Current Irrigation Management Practices Study

2007 – 2009

Government of Alberta

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SUMMARY

The Current Irrigation Management Practices study examined irrigation practices in southern Alberta fields irrigated by low pressure drop tube pivots and served with pipeline delivery in six Irrigation Districts – Bow River, Lethbridge Northern, Magrath, Raymond, St. Mary River, and Taber. For three growing seasons from 2007 to 2009, crop water use and irrigation applications for 110 field sites and 17 crop types were determined from soil moisture measurements, recorded precipitation, and irrigation monitoring using LOPAC on/off flow monitors. The study compared observed irrigation management practices and crop water use to modeled optimum crop water use as calculated in the Alberta Irrigation Management Model.

The study found that southern Alberta irrigation producers utilizing the most efficient means of water delivery (pipeline) and water application (low pressure pivots) met an average of 91% of optimum crop water use. The majority of field sites were irrigated to almost or fully meet optimum crop water requirements. However, one-sixth of field sites were irrigated to meet from 57% to 80% of optimum crop water use, suggesting opportunities for improved irrigation management. Higher value and specialty crops were irrigated more consistently and closely to optimum crop water use, whereas cereals and alfalfa were managed more variably relative to optimum crop water use. Less than 7% of field sites were irrigated in excess of crop requirements. In two out of three years, precipitation comprised more than half of average crop water use requirements.

This study determined that significant improvements could still be achieved in individual irrigation management practices to more closely meet optimum crop water use requirements. As districts continue to install pipelines in more of the delivery network and producers upgrade existing irrigation equipment to low pressure pivots, an increasing proportion of the irrigated area will be well-positioned to be irrigated close to or at optimum crop water requirements. Producers in southern Alberta are equipped to meet optimum irrigated crop water needs now and in the future, given additional system improvements and continued security and high quality of water supplies.

ACKNOWLEDGEMENTS

This study was possible due to the cooperation of the producers whose fields were monitored. Irrigation district managers and staff assisted greatly in identifying potential fields and turnouts suitable for monitoring and by permitting flow monitors to be installed on district turnouts.

Alberta Agriculture and Rural Development staff provided technical assistance to the project in the areas of soil sampling, water measurement, laboratory analyses, data interpretation, graphics, mapping, and review comments of the report. The authors thank these colleagues for their considerable contributions.

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Turnout pipe supplying pivot in the SMRID with LOPAC flow monitor installed (right) and transit time flow meter measuring water flow (left).

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INTRODUCTION

From 1996 to 2000, Alberta Agriculture and Rural Development (ARD), with the support of the Prairie Farm Rehabilitation Administration (PFRA), Alberta Environment, and the irrigation districts, conducted a major review of on-farm irrigation management practices. The study sought to determine the extent that on-farm irrigation managers were applying irrigation water to crops relative to optimum production levels. The 5-year study determined that producers applied, on average, sufficient irrigation water to meet 84% of the water requirements needed for optimum crop production, based on the Lethbridge Research Station Irrigation Management Model (LRSIMM) crop growth model. These findings were utilized in modeling future irrigation water demands in the South Saskatchewan River Basin.

Producers and irrigation districts have implemented significant improvements in on-farm irrigation systems and water conveyance in the last decade. From 1999 to 2009, the area irrigated by low pressure pivots increased from approximately 419,000 acres to 773,000 acres in the irrigation districts, or from 34% to 60% of the total irrigated area (Fig. 1). Low pressure pivots are equipped with drop tubes and low pressure nozzles, reducing evaporation losses compared with other sprinkler methods (i.e., high pressure pivots, side roll wheel moves) commonly utilized in Alberta. During that same time, almost 900 km of pipeline were installed to replace open-channel earth canals with funding from the Government of Alberta Irrigation Rehabilitation Program (ARD, 2011a). Pipelines are more efficient than open-channel canals, as water is conveyed with no seepage or evaporation losses, return flows are reduced or eliminated and water may be delivered with pressure which eliminates the need for pump priming and provides ease of operations. By 2009, almost 43% of the total conveyance length (7,636 km) in Alberta irrigation districts was in pipeline (ARD, 2010).

A follow-up study was initiated in 2007 to re-examine the findings of the 1996-2000 study. The need for updating this information had become important as water supplies in southern Alberta were fully allocated in some reaches of the SSRB and nearing full allocation in others. Irrigation is the largest consumptive water user in the basin; therefore, determining the present level of water use by the irrigation districts and producers is critical to properly assess current and future water demand. Future demand modeling scenarios analyzed by ARD assume that irrigation producers will manage water to meet 90% of optimum crop water use requirements. This study sought to determine the level of irrigation management practices of today's producers when utilizing the best delivery and application technologies.

The objectives of this study were to:

1. Determine the current irrigation water management and water use of crops grown in southern Alberta in fields irrigated with low-pressure centre pivots and with pipeline delivery.
2. Compare actual crop water use with optimum crop water use as determined in the Alberta Irrigation Management Model (AIMM).
3. Examine the relationship between reported crop yields and measured water use for the monitored fields.
4. Adapt and test the latest technology for measuring water use by on-farm irrigation systems.

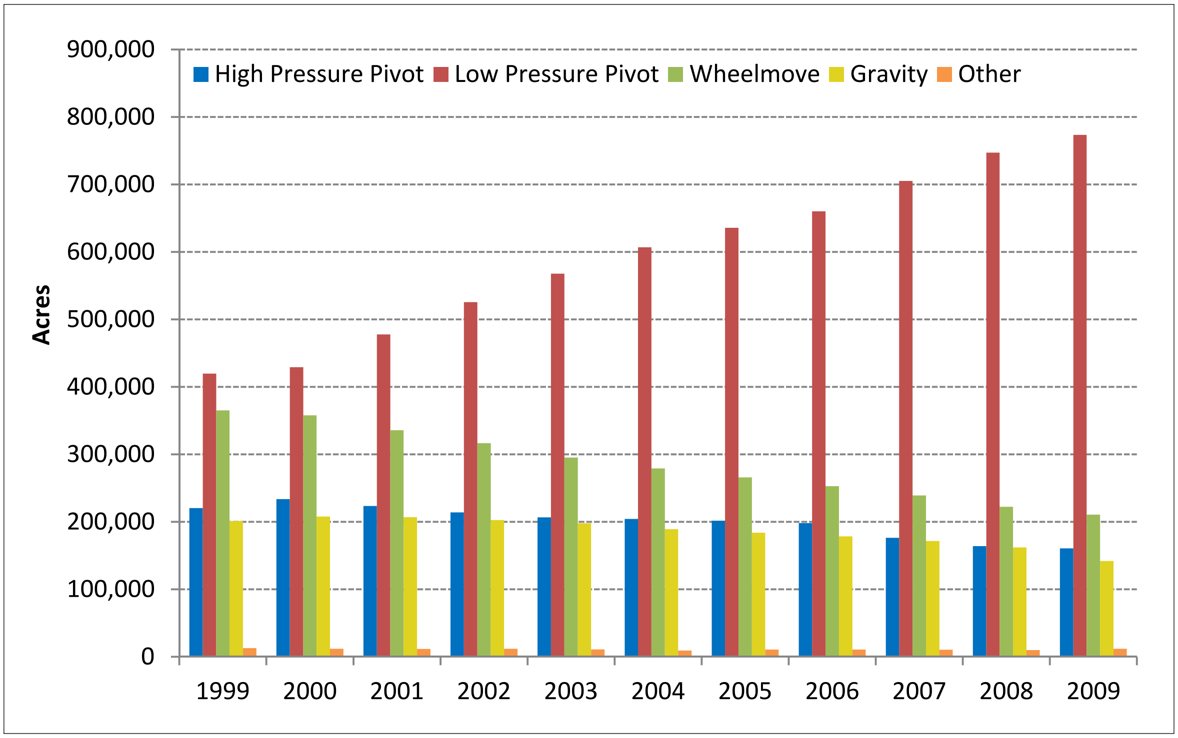


Figure 1. Acres irrigated by irrigation system type for the 13 irrigation districts in southern Alberta (ARD, 2010).

This report addresses the findings of the first three objectives listed above. The fourth objective is addressed in a separate technical report titled *Technical Evaluation for the Low Power Automatic Controls Flow Monitor*, available from ARD (Cordes et al., 2011).

METHODOLOGY

Site Selection and Crops Grown

The study focused on fields with the most efficient means of water delivery and application; fields for monitoring were supplied with irrigation water through closed pipelines and irrigated by low pressure pivots. Only fields with one crop on the entire quarter-section (to ensure uniform irrigation practices across the quarter-section) and only crops that are among the 52 different crops in the AIMM program were monitored. Limits were not placed on the number of fields of any particular crop, as it was difficult to find sufficient fields that met all the crop and irrigation system criteria and were suitable to meet the installation requirements for the monitoring equipment.

To ensure a broad cross-section of producers and of crop growth conditions (potential evapotranspiration and growing season precipitation), field sites were located in six Irrigation Districts – Bow River, Lethbridge Northern, Magrath, Raymond, St. Mary River, and Taber (Fig. 2). District managers were informed of the project and its objectives and were instrumental in identifying potential cooperating producers and suitable sites.

Producers agreed to participate in the study with an understanding that irrigation applications and timings in study fields would be monitored to assess the current state of irrigation management in the irrigation districts of southern Alberta. Producers received individual results after the study's completion to avoid influencing their management practices during the data collection phase.

Forty-seven field sites were established and monitored in 2007. Forty-four of the 2007 fields were again monitored in 2008, along with 23 new fields. The study was originally scheduled to collect field data in 2007 and 2008; however, southern Alberta experienced a widespread and damaging hailstorm season in 2008. Almost half of the 67 field sites monitored in 2008 received hail damage on the crops, eliminating the ability to assess their irrigation practices in a meaningful way. As a result, monitoring was extended to a third growing season in 2009, with 63 fields monitored that year. The majority of fields were monitored for the entire three years of the study, with different crop types on those fields each year (with the exception of alfalfa and brome grass). One year's crop production on a field is referred to as a "site year".

The crop distribution of the study fields differed slightly from the actual crop distribution reported for the 13 irrigation districts in Alberta. A majority of the fields monitored were in regions influenced by specialty crop rotations. As a general rule, the fields in the study included a greater proportion of oilseed and specialty crops than occurs for the overall irrigation district crop distribution (ARD, 2010).

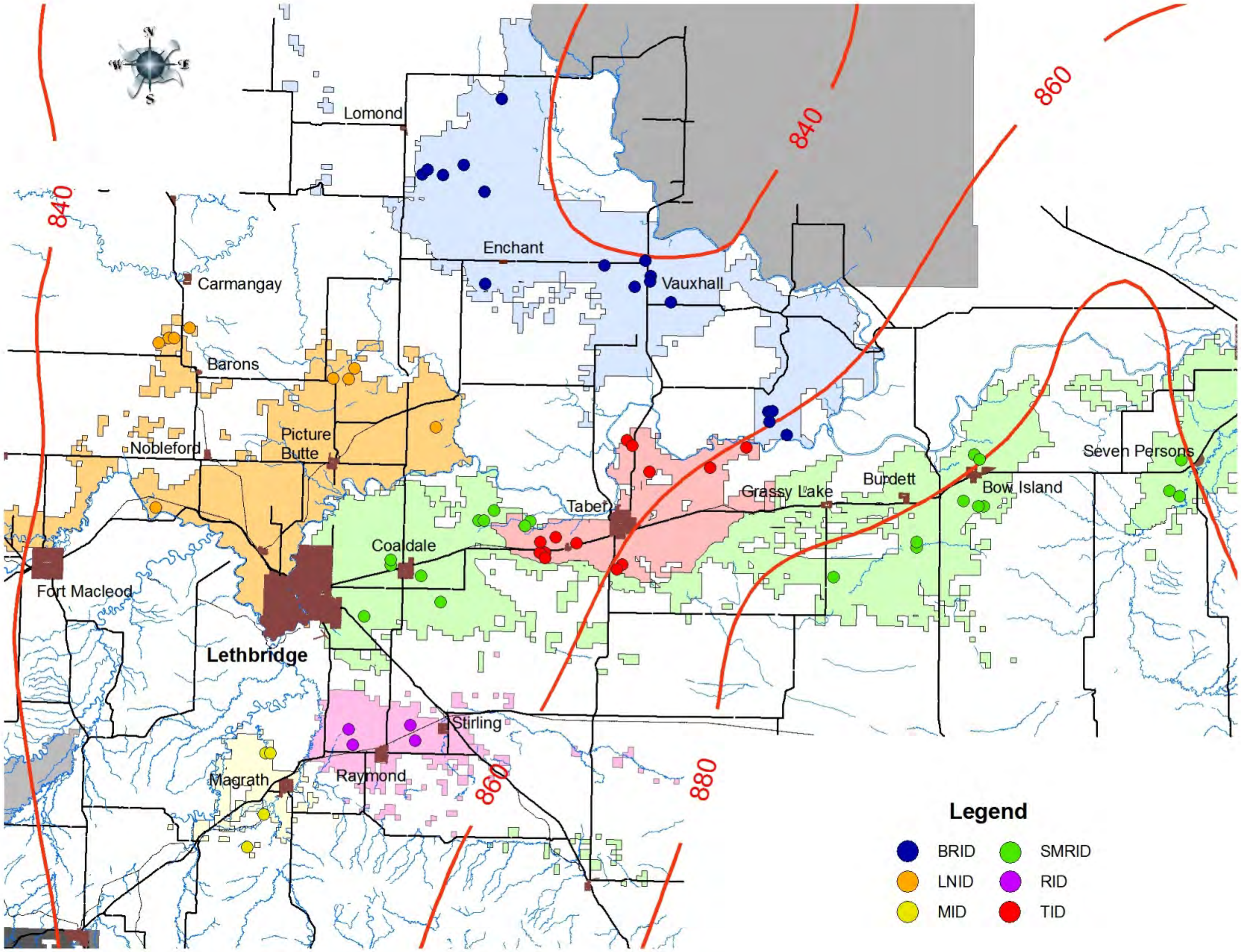


Figure 2. Fields monitored in the study. Potential evaporation (mm) isobars for the region are shown (Irrigation Water Management Study Committee, 2002).

Irrigation Management Monitoring

Each field site was instrumented with a LOPAC (Low Power Automatic Controls) flow monitor built by Aqua Systems 2000 to record the timings and durations of irrigation events. The cost of each monitor was $480 (uninstalled), a relatively inexpensive option compared to available commercial flow meters. The LOPAC monitor was installed at the irrigation turnout supplying the pivot (Fig. 3). Each flow monitor was equipped with a clock counter and a data logger (Fig. 4). At the bottom of the flow monitor, a flow vane installed into the turnout was triggered on and off by water flow through the pipe. This in turn, via a reed switch, activated the counter and recorded the change in flow status on the data logger. The total hours of irrigation were recorded on the counter, and the date and duration of each irrigation event was recorded by the data logger. A separate report on the installation requirements, performance of and adjustments made to the LOPAC flow monitors is available from ARD (Cordes et al., 2011).

Precipitation events were recorded at each field throughout the growing seasons. Each site was instrumented with a rain gauge equipped with a data logger to record the timing and amounts of precipitation (Fig. 3). The field-specific precipitation data were entered into the AIMM model.

Pivot flow was measured during the irrigation season with a GE Panametrics PT878 portable flow meter to determine the rate of water application of each pivot (Fig. 5). Flow was measured from one to three times during the season for each pivot. Gross irrigation amounts were calculated based on irrigation hours recorded by the LOPAC flow monitor at each turnout and the measured pivot flow at each field.

Sites were visited a minimum of once every three weeks during the growing season. Site visits included verification of LOPAC flow monitor function and pivot on/off status, monitoring equipment repairs, observation of crop growth, and pivot flow measurement when possible. Due to problems with the original LOPAC flow monitors, additional data were collected to provide a backup of irrigation hours provided by the LOPAC flow monitors. Suitable sites were outfitted with electric motor loggers to record pump hours, and energy readings were recorded from electrical and natural gas pumps where possible. Initially, irrigation records collected by producers were relied upon as a backup source of irrigation records; however, few producers kept detailed records and some producers referred ARD staff to their district water masters for their records. In turn, district records were found to be comparable in some cases, but in other cases, district records of irrigation dates disagreed with our field observations. The season total hours calculated by the districts tended to be comparable to LOPAC flow monitoring results. Generally, the level of detail required for the study (dates and times on and off) was not available from the producer or the irrigation district.

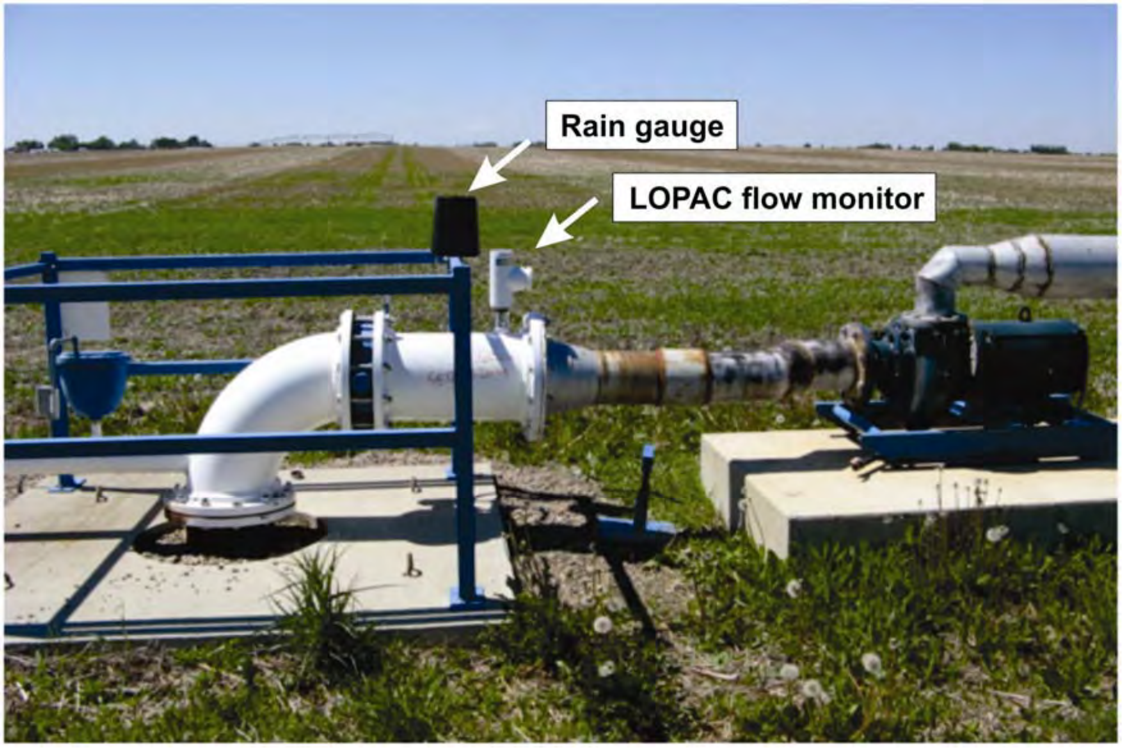
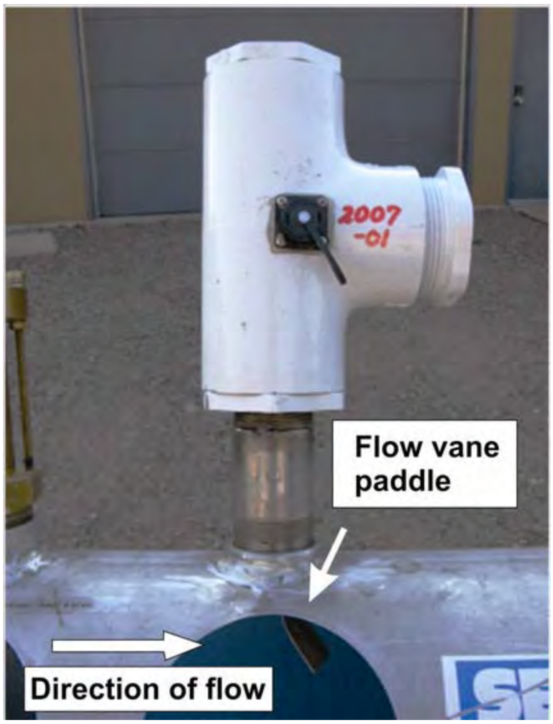


Figure 3. Field with LOPAC flow monitor and rain gauge installed at the turnout.

Four sites added to the project in 2008 were monitored by connecting district-installed McCrometer flow meters to data loggers to record irrigation on/off dates and times. These four sites were in the Keho-Barons region of the Lethbridge Northern Irrigation District, which supplies water to irrigation fields via a centralized pumping station.

Soil samples were collected in the spring after seeding and again after harvest. Changes in stored soil moisture were determined on composite samples from three sampling sites within each field. Samples were collected at 20-cm intervals to a depth of up to 120 cm, depending on the crop type. Soil samples were weighed prior to drying for 24 hours at 105º Celsius. After drying, soil samples were weighed again and gravimetric water contents were determined. Soil textures were determined by particle size analysis using the Bouyoucos 2-hr method and converting the data to a 24-hr reading (Karkanis et al., 1991). Bulk densities were calculated based on Saxton et al. (1986), and were used to convert gravimetric soil moistures to volumetric moisture values. Soil textures and volumetric moisture values were entered as AIMM input data.



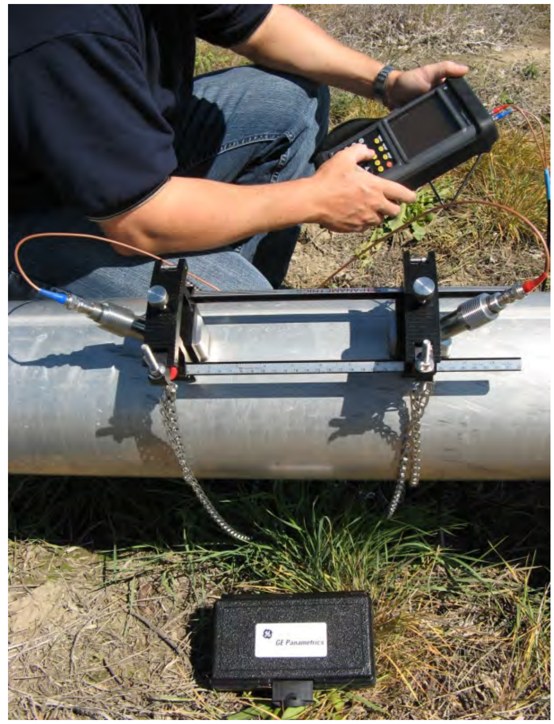


Figure 4. LOPAC flow monitor equipped with data logger and counter.

Figure 5. Measuring flow rate at a turnout supplying a monitored field with a portable flow meter.

Determination of Crop Water Use

Actual or observed crop water use (CWU) for each field site was determined using the water balance method as applied in AIMM, as follows:

$$CWU = P + I - L - O \pm \Delta S$$

where: CWU = Crop water use or evapotranspiration
P = Precipitation
I = Irrigation
L = Lost precipitation
O = Over-irrigation
ΔS = Soil moisture change

Actual CWU was determined from the date of seeding to the date of harvest. Since soil samples were typically collected in each field a number of days after seeding and harvest had actually occurred, corrections were applied as follows.

- For each field, a small positive correction was applied to account for crop water use from the seeding date to the spring soil sampling date, as estimated in the AIMM program (Online at *www.agric.gov.ab.ca/app49/imcin/aimm.jsp*).
- Similarly, a slight negative correction was applied to account for non-crop water evaporation from the soil for the time period from the harvest date to the fall soil sampling date.

The AIMM program tracks soil moisture changes through the growing season as the simulated crop grows and consumes water, based on crop growth functions specific to each crop that can be modeled in the AIMM. The required field parameters were entered into the model including seeding and harvest dates, crop type, soil texture, irrigation system output, nearest weather station weather conditions, and site-specific precipitation and irrigation dates and durations. Irrigation events (date and duration) recorded on each field's LOPAC flow monitor, and individual measured pivot flow rates were entered into the AIMM.

"Precipitation" was defined as precipitation considered potentially available to the crop. Single rainfall event amounts less than 3 mm were not included. Precipitation data were obtained from each field site's rain gauge.

"Irrigation" is the irrigation water that is potentially available for crop use, which is influenced by system type. For low-pressure centre pivot systems, the application efficiency value of 82% was used. This assumes that for every 100 mm total irrigation water applied through a low-pressure pivot, 82 mm is estimated to be potentially available to the crop. In reality, the efficiencies of the individual systems monitored in this study likely vary below and above 82%, due to system factors such as design and maintenance and weather factors such as wind. The "irrigation" value used in calculating CWU as shown above is not considered "effective irrigation", which takes into account over-irrigation.

"Lost precipitation" is calculated in the AIMM for rainfall events greater than 25 mm, based on soil moisture at the time of the rainfall event and field capacity of the soil. AIMM allows available soil moisture up to 110% of field capacity (to account for saturated hydraulic conductivity) – extra water greater than 110% is considered lost to runoff.

"Over-irrigation" is calculated in the AIMM program based on soil moisture. Water is added to the upper root zone; as it reaches 110% of field capacity, any additional water is added to the lower root zone. If the water added is greater than the field capacity of the lower root zone, water will then move out of the lower zone and is considered lost due to deep percolation and is reported as "over-irrigation" in the AIMM.

"Change in soil moisture" was calculated using the difference in root-zone moisture between spring and fall soil samples. A positive value indicates soil moisture was greater in spring than fall and net consumption occurred. A negative value indicates soil moisture was less in spring than fall and net storage of soil water occurred during the season.

Optimum Crop Water Use Modeling

For each field site, a theoretical optimum irrigation management regime and associated crop water use was determined in the AIMM program. In the model runs of optimum crop water use, the actual irrigation applications were removed from the model run, and theoretical irrigation events were added into the model as needed to maintain soil moisture at an optimal level. With this approach, effective irrigation and total irrigation amounts required to optimize crop water use during the growing season were determined. Examples of two fields analyzed in the AIMM to 1) reflect actual field conditions and 2) model optimum irrigation applications are shown in the Appendix (Fig. A-1 and A-2).

The protocol for optimum irrigation was specific for every crop, reflecting effective rooting zone, root zone transition dates, and harvest considerations. The main principle of the optimum irrigation scenario was to maintain crop growth without any moisture stress during the growing season. The detailed modeling approaches varied slightly by crop type and were as follows:

- <u>Perennial forages</u> (e.g. alfalfa, grass hay)
  Principle: Maintain available soil moisture above 50%.
  Details: Simulating the growth of the crop in the AIMM, "irrigate" to maintain available soil moisture in the entire root zone (1.2 m) above 50% for the growing season, except for harvest periods. Before the first cut, raise the available soil moisture in the entire root zone to 90-100%. From early September on, maintain available soil moisture in the upper root zone (0.6 m) above 50%. Add irrigation in increments of 25 mm effective irrigation (30.5 mm total irrigation), with a minimum of 3 days between applications and no irrigation during harvest periods. Dormancy was assumed to begin on September 15.

- <u>All other crops</u>
  Principle: Maintain available soil moisture above 70%.
  Details: Simulating the growth of the crop in the AIMM, "irrigate" to ensure available soil moisture in the upper half of the root zone (Appendix, Table A-1) is at least 70% at the start of irrigation season. Before the crop-specific root zone transition date (programmed in the AIMM; the date when crop moisture use extends from only the upper root zone to the entire root zone) is reached, raise the available soil moisture in the entire root zone to 90-100%. Then maintain available soil moisture in the upper and entire root zones above 70% for the growing season until the crop-specific irrigation cutoff date is reached. The last allowable irrigation before the irrigation cutoff date is applied only if the upper root zone available soil moisture would otherwise drop below 70%. Add irrigation in increments of 25.0 mm effective irrigation (30.5 mm total irrigation), with a minimum of 3 days between applications. For dry beans only, irrigation was added in increments of 19.0 mm effective irrigation (23.2 mm total irrigation) to avoid over-irrigating the shallow-rooted crop.

Meteorological Data

Meteorological data for the study were obtained from ARD's Irrigation Management Climate Information Network (IMCIN) (Online at *www.agric.gov.ab.ca/app49/imcin/about.jsp*). Data from nine weather stations situated throughout the study area were compared for growing season precipitation, corn heat units, and potential evapotranspiration to determine growing season conditions among sites and years. Additionally, the AIMM model relies on the IMCIN stations for meteorological inputs when modeling crop water use. For each study site, the nearest IMCIN station's data file was uploaded to the model.

Data Analysis

Following each growing season, producers were contacted to verify the recorded irrigation hours, and to report their crop yield results and information on hail and other production aspects that may have impacted irrigation management or crop yield.

For each field site, the actual crop water use determined from field measurements and the optimum crop water use determined by computer modeling through the AIMM were compared to determine how closely the producer met optimum crop water demand for the crop. Each field site was also assessed for over-irrigation by analyzing irrigation practices in AIMM.

A field site was excluded from the irrigation management analysis for that study year if monitoring equipment failed, resulting in lost data or more commonly, if crop production was noticeably impacted from agronomic adversities including hail damage, insects, disease, frost, and weed pressure. Of the 176 site years during the three years of the study, 110 site years were successfully monitored (Table 1). Forty-six site years were lost to hail and 20 site years were lost due to other reasons including agronomic production problems, or loss of irrigation or cropping data.

A field site was excluded from the crop yield analysis component of the project when yield results for a field were not provided or if crop yield was not expected to be a reflection of irrigation management (e.g., seed canola, where yields are highly variable).

Unless otherwise indicated, forage crops were grown for hay and cereal crops were grown for grain. The small number of study fields for some crops limited the analysis and conclusions that could be drawn from the data. Crops with only one or two site years of data were typically not discussed in the results.

Data from each field included in the final results were summarized and a report was provided to each cooperating producer in the form of a report (see example, Appendix Fig. A-3).

Table 1. Crop types for field sites monitored and analyzed.

Crop type		Site years			
		2007	2008	2009	*Total*
Forages	Alfalfa	5	3	4	*12*
	Brome hay	0	1	1	*2*
	Corn, Silage	0	0	1	*1*
Cereals	Barley	6	1	3	*10*
	Oats	1	0	0	*1*
	Triticale	1	0	0	*1*
	Wheat, Durum	1	3	6	*10*
	Wheat, HRS	5	4	9	*18*
	Wheat, Soft	2	1	0	*3*
	Wheat, Winter	0	1	3	*4*
Oilseeds	Canola	1	2	5	*8*
Specialty crops	Canola, Seed	0	5	7	*12*
	Corn, Sweet	0	2	0	*2*
	Dry beans	2	2	1	*5*
	Peas, Fresh	2	0	2	*4*
	Potatoes	3	3	5	*11*
	Sugar beets	3	0	3	*6*
Total		32	28	50	*110*

RESULTS AND DISCUSSION

Weather and Growing Conditions

Weather and growing conditions varied among locations and years as indicated by precipitation (Fig. 6), corn heat units (Fig. 7), and potential evapotranspiration (Fig. 8) recorded at the IMCIN sites in the study area. In general, growing season precipitation was greatest in 2008 and least in 2007. Precipitation also varied within the growing seasons. Three representative IMCIN stations in the study area had below average precipitation in June and July of 2007 (Appendix, Table A-2). In contrast, precipitation in 2008 was above average, particularly in May through July. Precipitation was less than normal in May and June but normal to above normal in July and August in 2009.

Potential crop water use, based on alfalfa as the reference crop, was generally greatest in 2007 and least in 2008 (Fig. 7). Alfalfa reference crop water use was above average in June and July in 2007 and slightly below average in May through June of 2008, as well as September 2008 (Appendix, Table A-2). In 2009, May, June and September were above average, with July and August below the long-term normal values. The data point to the variability in crop growth potential from year to year as influenced by weather conditions.

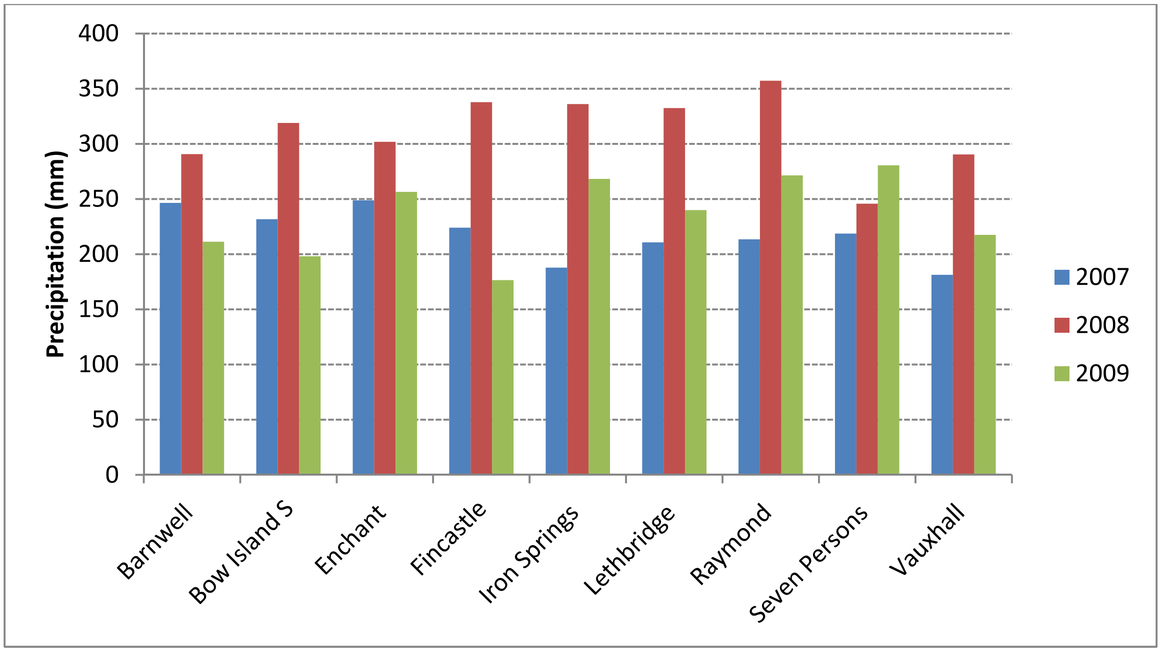


Figure 6. Growing season precipitation from April 1 to September 30 recorded at the IMCIN stations in 2007 to 2009.

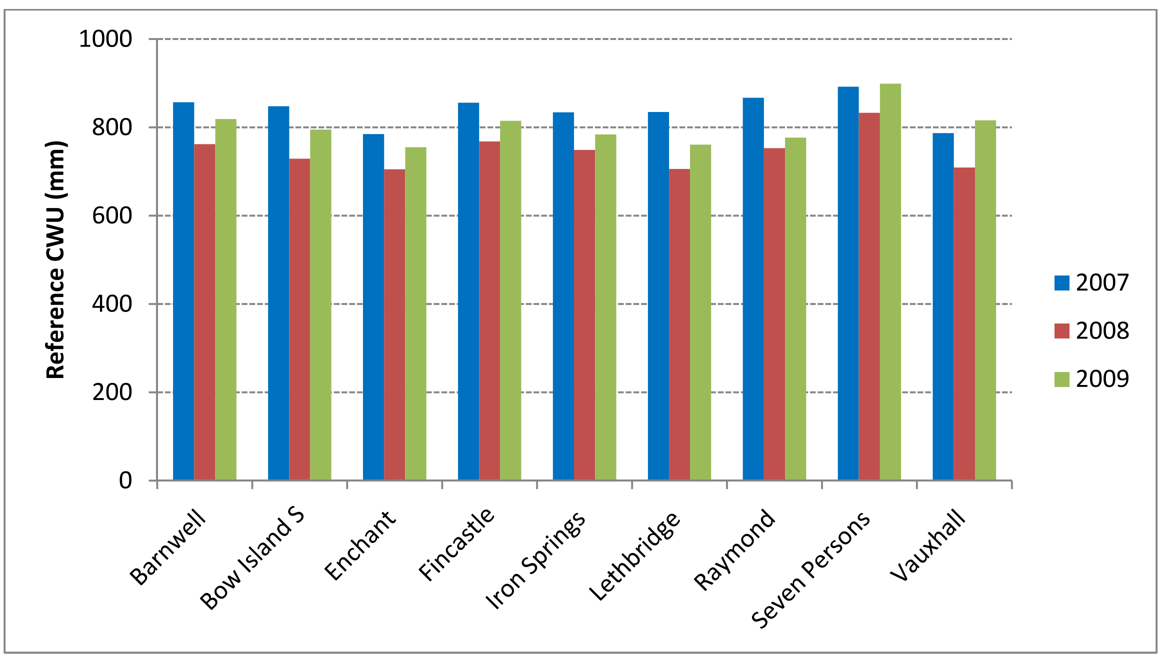


Figure 7. Reference crop water use (CWU) for alfalfa calculated for the IMCIN stations from 2007 to 2009.

Irrigation Water Applied

Irrigation water supply was not limiting in the three years for the irrigated areas in this study. Gross irrigation applications (irrigation water as measured at the farm turnout) were generally greatest in the relatively dry year of 2007 compared to the other years for the same crop, although a few exceptions were observed (Fig. 8). Variation in gross irrigation amounts for the same crop within or among years likely reflect influencing factors such as agronomic practice effects (e.g., tillage practices, crop rotations) on stored soil moisture, producers' irrigation management styles, and variability in agroclimatic factors (e.g., potential evapotranspiration, precipitation) (Table 2). For example, two fresh pea fields in 2007 received significantly different gross irrigation amounts; one received 143 mm and the other 379 mm. However, the field with the lower irrigation amount was seeded earlier and received much more precipitation.

The greatest gross irrigation amount was 470 mm applied to a potato field in 2007 (Table 2). The smallest amount, 40 mm, was applied to a winter wheat field that received a large rainfall event in July of 2008. Considering only crops where multiple field sites were monitored, sugar beets received the most irrigation on average, followed by alfalfa, potatoes, brome hay and fresh peas. Barley received the least gross irrigation amounts on average.

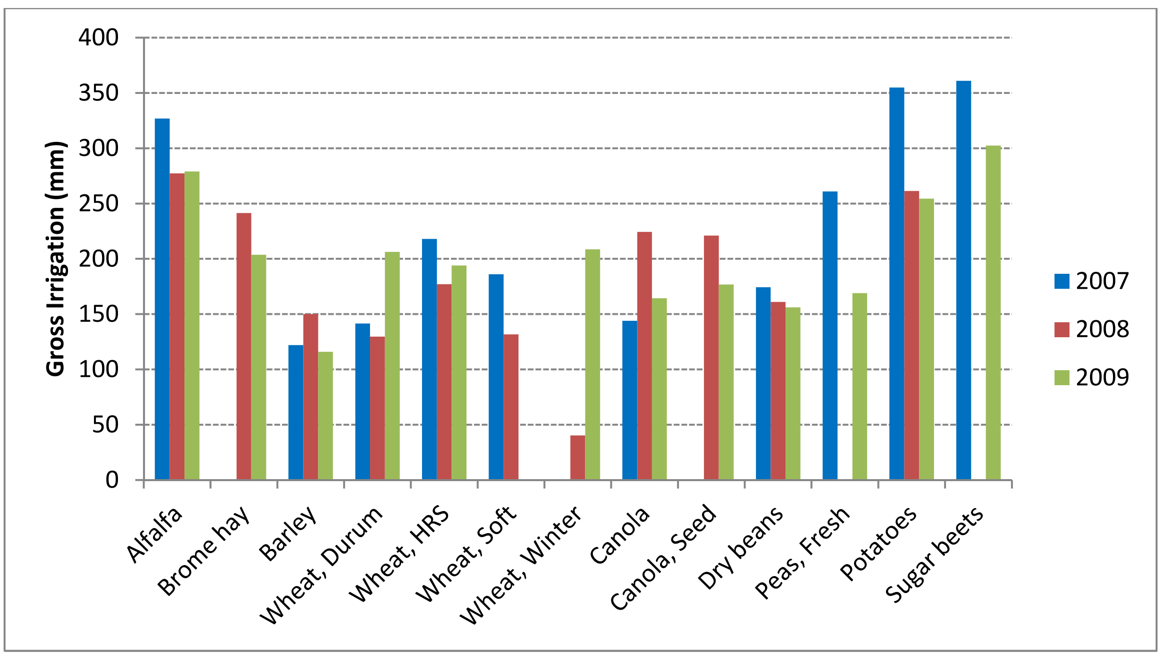


Figure 8. Mean gross irrigation applications by crop type from 2007 to 2009 for selected crops.

Table 2. Range of observed gross irrigation (farm gate) applied from seeding to harvest.				
Crop	*Site years*	Gross irrigation applied (mm)		
		Minimum	Maximum	Mean
Alfalfa	*12*	206	362	298
Brome hay	*2*	204	241	223
Corn, Silage	*1*	-	-	74
Barley	*10*	61	183	123
Oats	*1*	-	-	135
Triticale	*1*	-	-	255
Wheat, Durum	*10*	101	263	177
Wheat, HRS	*18*	121	355	197
Wheat, Soft	*3*	132	215	168
Wheat, Winter	*4*	40	243	166
Canola	*8*	107	304	177
Canola, Seed	*12*	160	244	195
Corn, Sweet	*2*	183	218	201
Dry beans	*5*	145	200	165
Peas, Fresh	*4*	143	379	215
Potatoes	*11*	193	470	284
Sugar beets	*6*	288	410	332
2007	*32*	74	470	235
2008	*28*	40	321	198
2009	*50*	61	320	202

Observed irrigation management practices and precipitation events were entered and assessed in the AIMM program for each field site to determine if any sites had received excessive irrigation. Of the 110 site years in the study, 7 site years received some amount of excessive irrigation or improper irrigation timing (irrigation water applied beyond the capacity of the soil to retain the water) (Table 3). Most of these fields received less than 50 mm of excess irrigation, while one field received in excess of 100 mm. Both fields that received more than 50 mm of excess irrigation were owned by the same producer. Overall, less than 7% of fields were over-irrigated by an average of 35 mm. In the 1996-2000 study, 11% of fields irrigated by pivot were estimated to have been over-irrigated by 23 mm on average (Hohm et al., 2002). By contrast, all surface irrigated fields and 34% of wheel-move fields were over-irrigated in the 1996-2000 study.

Table 3. Number of sites determined to have been over-irrigated.	
Actual over-irrigation (mm)	Site years
1-50	5
50-100	1
100-150	1
>150	0
Number of site years over-irrigated	7

Effective irrigation is summarized by crop in Table 4. Effective irrigation is defined as the amount of irrigation water actually available to the crop; therefore, these amounts are always less than the gross irrigation amounts. Effective irrigation does not include irrigation water delivered to the pivot but lost to evaporation, deep drainage, and runoff. Considering only crops with multiple field sites, the greatest actual effective irrigation amounts were applied to sugar beets, alfalfa, potatoes, brome hay and fresh peas.

Table 4. Range of observed effective irrigation applied from seeding to harvest.

Crop	*Site years*	Effective irrigation applied (mm)		
		Minimum	Maximum	Mean
Alfalfa	*12*	169	297	245
Brome hay	*2*	167	198	183
Corn, Silage	*1*	-	-	61
Barley	*10*	50	150	97
Oats	*1*	-	-	111
Triticale	*1*	-	-	209
Wheat, Durum	*10*	83	216	145
Wheat, HRS	*18*	99	218	157
Wheat, Soft	*3*	108	176	138
Wheat, Winter	*4*	33	199	137
Canola	*8*	88	249	145
Canola, Seed	*12*	131	200	160
Corn, Sweet	*2*	150	179	165
Dry beans	*5*	107	155	130
Peas, Fresh	*4*	117	286	170
Potatoes	*11*	158	281	222
Sugar beets	*6*	236	336	272
2007	*32*	61	336	186
2008	*28*	33	163	162
2009	*50*	50	262	165

Crop Water Use

Observed CWU varied considerably among crops and years (Fig. 9). Alfalfa, brome hay, sugar beets, and potatoes typically had the greatest CWU values, with barley, dry beans and fresh peas having the least CWU. Actual CWU was generally greatest in 2008 compared to other years, within the same crops, although a few exceptions were observed, and not all crops were represented in 2008.

The range of CWU within crops was considerable, even within the same year (Table 5). In particular, the ranges for barley, durum, and HRS wheat fields were large, as was observed for applied irrigation amounts. The numbers of fields for these crops were greater than other crops, and the fields were widespread through the study area, reflecting differences in growing conditions and irrigation management.

On average, for crops with multiple site years, CWU was greatest for alfalfa, followed by sugar beets, brome hay and potatoes. This pattern is similar to the trend observed for gross and effective irrigation applications. Fresh peas differ from other crops in the study; fresh peas tended to receive greater than average amounts of irrigation applications, but CWU was the least of any of the crops.

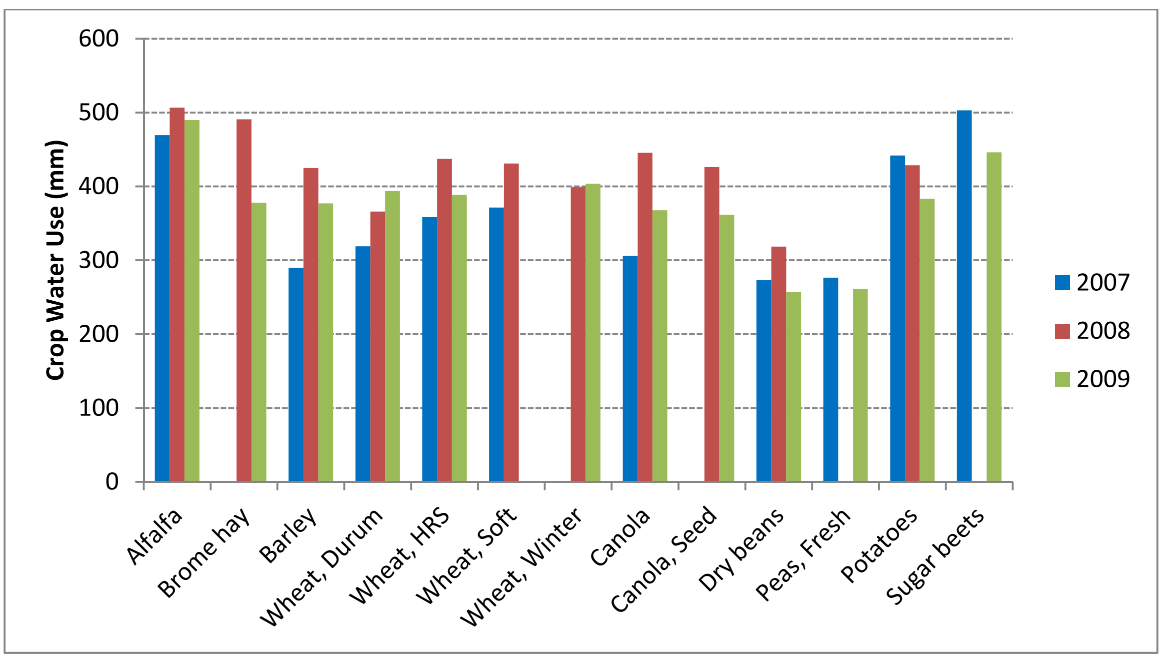


Figure 9. Mean crop water use by crop type for selected crops in 2007 to 2009.

Table 5. Range of crop water use by crop.

Crop	*Site years*	Crop water use (mm)		
		Minimum	Maximum	Mean
Alfalfa	*12*	403	536	486
Brome hay	*2*	378	491	435
Corn, Silage	*1*	-	-	339
Barley	*10*	249	425	330
Oats	*1*	-	-	311
Triticale	*1*	-	-	419
Wheat, Durum	*10*	263	449	378
Wheat, HRS	*18*	272	465	391
Wheat, Soft	*3*	346	431	391
Wheat, Winter	*4*	344	466	403
Canola	*8*	306	466	380
Canola, Seed	*12*	312	460	389
Corn, Sweet	*2*	384	419	402
Dry beans	*5*	257	340	288
Peas, Fresh	*4*	248	305	269
Potatoes	*11*	340	471	412
Sugar beets	*6*	419	526	475
2007	*32*	248	536	372
2008	*28*	263	536	424
2009	*50*	254	510	386

Crops access water for plant growth from three main sources – stored soil moisture, growing season precipitation, and irrigation. Crop water use (CWU) was calculated for each field by summing the amounts of water used from these three sources. Overall, the smallest amounts of crop water use were derived from stored soil moisture; in particular, a negligible amount of crop water use was from stored soil moisture in 2008, a year with the highest in-crop effective precipitation (Table 6). As the minimum soil moisture values suggest, in a number of sites soil moisture use was a net negative value, meaning that root zone soil moisture was greater at harvest than at seeding due to net additions from irrigation and precipitation. In 2007, a relatively dry year, 31 out of 32 fields used some amount of stored soil moisture during the season (data not shown). In 2008, a relatively wet year, only 13 of the 28 monitored fields had some amount of stored soil moisture used for crop growth. In 2009, 38 of the 50 field sites relied on some amount of soil moisture for crop water use.

Table 6. Range of observed crop water use originating from soil moisture, effective irrigation, and in-crop effective precipitation from seeding to harvest in 2007 to 2009.

Water source	*Site years*	Crop water use (mm)		
		Minimum	Maximum	Mean
Soil moisture				
2007	*32*	-2	127	72
2008	*28*	-58	102	2
2009	*50*	-35	117	32
Effective irrigation				
2007	*32*	61	336	186
2008	*28*	33	263	162
2009	*50*	50	262	165
Effective precipitation				
2007	*32*	12	185	122
2008	*28*	148	344	262
2009	*50*	86	265	187

As with soil moisture, the amounts of crop water use derived from precipitation and irrigation varied from year to year. In 2007, more crop water came from irrigation, whereas in 2008, precipitation contributed a greater amount. Similar amounts of precipitation and irrigation contributed to crop water use in 2009.

Soil moisture use for crop growth is summarized by crop in Table 7. Soil moisture use ranged considerably within and among crops, reflecting variability in spring soil moisture amounts, in-crop precipitation and crop-specific management. On average, cereal crops relied on approximately 45 to 100 mm of stored soil moisture for crop growth. Seventeen out of 47 field sites of cereal crops used approximately 90 to 125 mm of stored soil water for crop growth (data not shown). Oilseed and special crops, on average, relied on relatively small amounts of stored soil moisture for crop water use, less than 40 mm, although individual field sites used up to 90 mm of stored soil moisture.

Table 7. Range of observed soil moisture use from seeding to harvest.

Crop	*Site years*	Net soil moisture use (mm)		
		Minimum	Maximum	Mean
Alfalfa	*12*	-58	86	15
Brome hay	*2*	-11	5	-8
Corn, Silage	*1*	-	-	80
Barley	*10*	32	126	87
Oats	*1*	-	-	97
Triticale	*1*	-	-	89
Wheat, Durum	*10*	-5	102	43
Wheat, HRS	*18*	-10	115	56
Wheat, Soft	*3*	34	127	85
Wheat, Winter	*4*	25	88	66
Canola	*8*	-58	92	23
Canola, Seed	*12*	-54	86	12
Corn, Sweet	*2*	-2	40	19
Dry beans	*5*	-5	64	25
Peas, Fresh	*4*	-4	51	13
Potatoes	*4*	-57	32	-6
Sugar beets	*6*	-15	90	39

Comparison to Optimum Crop Water Use

Optimum CWU was determined in the AIMM program for each monitored field site by inputting observed climate data and field specific precipitation events, and modeling irrigation applications to maintain soil moisture levels at optimum throughout the growing season with modeled irrigation applications. As with observed CWU, each crop exhibited a range of optimum CWU (Table 8). The greatest optimum CWU was calculated for alfalfa at 624 mm. Alfalfa had a significantly greater optimum CWU range and average than all other crops in the study. Sugar beets had the next highest optimum CWU potential, averaging 543 mm, followed by sweet and silage corn, brome hay, and potatoes. Wheat crops averaged just less than 430 mm, while canola and canola seed averaged less than 400 mm. Barley, oats, dry beans, and fresh peas had the smallest optimum CWU requirements.

Table 8. Range of optimum crop water use as determined in the AIMM.

Crop	*Site years*	Optimum Crop Water Use (mm)		
		Minimum	Maximum	Mean
Alfalfa	*12*	558	720	624
Brome hay	*2*	442	455	449
Corn, Silage	*1*	-	-	451
Barley	*10*	337	403	369
Oats	*1*	-	-	354
Triticale	*1*	-	-	399
Wheat, Durum	*10*	367	463	429
Wheat, HRS	*18*	392	465	432
Wheat, Soft	*3*	424	464	438
Wheat, Winter	*4*	392	451	424
Canola	*8*	372	414	395
Canola, Seed	*12*	378	413	392
Corn, Sweet	*2*	465	492	479
Dry beans	*5*	269	392	341
Peas, Fresh	*4*	220	299	253
Potatoes	*11*	352	524	446
Sugar beets	*6*	495	595	543
2007	*32*	220	720	441
2008	*28*	387	624	453
2009	*50*	232	610	425

Table 9 examines the relationship of observed CWU to the AIMM-modeled optimum achievable CWU. Overall, observed CWU for the crops monitored in 2007 to 2009 averaged 91% of optimum CWU. However, observed CWU as a percent of optimum CWU was not consistent for all crops, so results were examined on a crop-specific basis.

The range of observed CWU relative to optimum CWU was lowest for alfalfa, at 60 to 86% of optimum crop water use. Alfalfa may be under-irrigated due to the difficulty of meeting crop water requirements at peak growing times, while also accommodating several weeks without irrigation at each cutting and baling period. Alternatively, the monitored alfalfa crops may have utilized soil moisture deeper in the profile than the 1.2 m active root zone depth set for the study.

Table 9. Observed crop water use as a percent of optimum crop water use by crop as determined with the AIMM.

Crop	*Site years*	Observed as a percent of Optimum Crop Water Use (%)		
		Minimum	Maximum	Mean
Alfalfa	*12*	60	86	78
Brome hay	*2*	86	108	97
Corn, Silage	*1*	-	-	75
Barley	*10*	71	107	89
Oats	*1*	-	-	88
Triticale	*1*	-	-	105
Wheat, Durum	*10*	57	102	89
Wheat, HRS	*18*	65	110	91
Wheat, Soft	*3*	82	93	89
Wheat, Winter	*4*	80	103	95
Canola	*8*	82	114	96
Canola, Seed	*12*	83	117	99
Corn, Sweet	*2*	83	85	84
Dry beans	*5*	76	96	85
Peas, Fresh	*4*	90	117	107
Potatoes	*11*	79	105	93
Sugar beets	*6*	81	93	87
2007	*32*	60	117	86
2008	*28*	57	117	94
2009	*50*	72	110	91
Mean of all site years		57	117	91

Considerable variation in irrigation management relative to optimum CWU was observed for cereal crops, perhaps a reflection of the large number of fields in the study that were in cereals and also likely an indication of diversity in producers' irrigation management practices. Cereal crops are generally not as profitable as specialty crops or canola, and may not receive as much intensive management. Crops such as alfalfa and cereal crops are generally thought to be tolerant of some moisture stress during the growing season, which may factor into producers' irrigation management decisions.

Specialty crops, canola and soft and winter wheat were managed more consistently among field sites/producers and more closely to optimum crop water needs relative to cereal and forage crops (Table 9). Crop quality is an important factor in production of these crops, and producers likely managed irrigation applications and timings to maximize crop quality.

The ratios of actual to optimum CWU varied among years, with greater average ratios observed in 2008 and 2009 than in 2007. This suggests that producers were able to manage irrigation amounts and timings more closely to optimum crop water needs in the latter two years of the study, because more precipitation was received in the 2008 and 2009 growing seasons than in the 2007 growing season. In particular, precipitation in June, July and August in 2007 was below to well below normal long-term average precipitation. In general, crop water demand for most crops is greatest from late June through the first half of August, thus timely rains can be of considerable benefit to supplement irrigation during peak crop water demand.

A considerable range of levels of irrigation management were observed during the three-year study. More than half of all field sites achieved at least 90% of optimum crop water requirements (Fig. 10). Approximately one-third of fields achieved between 80 and 89% of optimum CWU, while less than 15% of sites were irrigated to meet less than 80% of optimum CWU requirements.

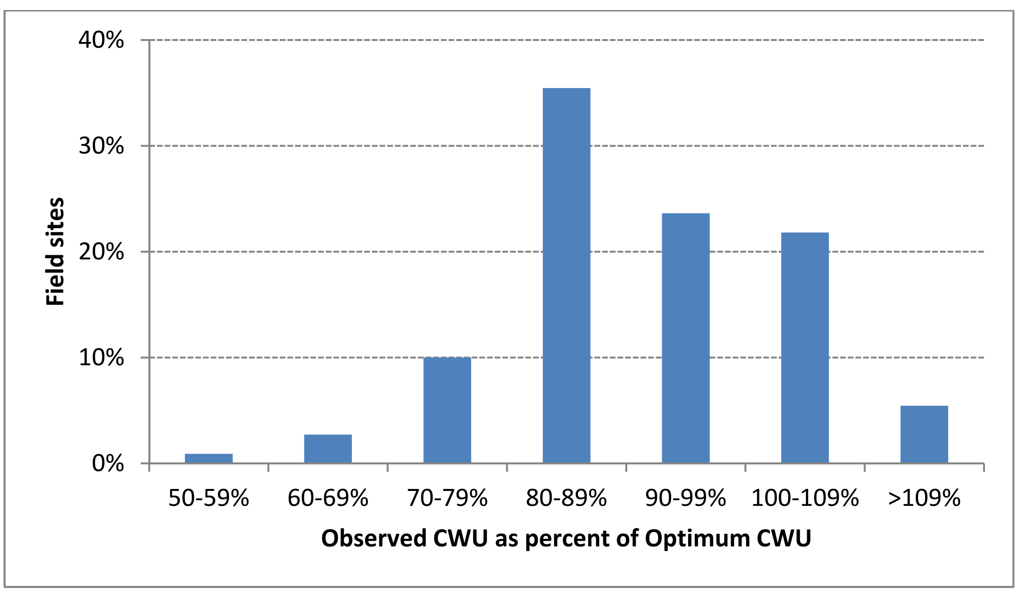


Figure 10. Distribution of observed crop water use in relation to optimum crop water use.

A number of field sites exhibited considerably greater observed CWU values than optimum CWU values (Fig. 10). Some variability is expected due to the methodology; nevertheless there may also be errors in the field observations or the AIMM results. Results suggest that the AIMM may have underestimated crop water use potential for fresh peas, canola and canola seed. Five of the six field sites with observed CWU at least 10% greater than optimum CWU were cropped to fresh peas, canola, or canola seed. Fresh peas are a minor crop in southern Alberta; therefore, data for determining fresh pea crop water requirements with for the AIMM are limited. For canola, the AIMM program relies on crop growth data that originated several decades ago and were calculated for rapeseed. With improvements in canola genetics, agronomic practices, and irrigation management, canola water use likely has increased in recent times.

Effective irrigation and CWU for major crops in the study were compared to data from the original Current Irrigation Management Practices study conducted from 1996 to 2000 (Hohm et al., 2002). For all six major crops, effective irrigation amounts were greater in the original study than in the 2007 to 2009 study (Table 10). Barley crops were irrigated 76% more and canola crops were irrigated 13% more on average in the first study than in the current study.

Comparison of CWU data shows that almost all crops had similar CWU values in the two studies. The greater irrigation amounts in the first study may reflect the slightly lower precipitation and slightly greater corn heat units in the first study. With the exception of canola and sugar beets, the differences for CWU for the same crops between the two studies were within approximately 30 mm.

Table 10. Comparison of effective irrigation and crop water use for major crops between the 1996-2000 study and the 2007-2009 study.

Crop	Effective irrigation (mm)		Crop water use (mm)	
	1996-2000	2007-2009	1996-2000	2007-2009
Alfalfa	317	245	494	486
Barley	178	101	315	330
Wheat	200	157	360	391
Wheat, Soft	201	147	361	391
Canola	167	151	334	380
Sugar beets	334	260	514	475

Producers were asked in 2008 and 2009 to indicate the factors influencing their irrigation management strategies (Table 11). Of the 80 responses to the survey, 83% indicated that maximizing yield was one of the main factors in their irrigation management decisions. Crop quality was an important factor for 55% of the responses, while 29% of responses were concerned with minimizing crop disease. Only one producer indicated that input costs were an important factor in decision-making for irrigation management.

The survey results suggest that the significant majority of producers manage their irrigation practices to maximize yield, which would imply maximizing crop water use. However, this is an overly simplistic assumption, as other agronomic factors influence producers decisions in deciding when and how much to irrigate. As discussed earlier, forage crops such as alfalfa require periods without irrigation for drying and baling of the harvested crop. For cereal crops, some producers avoid applying irrigation later in the season to minimize lodging or disease development. Dry bean producers indicated their irrigation management strategies included minimizing development of disease, which required that irrigation was avoided at times when the crop growth benefits of the added moisture were offset by the potential disease risk.

Table 11. Summary of participating producers' responses to the survey question posed in after the 2008 and 2009 study years – "Choose one or more factors from the list that influence your irrigation management decisions."

Factor	Response	
	Number	%
Maximize crop yield	66	83
Maximize crop quality	44	55
Minimize crop disease	23	29
Constraining input costs	1	1
Total producer responses	80	

Producers provided their yield results for the study fields. Reported yields for each crop with more than one field site are shown in Table 12. The yield of each crop was assessed relative to maximum or potential yield considered attainable under southern Alberta irrigated conditions.

For all crops except alfalfa, some of the reported crop yields approached or even exceeded the maximum potential yields for southern Alberta. Reported alfalfa yields ranged from 48 to 81% of the maximum attainable yield, which may reflect observed irrigation management practices, in that producers were meeting only 78% of optimum crop water use (Table 9), and may also be linked to other agronomic factors such as age of the alfalfa stands. Barley yields ranged from 61 to 93% of maximum potential yield. Wheat yields ranged from 57 to 109% of maximum or optimum yields. Individual dry bean yields were 77 to 94% of the maximum attainable yield. Canola yields varied from 54 to 100% of the maximum attainable yield. Reported sugar beet yields also varied considerably, from 65 to 94% of maximum potential yield.

Table 12. Range of reported yields for selected crops in the study.

Crop	Yield units[a]	Range of reported yields			Maximum yield[b]	Reported range as % maximum
		Min	Max	Average		
Alfalfa	mt/ac	3.5	5.9	4.7	7.3	48-81
Barley	bu/ac	82	125	108	135	61-93
Wheat, Durum	bu/ac	65	120	92	110	59-109
Wheat, HRS	bu/ac	65	110	88	115	57-96
Wheat, Soft	bu/ac	115	134	121	130	88-103
Wheat, Winter	bu/ac	94	125	110	120	78-104
Beans, Dry	lbs/ac	2450	3000	2600	3200	77-94
Canola	bu/ac	38	70	52	70	54-100
Potatoes	t/ac	16	27	20.5	30	53-90[c]
Sugar beets	mt/ac	21.5	31	27.3	33	65-94

[a] mt = metric tonnes, t = short tons

[b] "Maximum" yields based on maximum potential yields for southern Alberta as reported in Bennett and Harms (2011), except for winter and durum wheat values which are based on yield potentials as listed in Agdex 100/32-1 (ARD, 2008).

[c] Potato yields are strongly influenced by variety and harvest date; therefore, the comparison of reported yields to one optimum yield value is of limited merit.

Seed canola was not included in this assessment, as yields are highly variable and dependent on the specific variety being produced. Potato reported yields are shown, but a comparison to the optimum yield value is of questionable use, as potato yields are highly dependent on type (e.g. chipping, fry) and harvest date.

The relationship of reported crop yield in relation to observed crop water use was examined for alfalfa, barley, HRS and durum wheat, canola, dry beans, sugar beets and barley (Fig. 11). No apparent trends were observed for the influence of crop water use on yield for six of the eight crop types; however, positive relationships were observed for canola and potatoes. The limited number of field sites per crop, and the inherent variability in field-scale assessments of yield should be considered when drawing conclusions from the data. Research experiments that can control or measure other yield-influencing factors are ideally suited to determining the exact relationship and influence of irrigation management on crop yields.

Overall, there may be considerable potential to increase yields and crop production in southern Alberta. This study focused on irrigated fields with low-pressure pivot and pipeline technology, which represents about half of the irrigated acres in southern Alberta. Irrigated fields with less efficient and effective technology are unlikely to achieve greater yields than the fields in this study. Furthermore, this study did not include fields with obvious agronomic problems, since such fields would be expected to yield less than the field sites included in the study.

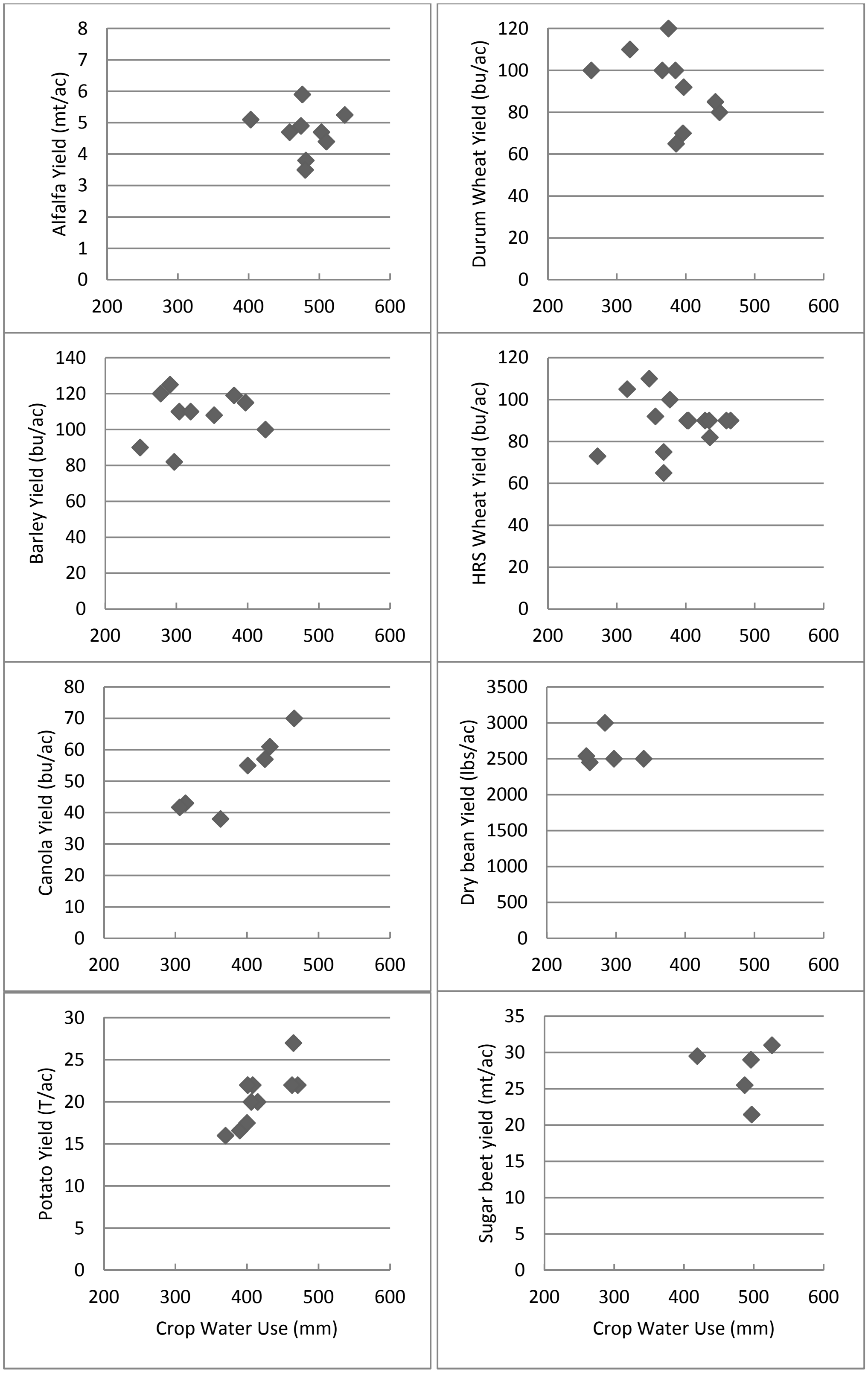


Figure 11. Reported crop yields in relation to observed crop water use for selected crops.

CONCLUSIONS

Irrigation producers with low pressure pivots and pipeline delivery managed their irrigation practices to meet, on average, 91% of optimum crop water use. During the three growing seasons examined, growing conditions (temperatures, precipitation) were representative of the region and irrigation water was not limiting; therefore, results were reflective of producers' practices under these conditions. This study confirmed ARD's use of 90% for overall district CWU as a percent of optimum CWU in Irrigation District Model analyses as an attainable future value.

Specialty and higher value crops were typically irrigated more consistently and close to optimum crop water needs, whereas forages tended to be managed well below optimum crop water needs. On average, cereal crops were managed close to optimum crop water needs, but there was considerable variability among irrigation management practices. One-sixth of field sites were irrigated from 57% to 80% of optimum CWU. These findings suggest opportunities for improvement in irrigation management practices, which would enhance crop yield and quality.

Producers relied on timely rainfall to meet a significant component of crop water requirements. In two out of three years, more than half of crop water use requirements was derived from precipitation.

Reported crop yields did not have a strong relationship with the level of irrigation management. This finding was not unexpected, as many factors other than irrigation influence crop yields. Reported yields ranged from less than 50% of maximum potential yield values up to and exceeding maximum potential yield values.

The study demonstrated that producers utilizing the best irrigation technology and management practices have the potential to achieve optimum crop water use and optimum yields in southern Alberta. The Alberta irrigation industry's continued direction of conversions from surface, wheel-move, and high pressure pivot irrigation methods to low pressure drop tube pivots will help achieve optimum crop water use and crop yields. The variability of observed irrigation management practices suggests there are significant opportunities to enhance irrigation and crop production management, even for producers currently irrigating with the best available technology.

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APPENDIX

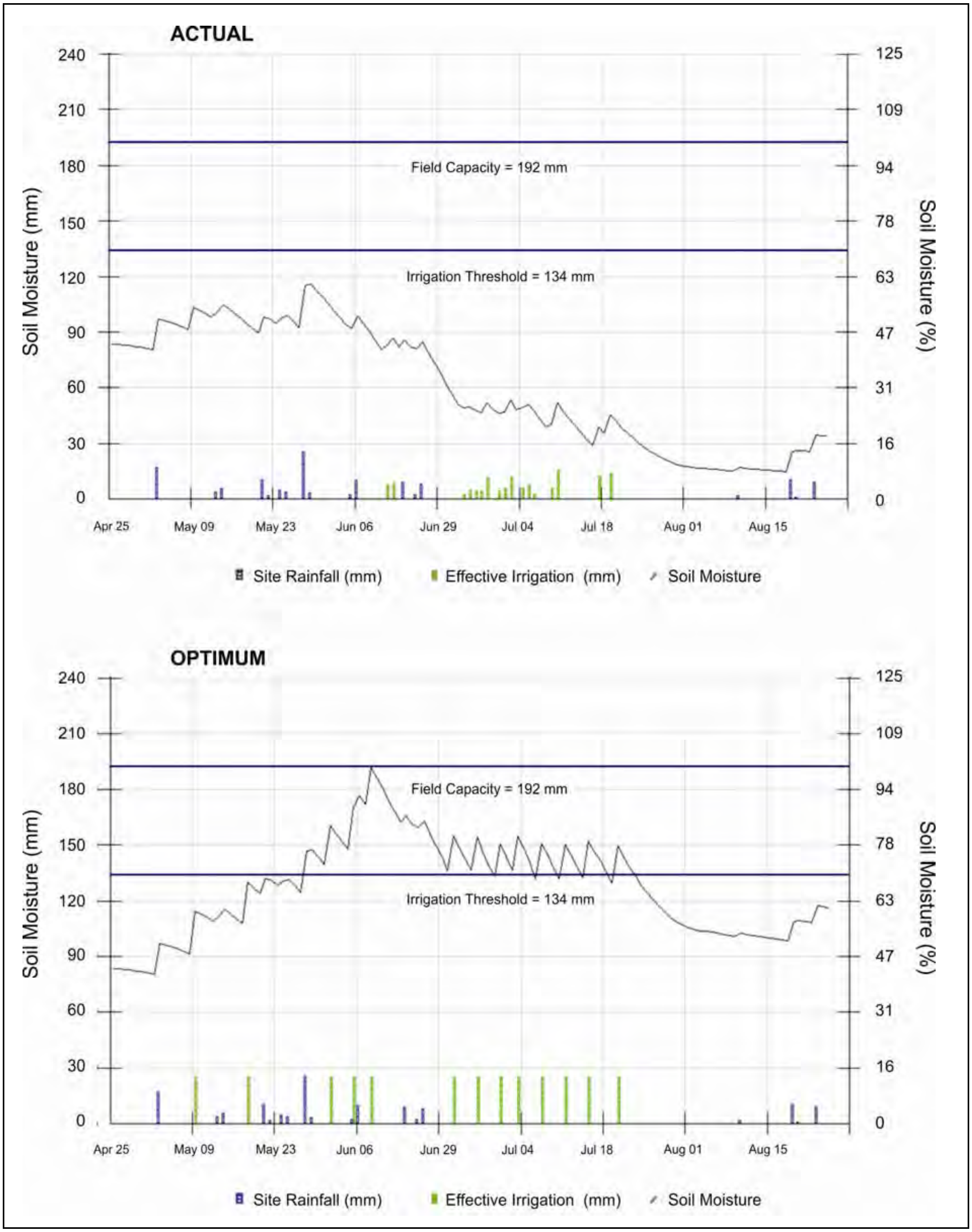

Figure A-1. AIMM-generated soil moisture profile in a soft wheat field in 2007 based on actual producer applied irrigations (top graph) and AIMM-modeled optimum irrigations (bottom graph). The producer applied 40% of the optimum irrigation amount and met 82% of the optimum crop water use.

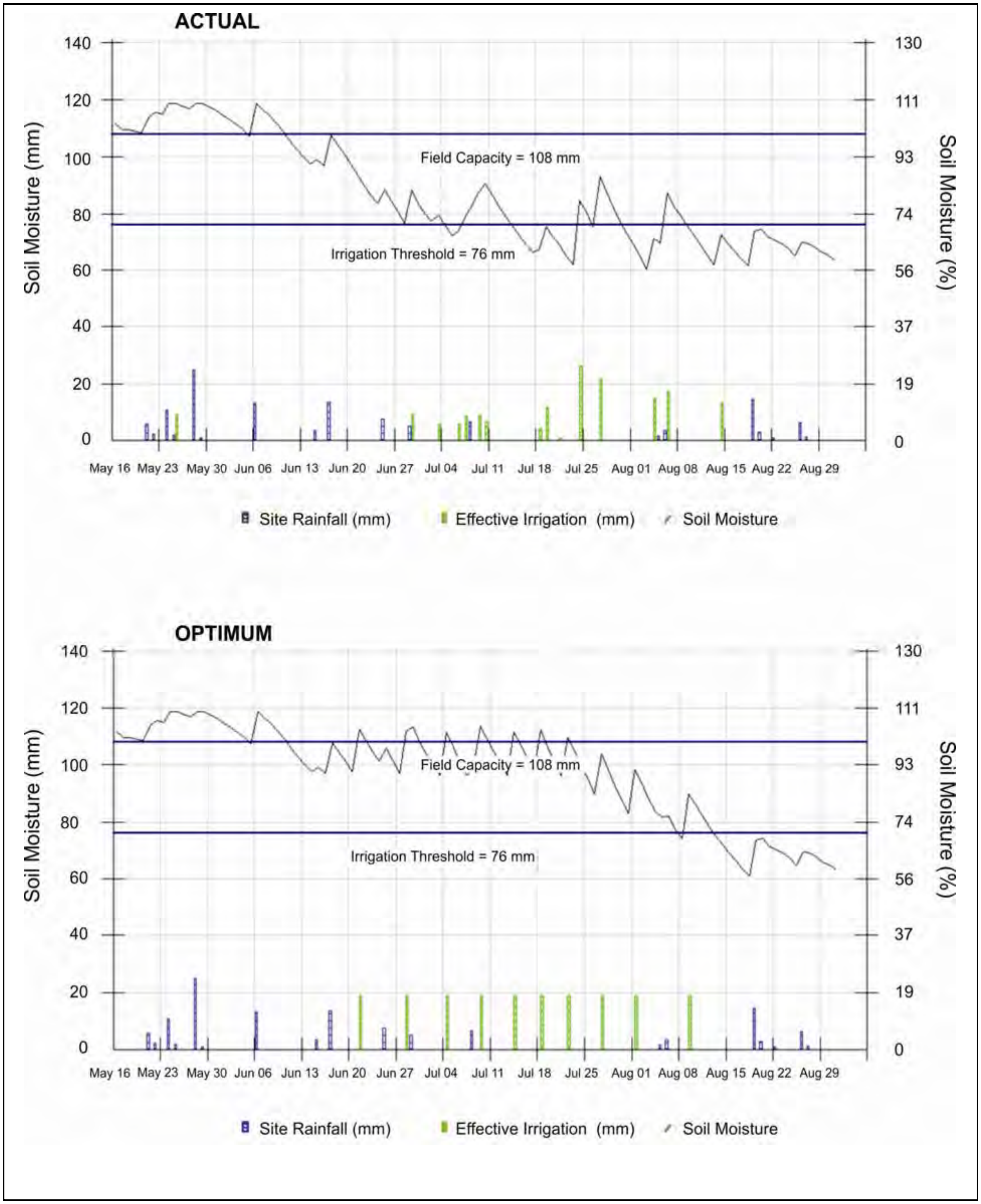

Figure A-2. AIMM-generated soil moisture profile in a dry bean field in 2007 based on actual producer applied irrigations (top graph) and AIMM-modeled optimum irrigations (bottom graph). The producer applied 82% of the optimum irrigation amount and met 85% of the optimum crop water use.

Table A-1. Upper and entire root zone depths entered in the AIMM program for crops modeled in the CIMP2 study.

Crop	Root zone (m)	
	Upper	Entire
Alfalfa	n/a	1.2
Barley	0.5	1.0
Beans, Dry	0.3	0.6
Brome grass	n/a	0.9
Canola	0.5	1.0
Corn, Sweet	0.5	1.0
Oats	0.5	1.0
Peas, Fresh	0.4	0.8
Potatoes	0.4	0.8
Sugar beets	0.5	1.0
Triticale	0.5	1.0
Wheat	0.5	1.0

Current Irrigation Management Practices 2 Producer Results

Field Location	Year	District	Measured Pivot Output		Irrigated hours
NW-01-001-01-W1	**2007**	**TID**	**830**	US GPM	**460**

Soil Information

Maximum Root Zone		Plant Available Water in Maximum Root Zone			
Sample depth	**Texture**			**(in)**	**(mm)**
0 - 8" (0 - 20 cm)	**Loam**	Field Capacity[a]		**7.6**	**192**
8 - 16" (20 - 40 cm)	**Clay Loam**	At seeding (estimated)		**3.3**	**83**
16 - 24" (40 - 60 cm)	**Clay Loam**	Measured[b]	**09-May-07**	**4.1**	**103**
24 - 32" (60 - 80 cm)	**Loam**	Measured[b]	**31-Aug-07**	**0.4**	**10**
32 - 40" (80 - 100 cm)	**Clay Loam**	*Soil samples were collected the first spring a field entered the study to determine soil texture and moisture holding capacity.*			

Crop Water Use Information

Crop	Seeding	Harvest
Soft wheat	**25-Apr-07**	**25-Aug-07**

	Actual Field		AIMM Modeled Optimum Scenario	
	(in)	**(mm)**	**(in)**	**(mm)**
Lost Water				
Lost Precipitation	**0.0**	**0**	**0.0**	**0**
Over Irrigation	**0.0**	**0**	**0.0**	**0**
Water Use				
Moisture from soil[c]	**3.4**	**86**	**-4.1**	**-104**
Effective Precipitation	**5.2**	**131**	**5.2**	**131**
Effective Irrigation[d]	**5.1**	**129**	**15.6**	**397**
Sum of Crop Water Use	**13.6**	**346**	**16.7**	**424**
Crop Water Use: Actual compared to AIMM Optimum		**82**	%	

[a] **Field Capacity** is the amount of plant accessible water held in the soil between the Field Capacity and Permanent Wilting Point levels in the maximum root zone. Otherwise known as "Bucket Size."

[b] **Measured plant available water** values represent plant available water in the maximum root zone at the time of sampling. Samples were collected as near as possible to seeding and harvest (swathing) dates and analyzed to determine soil moisture content at the beginning and end of a growing season.

[c] **Moisture from soil** used by crop (a negative value indicates net soil moisture gain over season).

[d] **Effective irrigation** assumes 82% efficiency for low pressure centre pivots. For every 1 inch delivered to the turnout, 0.82 inches is available to the crop. For every 1 inch available to the crop, 1.22 inches needs to be delivered to the turnout. Lost or over applied water is not considered effective irrigation.

Figure A-3. Example of producer report (same field as shown in Figure A-1).

Table A-2. Monthly growing season reference crop (alfalfa) water use and precipitation from 2007 to 2009 and long-term normals (LTN) for three IMCIN stations.

	Alfalfa reference crop water use (mm) [a]				Total precipitation (mm) [b]			
	2007	2008	2009	LTN	2007	2008	2009	LTN
Lethbridge								
May	153	130	165	149	74	71	29	51
June	180	144	162	151	27	88	57	78
July	210	164	144	183	0	85	42	43
August	173	166	133	149	6	29	81	40
September	119	102	157	115	42	60	6	41
Total	835	706	761	747	150	333	216	254
Bow Island S								
May	152	124	163	146	60	60	18	44
June	170	148	177	152	57	88	39	67
July	221	179	163	187	2	41	71	33
August	187	179	141	157	18	40	47	32
September	118	99	151	107	35	60	12	35
Total	848	729	795	749	171	288	187	211
Vauxhall								
May	146	131	171	148	57	66	30	42
June	164	142	172	147	32	85	45	67
July	212	164	164	177	10	51	48	33
August	158	177	145	147	28	34	85	34
September	107	95	164	107	11	48	4	34
Total	787	709	816	726	137	284	211	210

[a] Data from the Canada-Alberta Crop Development Initiative website www.demofarm.ca/cropetdata.htm.
[b] Monthly data (2007-2009) from IMCIN. Long-term Normal (LTN) data from Agro Climatic Information Service (1961-2008).