ per dam^3)
Red Deer	$237.70	$40.92
Oldman	$245.69	$42.29
Bow	$216.67	$37.30
SSRB-AB (Lower)	$230.31	$39.65
SSRB Alberta	$236.43	$40.70

less any additional cost of production from irrigation during a drought period. It seems that the Oldman River Basin had a greater proportion of its cropping extent in potatoes and dry beans compared to the other sub-basins, and this contributed to a larger benefit of drought mitigation than in other sub-basins. Overall value of irrigation water for drought mitigation was estimated at between $37 and $42 per dam^3. The smaller value was for the Bow River sub-basin and the larger value for the Oldman River sub-basin. These values are additional benefits of irrigation water to the producer.

Although we could not find studies that had placed a value on irrigation water for drought proofing, conceptually this issue is implied by some studies. For example, Mendelsohn and Dinar (2003) suggest that beneficial effects of warmer temperatures are augmented when water or irrigation is included in the model, and also that irrigation is a suitable strategy to adapt to a warming climate. Their conclusions were based on a hedonic model applied to land values to find the interaction of climate change and irrigation. Renzetti (2006) suggests that producers do not take farm inputs and crop outputs as given, but that they would substitute among them to make adaptations to drought conditions. As an example of input substitution, producers could substitute water for more labour to improve maintenance of irrigation equipment and improve efficiency. As in this study, producers' choice of substituting other inputs or outputs under drought conditions is not considered; the estimated values should be taken as an upper bound on the drought mitigation value of irrigation water. Furthermore, drought proofing the farm economy also leads to more stability in the related crop processing industries in the region as well as in rural communities (Wheaton *et al.*, 2008). Perhaps further research on lines of the hedonic valuation may be conducted to consider such adaptations and refine the value of irrigation water for drought mitigation.

Policy makers could use these values to assess future climate change impacts where the frequency of drought is expected to increase. However, these other benefits are left for future research in this area.

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