Chapter IV.

Key Research Findings

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Following is a summary of key findings of the research projects of the Irrigation Water Management Study, and the extensions of those research findings. The results help define the current status of the 13 irrigation districts and the irrigation industry in Alberta, and their prospects for the future.

Where possible, comparisons were made between these study findings and the assumptions made in 1991 to determine the *Regulation* licence volumes (Table 4). These comparisons were made to give an appreciation of why the irrigation districts may (or may not) expand their irrigated area from that specified in the 1991 *Regulation* within the constraints of the proposed licence volumes.

A distinction is made between on-farm components (irrigation methods, management practices, etc.) and district components such as seepage and evaporation (Figure 14). The research findings indicated areas where improvements could be made, by whom, and the likely impacts of the improvements. This serves to focus the attention of farmers and irrigation district managers on issues they can influence, and those that will provide the best outcomes for the effort and resources invested.

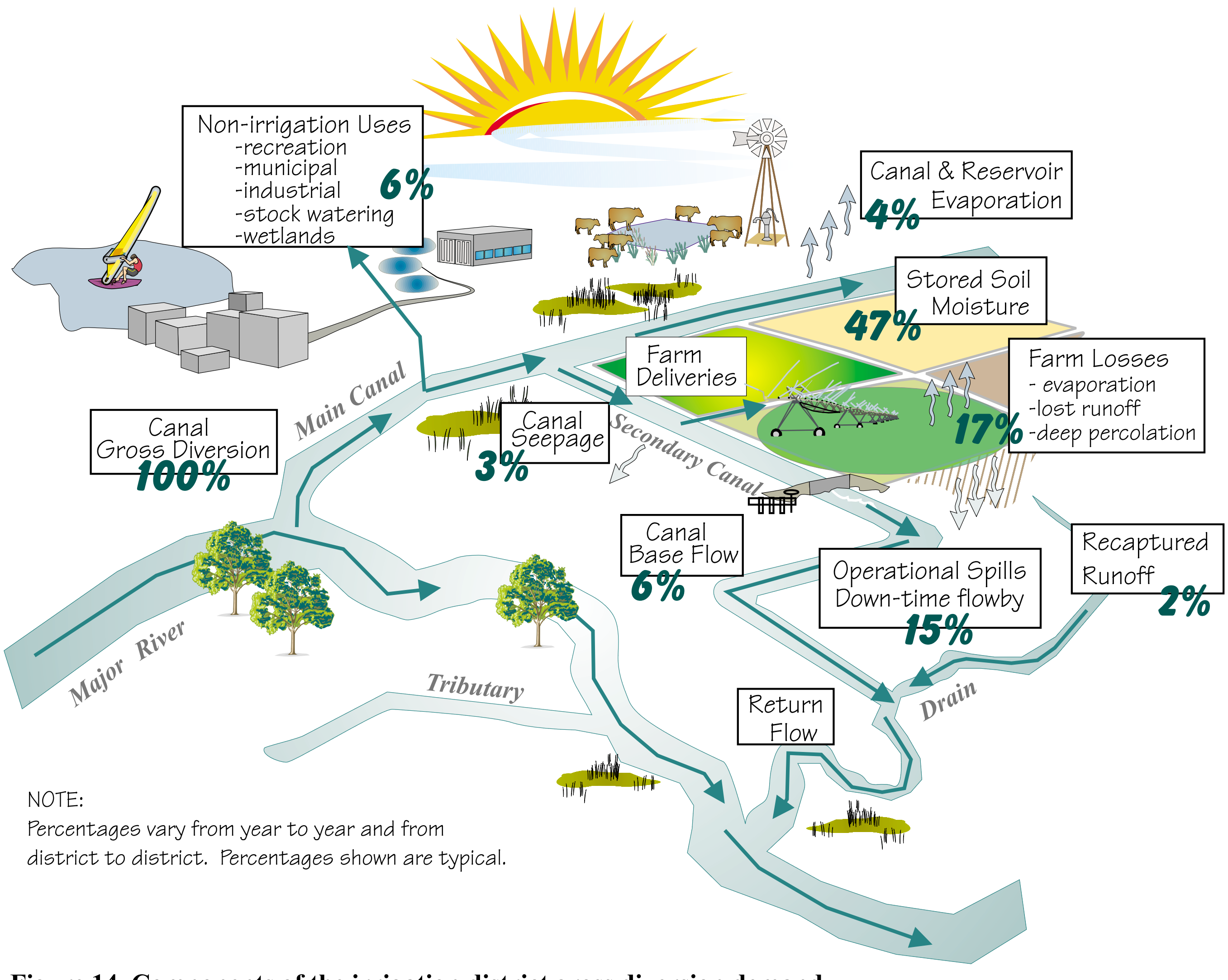


Figure 14. Components of the irrigation district gross diversion demand.

Potential evapotransporation refers to the maximum transfer of water from the soil to the atmosphere, due to evaporation from the soil surface and transpiration from plants, and assuming a continuously moist soil profile.

A. ON-FARM COMPONENT

On-farm factors that affect irrigation water requirements and irrigation application efficiencies are climatic conditions, crop types, irrigation methods, and on-farm management practices.

1. Agro-climatic Database

AAFRD has supplemented existing geographic agro-climatic information by computing and incorporating parameters that are of particular interest to the irrigation community. Maps showing the variations in potential evapotranspiration, growing season precipitation and net moisture deficit across the SSRB were developed. Although data gaps exist, in general the Gridded Prairie Climate Database (GRIPCD) provides daily values at 50-km grid points for the following parameters and periods:

- Maximum and minimum air temperatures – 1920 to 1995;
- Solar radiation – 1951 to 1995;
- Dew point temperature – 1955 to 1995;
- Rainfall – 1920 to 1995;
- Snowfall – 1920 to 1995;
- Precipitation – 1920 to 1995; and
- Snow depth – 1956 to 1995.

To complement the GRIPCD, additional parameters, such as potential evapotranspiration, growing season precipitation, net growing season moisture deficit, corn heat units and frost-free days were computed for the period 1920 to 1995. Of particular interest in this study are potential evapotranspiration, growing season precipitation and net growing season moisture deficit.

Potential evapotranspiration is a key parameter on which most assessments of irrigation water requirements are based. Five equations for the computation of potential evapotranspiration were reviewed and evaluated. A modified Priestly-Taylor equation provided the best correlation with research data published by Agriculture and Agri-Food Canada and was selected for the computations. The Priestley-Taylor equation is based on maximum and minimum temperatures and solar radiation. Solar radiation data have been recorded in southern Alberta only since 1950, and these records have significant data gaps. Solar radiation was estimated by AAFRD based on maximum and minimum temperatures, latitude, and elevation, to provide daily data for the 76-year period 1920 to 1995. Daily potential evapotranspiration values for the full period were computed for each of the grid points. Potential evapotranspiration values represent the evapotranspiration for the lush green growth of a high water use crop, such as alfalfa. Evapotranspiration for alfalfa and other crop types can be computed by multiplying the potential evapotranspiration value by a crop coefficient. Coefficients for various crop types have been developed by Agriculture and Agri-Food Canada (Foroud and Hobbs 1983).

Growing season precipitation is natural moisture that is provided to the soil profile to support plant growth. The growing season was taken to be the period between the last killing frost day in the spring and the first killing frost day in the fall. A killing frost day is defined as a day in which the minimum temperature was less than –2.0 degrees C.

The net growing season moisture deficit is the difference between evapotranspiration and growing season precipitation. It represents the irrigation requirement for the optimum yield of a high water use crop such as alfalfa.

The design of irrigation district infrastructure and on-farm systems is normally based on irrigation requirements during hot, dry periods. The objective is to ensure there will be sufficient capacity in the system to meet demands when irrigation is most needed and most beneficial. For this reason, crop water requirements during extreme conditions were of primary interest. The volumes of water licensed or proposed to be licensed to the irrigation districts were also based on the 90th percentile irrigation requirements, the water requirements that would be expected to be exceeded in only 10% of the years.

Maps have been prepared showing the 90th percentile evapotranspiration (Figure 15), the 10th percentile growing season precipitation (Figure 16), and the 90th percentile net growing season moisture deficit (Figure 17). These maps provide indices showing the variations in crop water requirements and irrigation demands for a high water demand crop and hot, dry conditions in the SSRB. In general, growing season precipitation decreases from west to east, and potential evapotranspiration and net growing season moisture deficit increase from west to east. The net growing season moisture deficit is about 100 mm higher in the Medicine Hat area than in the Cardston, Fort Macleod, and Strathmore areas.

The gridded database was the source of all weather data for determining crop specific water demands, soil moisture balances and evaporation losses in the Irrigation District Model (IDM). The database was also used to assess the impacts of irrigation water shortages on crop yields in the Farm Financial Impact and Risk Model (FFIRM). AAFRD has used the database to develop an index of agro-climatic factors that will assist in the design of on-farm irrigation equipment for specific crop types and regional climatic conditions.

2. Crop Types and Water Requirements

There are several agronomic factors that influence crop growth and yields. A key factor is the availability of soil moisture. (Other factors include soil fertility, diseases and pests.) While giving due consideration to these other factors, providing adequate soil moisture for high crop yields is the essence of irrigation water management. Irrigation planning and management requires that crop water requirements for optimum yields be known and factored into the design and operation of the irrigation system.

A wide variety of crops is grown on irrigated land in southern Alberta. However, much of the crop water use information commonly used today is based on decades of field monitoring and research conducted more than 30 years ago. In 1998 and 1999, research was conducted on alfalfa to determine if new varieties and irrigation management techniques have significant effects on irrigation water use. Randomized, replicated research plots were located near Picture Butte, Rolling Hills and Bow Island (Olson et al. 2000). Five irrigation management strategies or treatments were tested.

50-100 Non-stress Treatment:	Irrigate to maintain available soil moisture (ASM), including precipitation, at 50% to 100% of field capacity.
50-80 Non-stress Treatment:	Irrigate to maintain ASM at 50% to 80% of field capacity.
30-60 Stress Treatment:	Irrigate to maintain ASM at 30% to 60% of field capacity.
Volume-Restricted Treatment:	Maximum irrigation application of 275 mm.
Date-Restricted Treatment:	Cut off irrigation on June 30.

The crop mix in the irrigation districts has changed during the past 30 years. The area planted to forage, specialty and oilseed crops has increased, and the area of cereal crops has decreased. It is expected this trend will continue in the future. In spite of this change in crop mix, there will probably not be a significant change in the overall crop water requirements for the districts.

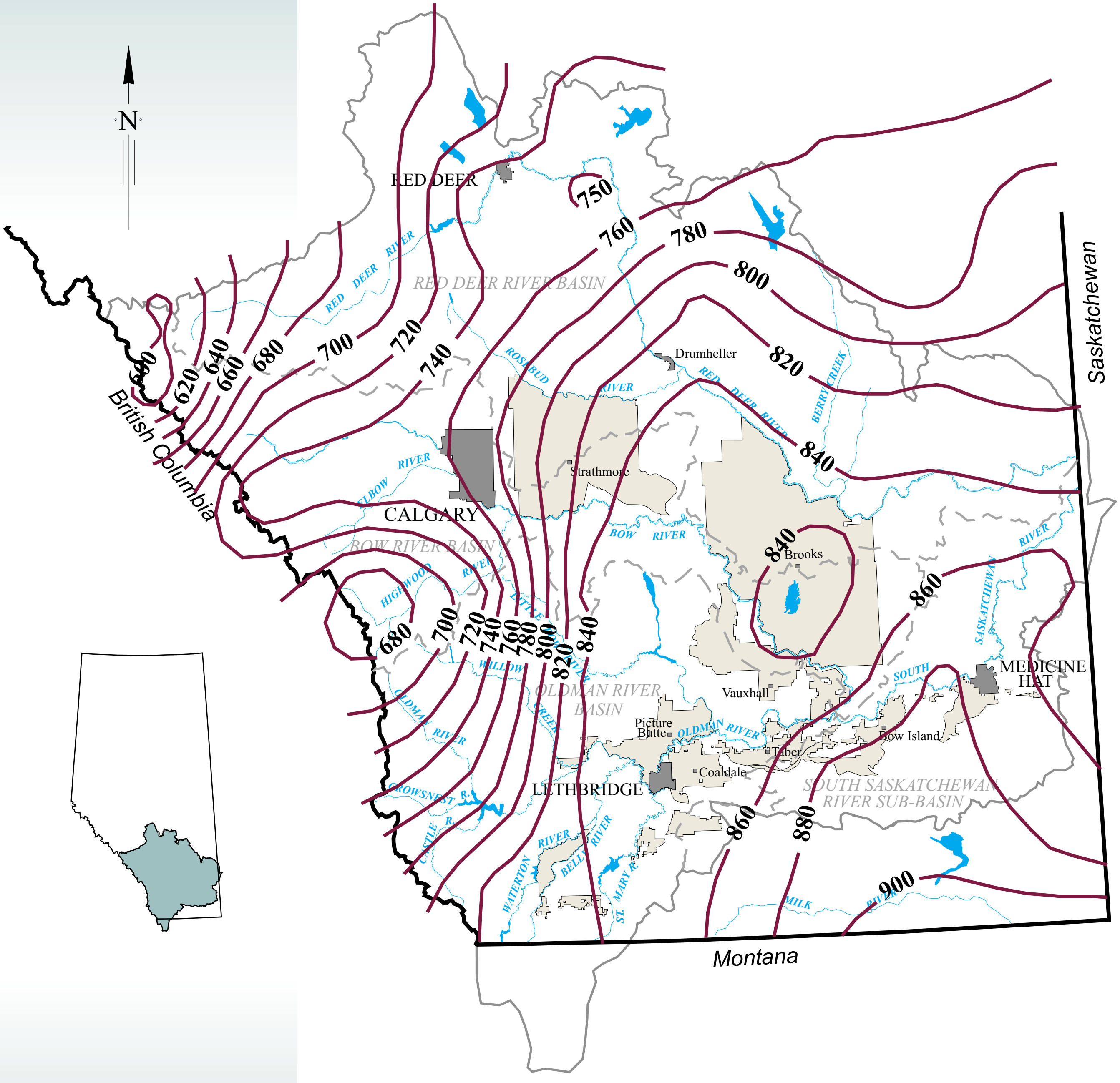


Figure 15. Potential evapotranspiration in the South Saskatchewan River Basin.
(90th percentile values for the killing frost-free period, in mm)

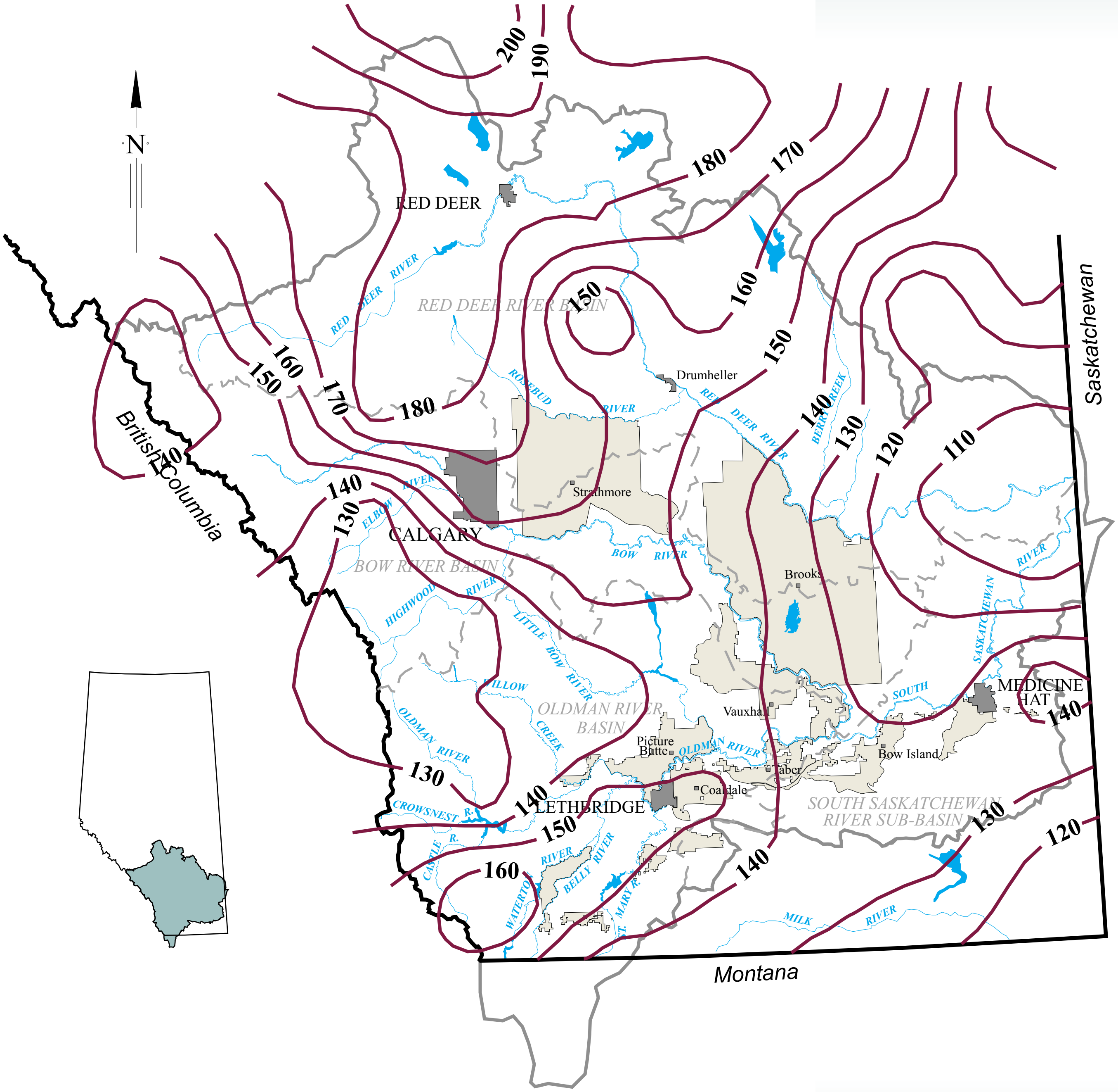


Figure 16. Growing season precipitation in the South Saskatchewan River Basin.
(10th percentile value for the killing frost-free period, in mm)

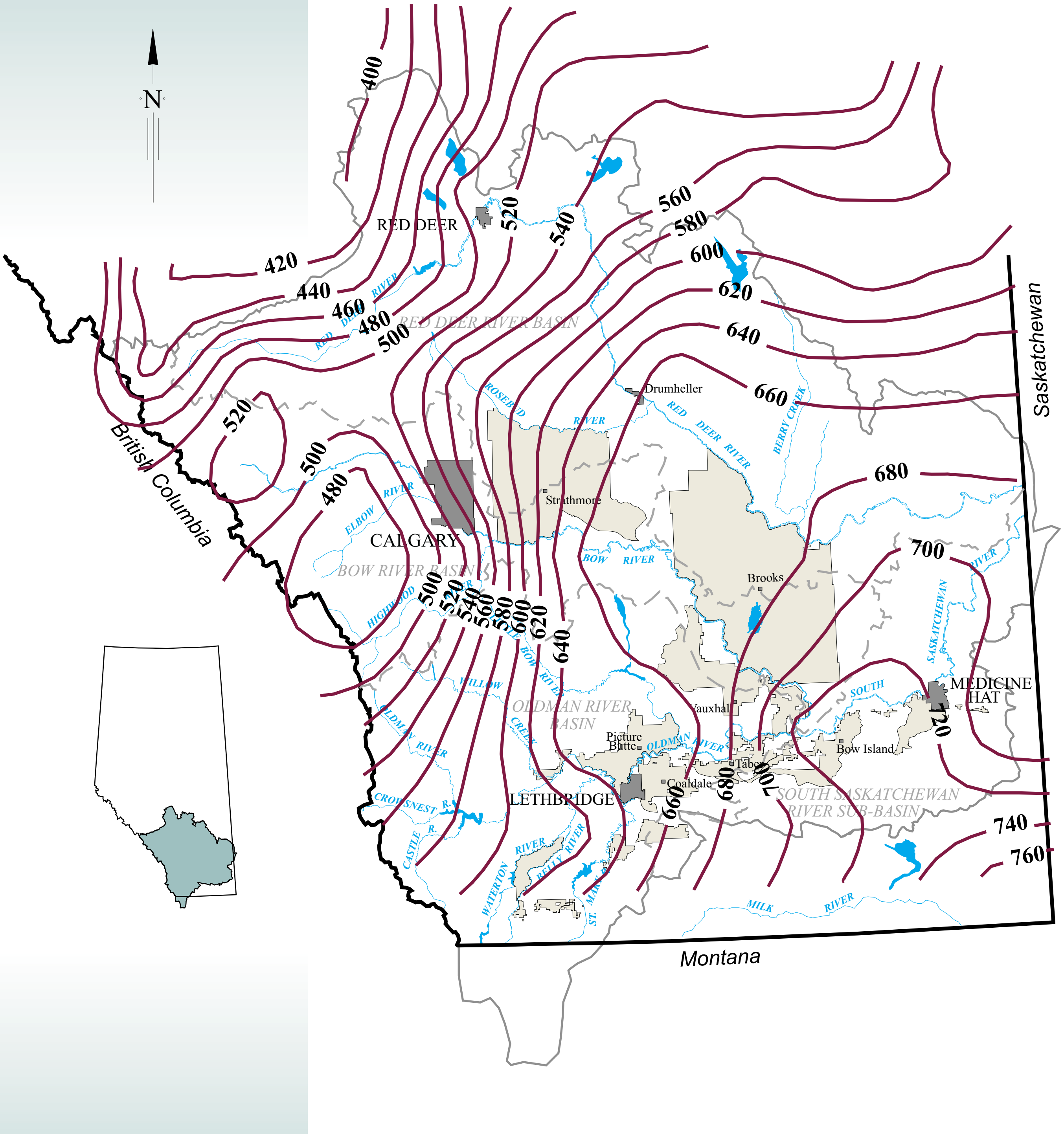


Figure 17. Net growing season moisture deficit in the South Saskatchewan River Basin.
(90th percentile value of the annual difference between potential evapotranspiration and precipitation for the frost-free period, in mm.)

All plots were treated equally in the establishment year. Following the establishment year, all five treatments were applied to the four plots at three sites (Figure 18). Water use and yields were monitored for all plots and all treatments. Differences that were statistically significant at a 5% level of probability were noted. There were no significant differences in crop consumptive use between the two non-stress treatments. The non-stress consumptive use ranged from 530 mm to 601 mm for four of the five treatments.

For research conducted in the 1960s, Sonmor (1963) and Krogman and Hobbs (1966) reported consumptive use for alfalfa ranging from 660 mm to 680 mm. Preliminary consumptive use values from current research are significantly lower than those of the 1960s. Additional results are necessary to determine the reasons for the difference (alfalfa varieties used, research methods, irrigation techniques, etc.). Consumptive use and yields over a variety of weather conditions should also be monitored before any definitive conclusions can be drawn. Research is continuing. Based on results to date, no change in past procedures for determining crop water requirements is warranted.

The non-stress consumptive use for the Bow Island crop was substantially lower than for crops at other sites, with no yield reduction. The Bow Island site has a shallow water table that is probably a non-monitored contributor to crop water needs.

Consumptive use for the 30-60 Treatments was significantly less than the 50-100 Treatments in only two of the five crops – Rolling Hills 1, 1998, and Rolling Hills 1, 1999. The consumptive use for the Volume-Restricted Treatments was significantly less in two of the five crops – Rolling Hills 1, 1998, and Picture Butte 1, 1999. The consumptive use for the Date-Restricted Treatments was significantly less in all crops except Bow Island, 1999.

Total yield for all treatments at all sites (Figure 19) was measured from three cuts, except at Rolling Hills 1 site, 1998, where four cuts were obtained. There was a tendency for yields to decrease with each successive cut at all sites. Annual yields for the 50 - 100, 50 - 80 and 30 - 60 Treatments were similar and tended to be the

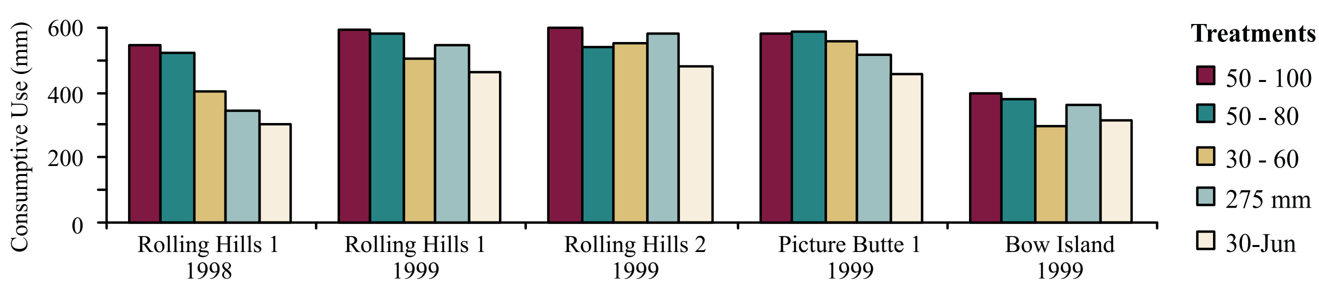


Figure 18. Alfalfa project consumptive water use.

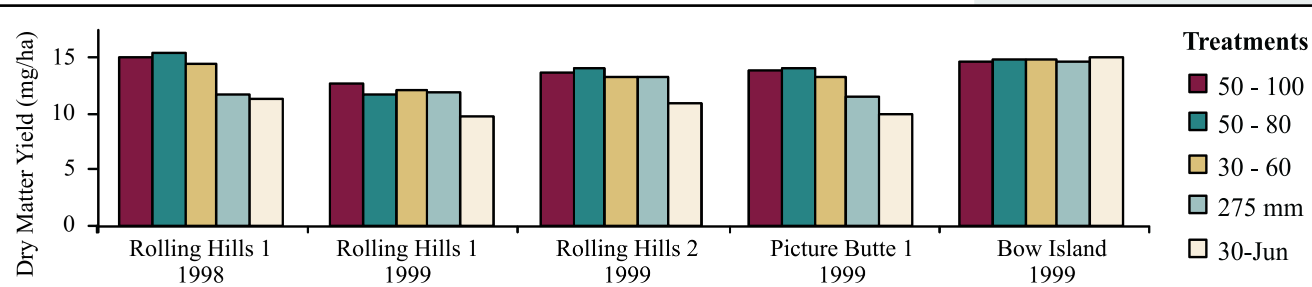


Figure 19. Alfalfa project yields.

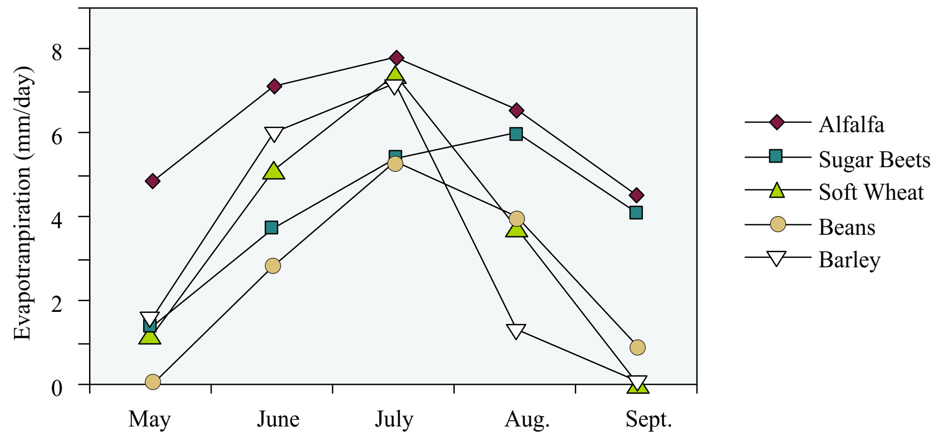


Figure 20. Monthly mean water demand for optimum yields of selected crops.

highest at each site. The yields from the Volume-Restricted Treatment tended to be less. However, they were significantly less than the 50-100 Treatment yields only at Rolling Hills 1, 1998, and Picture Butte 1, 1999. The Date-Restricted Treatments had the greatest impact on yields. Significant reductions were observed for all crops except at Bow Island, 1999.

Water use patterns have been monitored by researchers for several decades, beginning in the 1960s. The timing and total crop water requirements for optimum yields for various crops differ substantially (Figure 20). For most crops, the peak moisture use occurs in July, which is a key consideration in the design and operation of irrigation projects. On-farm systems, main canals and laterals may be operating at their full design capacities during the month of July. The peak water requirement for sugar beets is later than most other crops, which helps to distribute the demand in an irrigation block with a mix of crop types. Alfalfa has the highest water requirements in all months. In some months, the water requirement for alfalfa is more than double the requirement for other crops.

The crop mix within an irrigation block has a significant bearing on the irrigation water requirement for the block. In 1998, more than 50 different crops were grown in the irrigation districts of southern Alberta. Crops have been grouped into seven categories for the purpose of characterizing water use. Representative crop types and their water requirements are shown in Table 6.

Table 6. Irrigated crop water requirements.

Crop Category	Typical Crop Type	Max. Daily Water Use[1] (mm)	Total Seasonal Water Use[1] (mm)	Growing Season (Days)
Cereal – LoCU[2]	Malt Barley	7.2	390	85
Cereal –HiCU	Soft Wheat	7.4	480	115
Forage – LoCU	Barley Silage	7.2	370	70
Forage – HiCU	Alfalfa	7.6	680	140
Oilseed	Canola	7.7	450	110
Specialty – LoCU	Field Beans	5.7	380	105
Specialty – HiCU	Sugar Beets	6.0	560	135

[1] 90th percentile requirements. [2]CU= consumptive use.

The crop mix categories grown within the irrigation districts in 1999 are shown in Table 7. In general, districts in the western part of the basin, with higher elevations and cooler, moister climatic characteristics, are dominated by cereal and forage crops. These crop types complement the livestock-based farm enterprises in that part of the basin. In districts located farther east, where temperatures are higher and the growing season is longer, the crop types are markedly more diverse (Figures 21, 22, 23).

During the 1970s, agricultural policy in Alberta focused on increasing both dryland and irrigated crop production through increasing the cropped area. During this period, the irrigated area within the districts experienced unprecedented growth (Figure 4, page 16). During the 1980s, the emphasis on agriculture shifted to crop diversification and, specifically, growing a variety of higher value crops on irrigated lands. Generally, these crops were grown for the export market and shipped as unprocessed produce.

Table 7. Crop mix within the irrigation districts of southern Alberta - 1999.

Irrigation District	Cereal Crops (%)		Forages (%)		Oilseeds (%)	Specialty Crops (%)	
	LoCU[1]	HiCU	LoCU	HiCU		LoCU	HiCU
Aetna	19.3	0.0	11.5	68.1	1.1	0.0	0.0
Bow River	23.0	20.7	4.4	23.1	13.3	6.1	9.4
Eastern	25.0	4.6	8.6	43.8	8.0	2.9	7.1
Leavitt	12.5	7.5	38.3	41.2	0.0	0.0	0.0
Lethbridge Northern	19.9	6.6	40.9	15.9	7.4	1.0	8.3
Magrath	46.8	3.0	6.2	34.3	9.3	0.4	0.0
Mountain View	3.9	4.5	20.7	70.4	0.6	0.0	0.0
Raymond	35.2	0.7	11.8	42.5	9.7	0.0	0.1
Ross Creek	0.0	0.0	6.6	93.4	0.0	0.0	0.0
St. Mary River	23.6	16.7	7.7	21.0	12.4	10.4	8.2
Taber	14.8	13.1	9.8	23.6	3.1	13.1	22.6
United	44.5	2.7	16.5	29.7	6.3	0.2	0.1
Western	36.9	1.1	20.9	35.2	12.4	1.9	1.5
Weighted Mean	**24.2**	**10.9**	**13.2**	**28.2**	**10.0**	**5.6**	**7.9**

[1]CU = consumptive use.

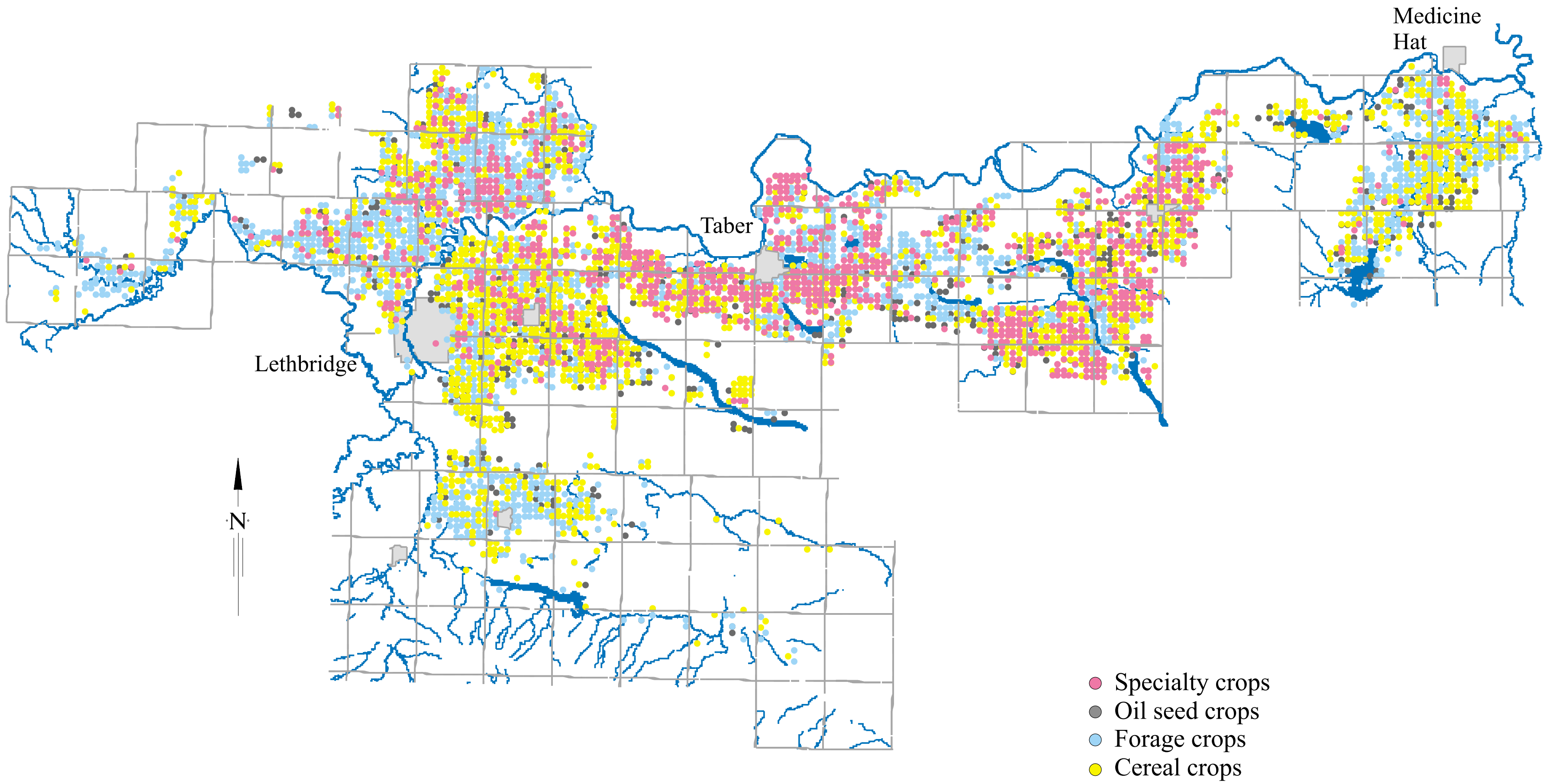


Figure 21. St. Mary Project and LNID 1999 crop group distribution.

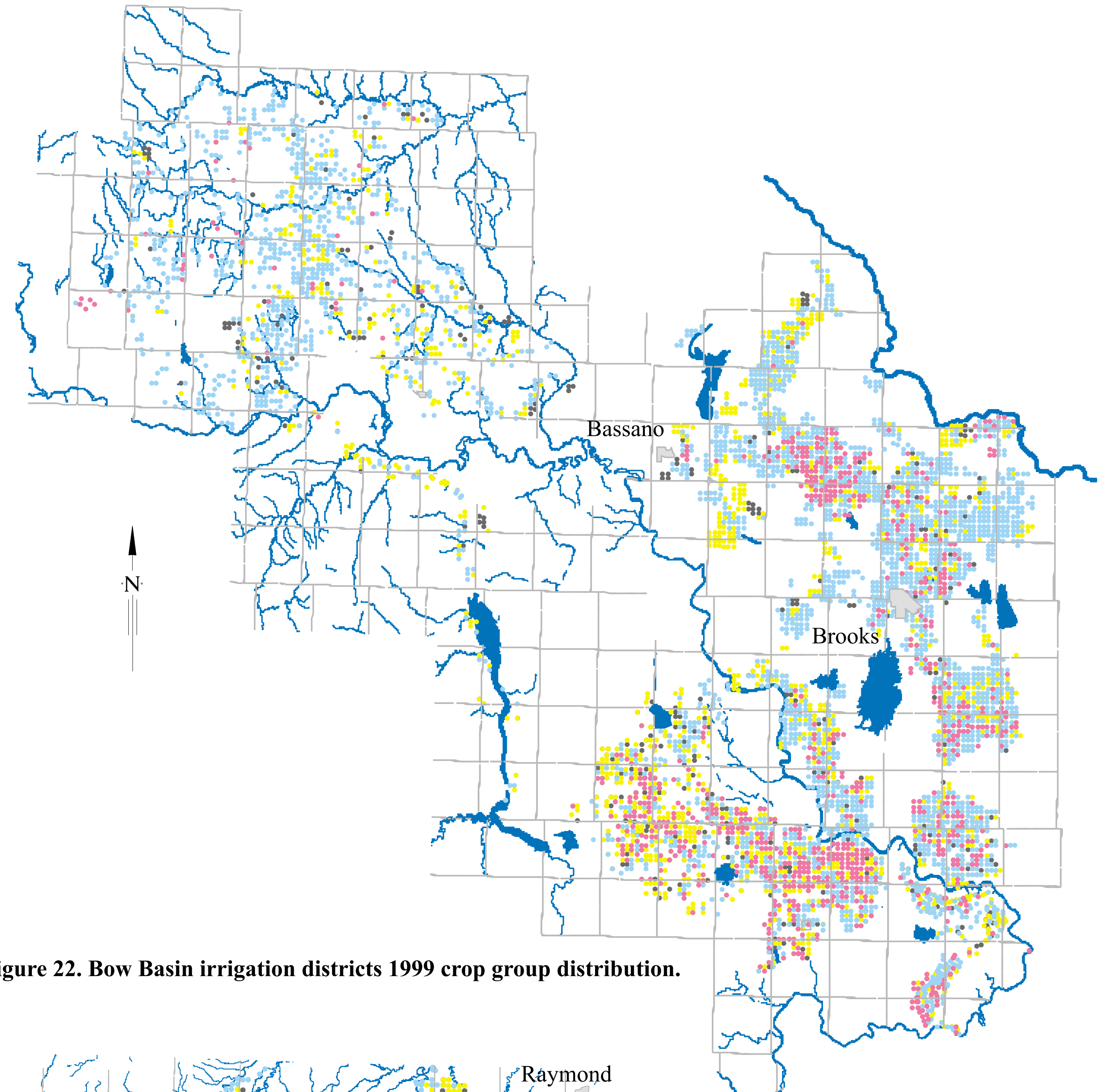


Figure 22. Bow Basin irrigation districts 1999 crop group distribution.

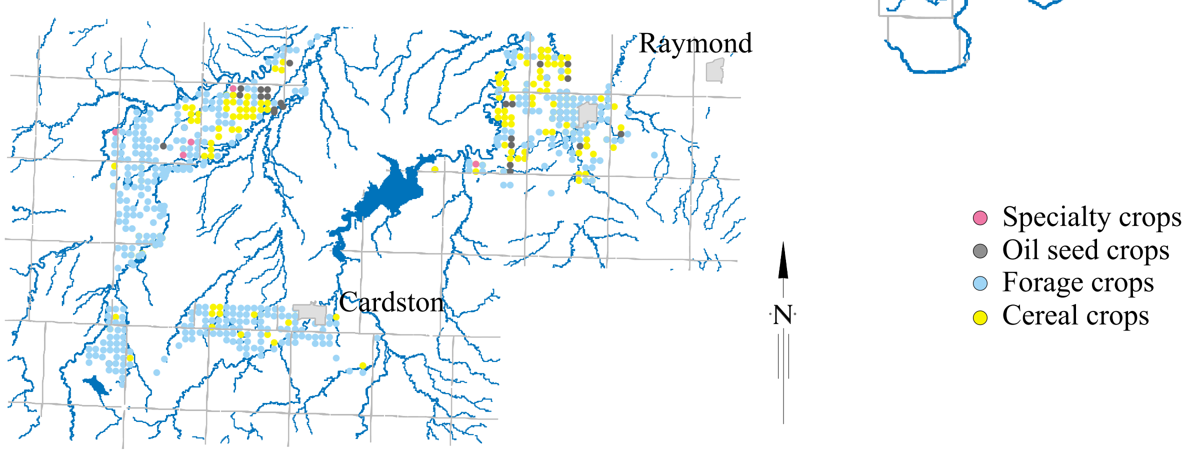


Figure 23. Foothills irrigation districts 1999 crop group distribution.

During the 1990s, the agricultural economic strategy focused on value-added processing of specialty crops and livestock. This strategy has stimulated an increase in the area of forage crops and in the area and variety of specialty crops (Figure 24).

Current emphasis on value-added processing bodes well for the continued increase in forage production and specialty crops in the irrigated areas of Alberta, and probably a continued decrease in the area of cereal crops. Most specialty crops require high heat units and a dependable supply of moisture that are available only in southern Alberta. In particular, growth in the areas of potatoes and sugar beets could accelerate with the recent arrival or expansion of several large, world-class processing facilities. Much of the meat processing industry is also linked to irrigated forage production and the numerous large feedlots in southern Alberta. Local processing of oilseeds and the introduction of new, higher yielding varieties of canola, are expected to stimulate an increase in the production of oilseeds.

While shifts in the irrigated crop mix may have significant implications on crop water requirements for specific irrigation blocks, they are not likely to represent a substantial change in the overall crop water requirement, considering all blocks and districts. The crop mixes and water requirements for 1999 and for a scenario reflecting the trend toward a major shift from cereal crops to forage and specialty crops, are shown in Table 8. The crop water requirements were not significantly different in the two cases presented, assuming that both crops are irrigated to their respective full water requirements. The weighted-mean crop requirement increases from 498 mm to 507 mm, an increase of 1.8%.

On-farm irrigation management and irrigation methods will likely be more significant than changes in the crop water requirements in increasing future water requirements. Specialty crops generally have higher input costs and higher market values than cereal crops. Irrigation water users tend to be more diligent in managing their operations for higher value crops, which generally results in higher irrigation applications. The continuing shift in irrigation methods, from labour intensive surface irrigation to less onerous automated sprinkler systems, would also encourage higher applications to increase yields. Both these issues are dealt with in subsequent sections of the report.

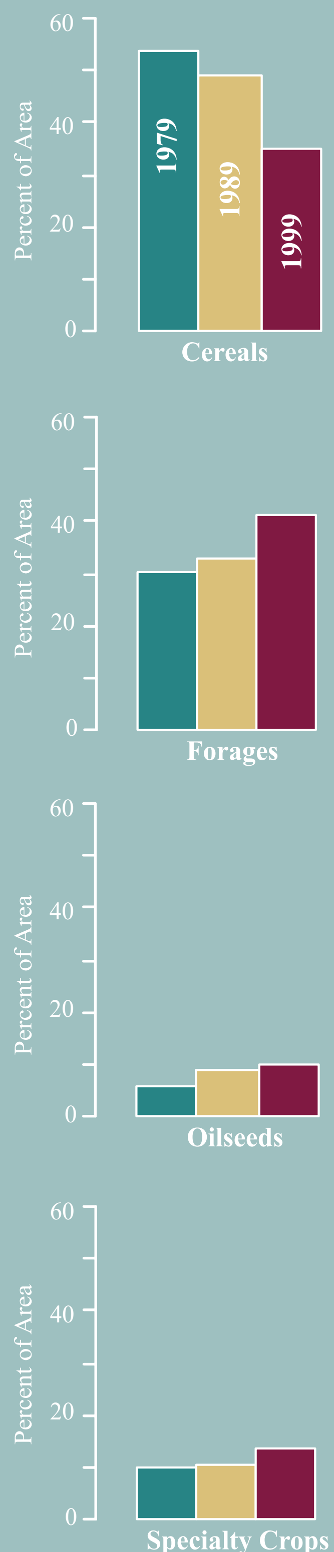


Figure 24. Historical cropping patterns within irrigation districts.

Table 8. Current and possible future crop mix and water requirements.

Crop Category	90th Percentile Crop Requirement	1999 Crop Mix	Future Scenario Crop Mix
Cereal – LoCU[1]	390 mm	24.2%	8%
Cereal – HiCU	480 mm	10.9%	10%
Forage – LoCU	370 mm	13.2%	20%
Forage – HiCU	680 mm	28.2%	30%
Oilseed	450 mm	10.0%	12%
Specialty – LoCU	380 mm	5.6%	9%
Specialty – HiCU	560 mm	7.9%	11%
Weighted-Mean Crop Requirement		**498 mm**	**507 mm**

[1]CU = consumptive use.

3. On-farm Irrigation Systems and Application Efficiencies

During the past 40 years, there have been substantial gains in on-farm efficiencies due to changes in irrigation methods and technological improvements in equipment. Current (1999) on-farm efficiency was estimated to be about 71%. Efficiencies will continue to improve. Given the current state of technology and the type of irrigation practiced in southern Alberta, an application efficiency of 75% is considered to be appropriate for long-term planning.

The various components of an on-farm water balance and factors affecting on-farm application efficiency are shown in Figure 25.

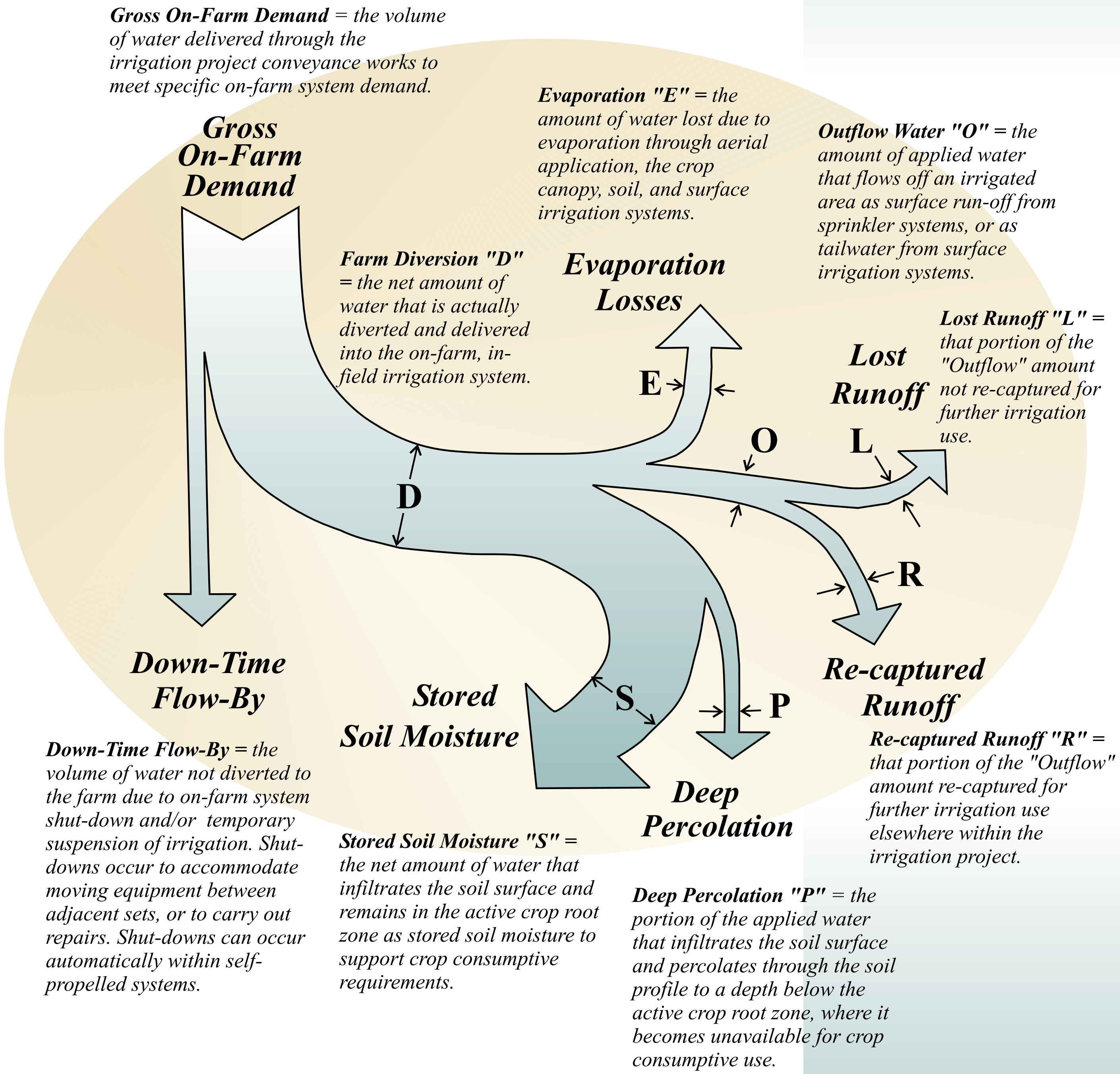


Figure 25. Components of the on-farm irrigation water balance.

For the purposes of this report, on-farm application efficiency (E_a) is defined as the ratio between the amount of irrigation water applied and retained within the active root zone and the total amount of irrigation water delivered into the on-farm system. The magnitude of each of the components of the on-farm water balance is, to a great extent, dependent on the irrigation method and the equipment used to apply water to the soil.

$$\text{Application Efficiency, } \mathbf{E_a} \text{ (\%)} = \frac{\text{Stored Soil Moisture, } \mathbf{S}}{\text{Farm Diversion Amount, } \mathbf{D}} \times 100$$

For instance, for a surface irrigation system, deep percolation, **P**, and outflow, **O**, is expected to be high since fields are flooded and surplus water is drained off. For a high pressure sprinkler system, **O** and **P** would probably be small, but evaporation losses, **E**, may be relatively high.

During the past century, irrigation methods and equipment have changed drastically. During the first half of the century, surface irrigation systems (sometimes referred to as gravity systems) predominated, primarily operating as wild flood schemes. During the 1960s, land leveling to control field slopes became more common, and surface irrigation continued to expand (Figure 26). The adoption of border-dyke and furrow methods to control the flow of water over the land increased the effectiveness and efficiency of surface irrigation.

The advent of aluminum pipe after World War II marked an increase in sprinkler irrigation systems and more efficient water use. Sprinklers also enabled irrigation of rolling land and land "above the ditch". Sprinkler systems did not significantly impact irrigation expansion until the 1960s when labour-saving, wheel-move systems became popular. In the 1970s, centre pivot irrigation systems began showing up. Sprinklers, both wheel-move and centre pivot, began to replace surface irrigation systems. Technological advances in centre pivot systems during the past 20 years, including the addition of corner systems and low pressure application devices, have greatly improved their efficiency and effectiveness. The centre pivot system, with its diversity and adaptability, is currently the system of choice. There is only a minor amount of purchasing and development of any other irrigation system or method in Alberta.

Pump and sprinkler technology enabled the irrigation of land with rolling topography and land above the ditch. This considerably reduced the labour involved in irrigation farming. These factors contributed to more than a doubling of the irrigated area in Alberta since 1970.

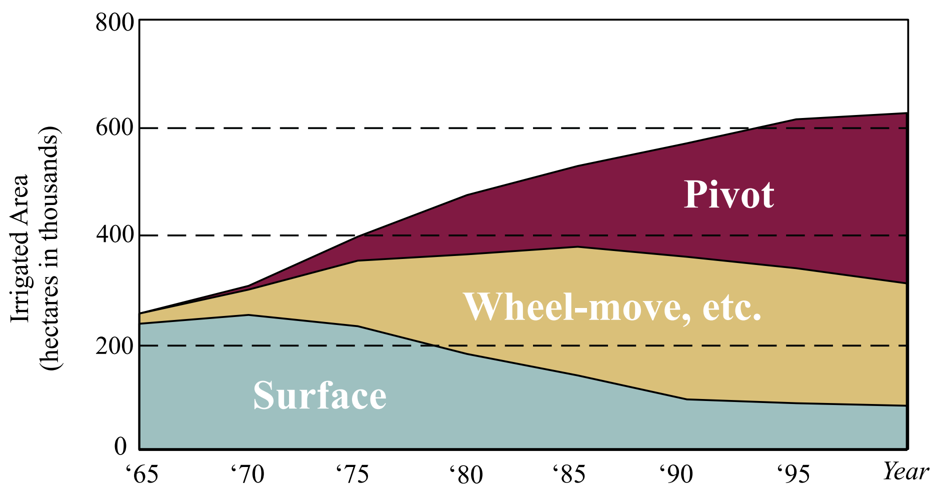


Figure 26. Irrigation expansion and on-farm irrigation methods.

Through many years of system testing, field monitoring, literature searches and consultations with other jurisdictions, a range of application efficiencies for each type of irrigation equipment and method was derived and accepted as an industry standard in Alberta. There are many factors that can affect the efficiency for any given system or method. For instance, properly levelled and designed surface systems can have efficiencies up to 75%, whereas poorly designed and managed surface irrigation systems may have efficiencies less than 60%. A low pressure, down-spray sprinkler can range in efficiency from 75% to 90%. Design of the sprinkler nozzle, spray devices, capacities and pressure at which water is ejected must be in keeping with site-specific soil texture, topography and agro-climatic conditions to maximize the efficiency of the system. In addition, farm management can have a major impact on efficiencies, even on the best designed systems.

Based on AAFRD's research, the following application efficiencies are considered to be representative of various on-farm irrigation methods and systems in Alberta.

- Surface (undeveloped) - 30%
- Surface (developed) - 65%
- Hand-move sprinklers - 65%
- Wheel-roll sprinklers - 68%
- Centre pivots (high pressure) - 74%
- Centre pivots (low pressure) - 80%

On-farm irrigation methods generally fall into three categories:

- *Surface irrigation*
- *Sprinkler irrigation*
- *Micro or drip irrigation*

On-farm irrigation systems are comprised of the actual works used to apply water to the land. In the Irrigation District Model, 18 different system-types are represented among the three application method categories.

AAFRD has tracked on-farm methods and equipment in the 13 irrigation districts for several decades. Based on this information and the system/method application efficiencies, a chronology of average district on-farm efficiency changes since 1965 was computed (Table 9). On-farm application efficiencies improved markedly from 1965 to 1995, largely due to the shift from surface irrigation to sprinkler irrigation, and more recently, to centre pivot systems. The magnitude of the improvement varies from district to district, depending, to a degree, on crops grown and the extent to which irrigation is a critical input to crop yields.

Table 9. On-farm application efficiencies based on methods and equipment.

Irrigation District	Average Efficiency for Year (%)				
	1965	1980	1990	1995	1999
Aetna	30	33	44	45	65
Bow River	37	59	66	66	71
Eastern	32	53	64	64	67
Leavitt	30	33	42	42	65
Lethbridge Northern	32	56	67	69	73
Magrath	31	50	56	58	72
Mountain View	30	31	32	32	32
Raymond	32	52	61	66	72
Ross Creek	40	49	51	53	N/A
St. Mary River	35	64	70	71	73
Taber	38	65	68	69	73
United	31	39	40	40	61
Western	35	51	67	68	69
Weighted Mean	**34**	**58**	**60**	**67**	**71**

The average, overall on-farm application efficiency in 1999 for all the irrigated areas in southern Alberta was estimated to be 71%. This value would probably be slightly higher for private irrigation, due to the predominance of sprinkler systems in those operations.

Significant gains in on-farm application efficiencies have been realized. It is expected improvements will continue in the future as producers shift to more efficient systems and as irrigation management techniques improve. With the current state of technology and with systems in common use today on the Canadian prairies, average on-farm efficiencies beyond 80% are unlikely. Well-designed centre pivot or linear sprinkler systems with low pressure drops range in application efficiency from about 75% to 90%, depending on site-specific soil textures, topography and climatic conditions. The mean efficiency for such systems is about 80%. A widespread shift to drip or trickle irrigation systems with 90% efficiencies is unlikely for the crops irrigated in southern Alberta without a major change in commodity prices. For the foreseeable future, a 75% on-farm application efficiency is considered to be a reasonable target for planning purposes. An on-farm efficiency of 75% was assumed for determining the 1991 *Regulation* licence volumes.

4. Irrigation Management Practices

It has long been recognized that irrigation farmers in Alberta apply less water to their crops than that required for optimum yields. Based on monitoring conducted during the past five years, it is estimated that irrigation water users are meeting, on average, about 84% of water requirements for optimum yields. This level of irrigation management, or water application, has increased during the past 10 years, and will continue to increase. However, it is believed the level of irrigation management will not increase beyond 90% of optimum for the types of crops grown, and cultural and harvesting practices in southern Alberta.

Approximately 60 irrigated fields were monitored each year from 1996 to 2000 to determine the extent to which actual irrigation crop water management compared with crop water requirements for optimum production. The crop water requirements for optimum production were estimated for various crop types and regions using the Lethbridge Research Station Irrigation Management Model (LRSIMM). LRSIMM simulates evapotranspiration and soil moisture conditions using the Jensen-Haise equation and calibrated crop type coefficients. The timing of optimal irrigation applications was determined based on the objective of keeping soil moisture in the irrigated field above 70% of field capacity for centre pivot systems, and above 50% of field capacity for wheel move and surface systems. It was assumed pivot systems added 25 mm in each application and wheel moves added 72 mm. Each application brought surface systems up to field capacity. Actual applications were monitored.

Computation results for optimal water requirements and actual crop water management were compiled by crop type, by on-farm irrigation system and by region. Modelled versus monitored crop water requirements or consumptive use (CU) varied by crop type (Table 10). Note that the monitored CU includes precipitation and irrigation as well as changes in soil moisture. Alfalfa had the highest crop water requirement for optimum production (638 mm), almost double the requirement of silage barley, the crop with the lowest water requirement. On average, irrigation water users are meeting about 84% of the crop water required for optimum production. The consumptive use ratios range from 77% for alfalfa to 98% for sugar beets. The low consumptive use ratio for alfalfa may be due in part to the fact that the LRSIMM model computed requirements throughout the growing season until the first killing frost. In some regions, two cuts of alfalfa is the common practice, rather than three cuts.

Irrigation farmers generally do not irrigate during harvesting operations. High input costs associated with higher value crops, such as sugar beets, and the more serious consequence of lower than optimum yields, may foster higher levels of irrigation management for specialty crops.

Table 11 shows the variation in on-farm management by irrigation method and system type. On average, there was very little difference in the percentage of optimum requirements consumed by crops grown under centre pivot (84%) and wheel move (81%) systems. Surface systems met, on average, 71% of the crop water requirement.

Table 10. Variation in on-farm water management by crop type.
(Five-year averages for all regions - CU = consumptive use)

Crop Type	Crop Water Requirement - Consumptive Use (CU)		
	Optimum CU (mm)	Monitored CU	
		mm	% of Optimum
Alfalfa	638	494	77
Barley	352	315	90
Silage barley	322	285	89
Canola	390	334	86
Soft wheat	437	361	83
Sugar beets	525	514	98
Wheat	419	360	86
All crops (weighted mean)	469	396	84

Table 11. Variation in on-farm water management by irrigation system type.
(1996 to 1999 averages for all regions and all crop types. CU = consumptive use)

System	Crop Water Requirement			Average Annual % of Fields	
	Optimum CU (mm)	Monitored CU		Over-irrigated at Least Once	Under-irrigated at Least Once
		mm	%		
Centre pivots	468	401	84	11	57
Wheel moves	481	381	81	34	60
Surface	437	357	71	100	20

All the surface irrigated fields, 34% of the wheel move fields, and 11% of the centre pivot fields were over-irrigated at least once during the growing season. Examination revealed that 69% were over-irrigated due to operator decisions, such as using 12-hour rather than 8-hour sets, or starting irrigation too early in the season. System design problems, such as excessive run lengths or an incorrect nozzle package for the soils, accounted for 31% of the over-irrigation.

Only 20% of surface irrigated fields were under-irrigated at least once. In comparison, close to 60% of the wheel move and pivot irrigated fields were under-irrigated at least once. Sprinkler under-irrigation tended to occur in years that were cool and wet. Almost all of the under-irrigation could be attributed to operator decisions, such as starting too late or quitting too early. None of the under-irrigated fields were a result of insufficient delivery of water.

Corn heat units are indicators of the capacity of a climatic area to grow crops requiring relatively high temperature regimes. They are, essentially, the accumulation of heat, measured in degree-days above certain thresholds, during the growing season.

Long-term normal corn heat units, 1996 to 2000 monitoring-period corn heat units, and precipitation provide an indication of the variation in climatic conditions in the six regions where monitoring was carried out (Table 12). As expected, the regions with the lowest heat units during the study period (Strathmore and Brooks) had the lowest crop water requirements. The average application ratios ranged from 72% in the Strathmore region to 93% in the Bow Island region. The highest levels of irrigation management were in the Medicine Hat and Bow Island regions where long-term normal heat units are highest and normal precipitation is lowest. These regions have a higher percentage of specialty crops than the other regions. (The Taber Irrigation District has the highest percentage of specialty crops of all the districts, however, AAFRD's Taber district office monitored projects in both the Taber and Bow River districts.) The lower levels of irrigation management in the Strathmore and Brooks regions may be a reflection of the lower percentage of specialty crops. A portion of the alfalfa grown in the Western and Eastern irrigation districts, their predominant crop, is also managed for two cuts rather than three. The LRSIMM was used for estimating crop water requirements during the full frost-free period.

Table 12. Variation in on-farm management by region. (Five-year averages for all crop types)

Region	Crop Water Requirement			Corn Heat Units		G.S. Precipitation[2]	
	Optimum CU (mm)	Monitored CU[1]		Long-term Normal	1996 to 2000 Mean	Long-term Normal (mm)	1996 to 2000 Mean (mm)
		mm	%				
Strathmore	418	301	72	1993	2079	258	220
Brooks	451	360	80	2256	2418	217	185
Lethbridge	473	398	84	2294	2424	254	219
Taber	496	411	83	2359	2617	219	179
Bow Island	484	449	93	2474	2529	212	165
Medicine Hat	492	454	92	2414	2522	216	172
Average	469	396	84	2298	2432	229	190

[1]CU = consumptive use. [2]G.S. = growing season.

Overall, the level of irrigation crop water management in 2000 is estimated to be about 84%. That is, the level of consumptive use, on average, is about 84% of that required for optimum crop yields. The level of crop water management is expected to increase in the future for the following reasons.

- There will be a continued shift in irrigation methods from surface irrigation to sprinkler irrigation.
- There will be a shift in irrigated crop types from cereals to higher value specialty crops. The gains made from this shift may be partially offset by a shift from cereal crops to forage production.
- Training and education of irrigation farmers on techniques and benefits of higher levels of crop water management will increase.
- Improvements in irrigation scheduling technology and widespread use of scheduling techniques will continue.
- On-farm system design will improve.

While improvements will be made, it is a consensus of opinion among irrigation district and AAFRD staff that the level of crop water management is unlikely to increase beyond 90% of optimum, for the crops grown, and the cultural and harvesting practices in southern Alberta. This conclusion is supported by research and the opinions of irrigation practitioners in the north-western United States.

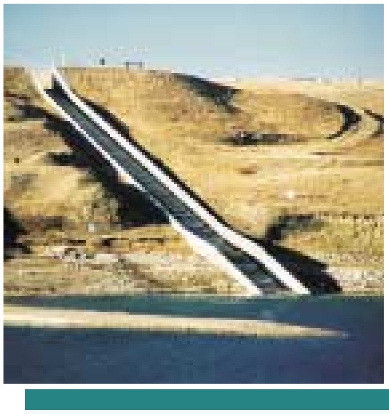
The 1991 *Regulation* licence volume was based on irrigating to the optimum crop water requirement, implying a 100% irrigation management factor. The prevailing irrigation management factor in 1991 was estimated to average 80%.

B. IRRIGATION DISTRICT DISTRIBUTION SYSTEM

The three main tributaries of the South Saskatchewan River – the Red Deer, Bow and Oldman Rivers – rise in the Rocky Mountains and foothills of southwestern Alberta and flow eastward across the prairies. The St. Mary River, the Belly River, and its major tributary, the Waterton River, rise in the mountains of Montana and flow northeast to join the Oldman River near Lethbridge. On average, about 75% of the total annual flow of these rivers originates in the mountain and foothills region. Although variable from year to year, the mountain and foothills runoff is more dependable than that of the prairies.

In the late-1800s, government resource administrators observed the frustrations of settlers attempting to earn a living farming the dry prairie. They concluded the waters of the Rocky Mountains should be made available to the settlers to enable them to remain on the land. Irrigation was promoted and projects were developed by individuals and by corporate land developers. The development of the irrigation projects that were eventually to become the current 13 irrigation districts typically involved four basic components.

- Works to divert water from the source, usually a river.
- Works to convey water from the source to the irrigation district.
- Distribution works within the district to convey water to individual farmers.
- On-farm works to apply water to the land.



For 11 of the 13 irrigation districts in Alberta, the first two components, referred to as headworks, are owned and operated for multi-purpose use by AENV. The Eastern and United irrigation districts own and operate their own headworks. The UID is negotiating transfer of their headworks to the province. Distribution works are owned and operated by the individual districts. The on-farm works are farmer-owned.

1. District Characteristics

In the early years, the layout of the distribution system was aimed at getting as much land as possible under the ditch, so it could be irrigated by surface methods. Canals were located and designed to minimize earthwork, which was dependent on horse-drawn equipment. As such, canals usually followed the contour of the land. Seepage from canals was unchecked and high in some areas. Structures were often made of untreated timber. Washouts were common and maintenance was high.

In some areas, the landowners did not greet the arrival of irrigation water with the enthusiasm expected. Irrigation uptake by dryland farmers was particularly slow and spotty where there were good prospects for a dryland crop in most years. However, both irrigating and non-irrigating landowners came to depend on the canals for their domestic and stock watering supplies. Communities used the irrigation canals to meet their municipal needs.

The ratio of irrigated area to canal length varied from project to project. These ratios have persisted through the years and are a significant characteristic of the districts of today (Figure 27). Low ratios have major implications for funding, operation, maintenance and efficiencies of district works.

The layout and design of the distribution systems in the early years established patterns of land use and water dependencies that were inherited by today's districts. With this inheritance came an inefficient, high maintenance distribution system, and in some cases a limited ability to make rational changes to the system without major impacts on the landowners and the communities dependent on the canals for their water supplies.

By the 1960s, infrastructure within the irrigation districts was in a serious state of disrepair. Without major rehabilitation, water supplies in many areas would have been threatened. The required rehabilitation was clearly beyond the fiscal capability of water users within the districts, so assistance from the province was sought and granted. Since 1969, AAFRD and AENV have cost-shared with the districts the rehabilitation of infrastructure. To date, more than 4,200 km of canals have been rehabilitated, representing about 55% of the district conveyance works (Figure 28; Table 13). This work is continuing. Most of the rehabilitation work has been funded with AAFRD and AENV cost-sharing. Some districts, such as the EID and SMRID, have solely funded part of their rehabilitation programs.

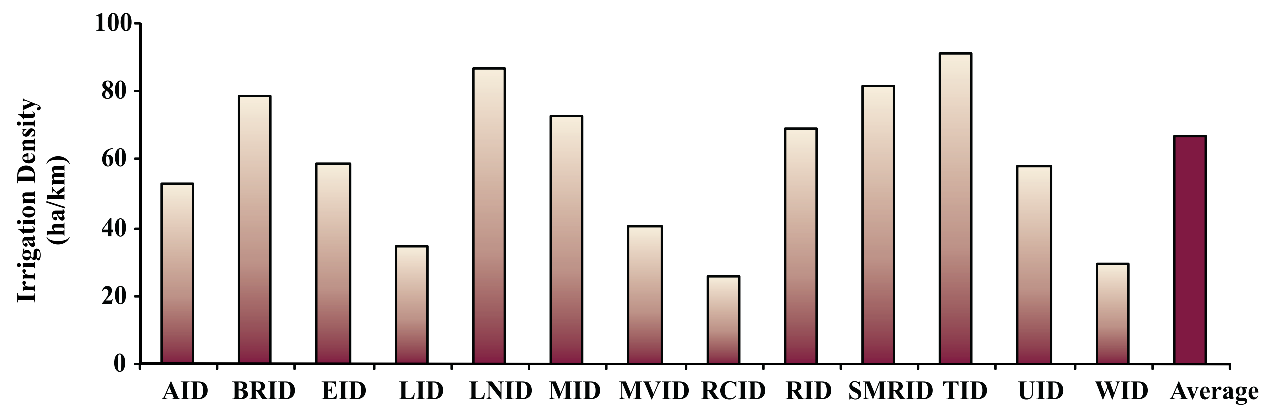


Figure 27. Ratio of assessed irrigation area to length of distribution system (district density).

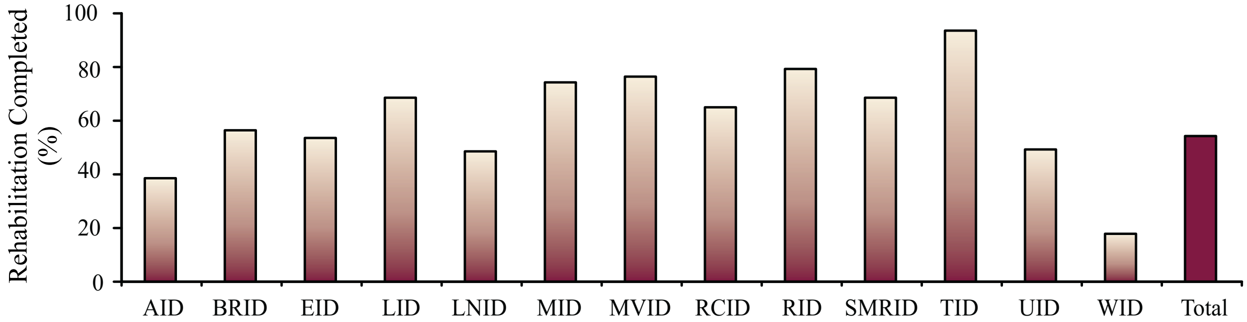


Figure 28. Progress on rehabilitation of irrigation district works.

Table 13. Irrigation district distribution systems.

Irrigation District	Unrehab'ed Canals (km)	Rehabilitated Conveyance Works[1]				Total Rehab'ed and Unrehab'ed (km)	Percent Rehab'ed
		Canals (km)		Pipelines (km)	Total Rehab'ed (km)		
		Earth	Lined				
Aetna	17	1	0	10	11	28	40%
Bow River[2]	473	202	217	189	609	1082	56%
Eastern[2]	890	386	218	428	1032	1921	54%
Leavitt	18	20	3	15	38	56	68%
Lethbridge Northern	369	69	106	170	344	714	48%
Magrath	26	36	1	39	76	102	74%
Mountain View	9	17	0	12	28	37	77%
Ross Creek	7	9	1	2	13	19	65%
Raymond	55	124	4	84	211	267	79%
St. Mary River[2]	563	424	204	590	1218	1781	68%
Taber	24	84	89	159	333	357	93%
United	120	52	14	52	118	239	50%
Western	981	126	38	49	213	1194	18%
Total	3552	1550	895	1798	4243	7796	54%

[1]Rehabilitated works include district works constructed with provincial and district cost share funding.

[2]Data for BRID, EID and SMRID current to November 1999; all other districts current to June 1999.

The rehabilitated works are much more efficient than the works they replaced. Canals have been lined where seepage was significant and seepage has almost been eliminated. Waterlogged and salinized land is being reclaimed. More constant canal side slopes and bed widths, and gravel armouring on side slopes, have lowered maintenance costs and helped to convey water more effectively. Canal alignment changes have been made to accommodate modern irrigation techniques. Automation of appurtenant structures (drops, checks, wasteways, etc.) has reduced response time, spills and return flow.

In recent years, many districts have replaced small canals with pipelines. The capital costs of pipelines are often competitive with lined canal costs, and pipelines offer significant advantages, including the following.

- No tailouts, therefore minimizing return flow. (About 90% of installed pipelines are closed systems).
- Increased efficiencies by eliminating seepage and evaporation losses.
- Eliminating canal right-of-ways, thereby increasing the irrigable land.
- Commonly used PVC pipe has a life expectancy of 100 years.
- Low maintenance costs. Only appurtenant equipment (flanges, inlets, flow meters, etc.) requires maintenance.
- Less danger to the public than an open channel.
- Less opportunity for water contamination.
- Static head within the pipe can reduce or eliminate pumping costs.

Recently introduced 1200-mm diameter PVC pipe can carry flows up to 2.8 cubic metres per second. Proposed 1500 mm pipe will increase the carrying capacity to about 4.2 cubic metres per second .

It is expected the districts will continue to upgrade their distribution systems by rehabilitating their canals and replacing the smaller ones with pipelines. As pipelines become more numerous and larger, new issues will arise, such as the effects of water hammer and cyclical surges on the life of the pipes. Changes in water use from pipelines, due to power outages or heavy rains, will have immediate effects on feeder canal flows and water levels. Automation of operations, monitoring and communications will become more critical, to enable timely responses to avoid washouts and minimize spills.

Reservoirs are integral components of both the headworks and the irrigation district infrastructure. Alberta Environment and the districts operate 49 reservoirs to supply water for instream flow needs, communities, industries, recreation users, domestic users and stock within the irrigated area of Alberta. AENV operates both onstream and offstream reservoirs that are critical to supplying the needs of the irrigation districts (Table 14).

Onstream reservoirs on the Waterton, St. Mary and Oldman rivers are used to store water during the high flow periods – usually early May to mid-July – for controlled releases to meet instream flow needs, and for consumptive uses and interprovincial apportionment commitments during low flow periods. The St. Mary River and Oldman River reservoirs are large enough to carry storage over from most high flow years to supply water needs during periods of drought. AENV also owns and operates eight offstream storage reservoirs within its network of irrigation headworks. The accumulation of storage in offstream reservoirs is constrained by the capacity of the canals conveying water to the reservoirs from the source streams. Most offstream reservoirs are used to accommodate seasonal variations in supply and demand. The offstream reservoirs are not as effective as the onstream reservoirs in contributing to instream flow needs and apportionment. However, some projects, such as McGregor Lake Reservoir, are large enough to provide annual carry-over storage.

Table 14. Reservoirs associated with irrigation and other water uses in southern Alberta.

Location	Reservoir	Live Storage (dam^3)		Full Supply Level Surface Area (ha)	
Alberta Environment Headworks Reservoirs			Sub-totals		Sub-totals
Carseland-Bow River (BRID)	Little Bow	21,078		530	
	McGregor Lake	351,059		5,100	
	Travers	104,638	446,775	2,265	7,895
Cavan Lake (RCID)	Cavan Lake	4,625	4,625	135	135
Lethbridge Northern (LNID)	Keho Lake	95,635		2,350	
	Oldman River	490,180	585,815	2,425	4,775
Mountain View, Leavitt, Aetna	Payne Lake	8,690	8,690	240	240
Waterton-St.Mary (SMRID, MID, RID, TID)	Jensen	19,000		200	
	Milk River Ridge	127,297		1,415	
	St Mary	369,310		3,765	
	Waterton	111,196	626,803	1,095	6,475
Irrigation District Reservoirs					
Bow River Irrigation District	Badger	53,650		890	
	H Reservoir	2,220		130	
	Lost Lake	5,050		485	
	Scope	19,740	80,660	575	2,080
Eastern Irrigation District	Cowoki	19,735		730	
	Crawling Valley	130,500		2,515	
	J Reservoir	615		115	
	Kitsim	26,520		690	
	Lake Newell	320,215		6,495	
	One Tree	2,345		90	
	Rock Lake	9,250		225	
	Rolling Hills	17,515		585	
	Snake Lake	18,230		105	
	Tilley "A"	33,300		620	
	Tilley "B"	38,235	616,460	1,410	13,580
Lethbridge Northern Irrigation District	Park Lake	740		85	
	Picture Butte	1,600	2,340	100	185
Raymond Irrigation District	Corner Lake	495		15	
	Craddock	615		13	
	Factory Lake	370	1,480	29	57
St. Mary Irrigation District	Bullshead	125		13	
	Chin	190,330		1,590	
	Cross Coulee	2,590		85	
	Forty Mile	86,345		745	
	Murray	30,590		1,665	
	North East	2,095		210	
	Raymond	1,600		60	
	Sauder	37,745		1,245	
	Seven Persons	1,355		60	
	Sherburne	10,625		410	
	Stafford	23,315		490	
	Yellow	n/a	386,715	1,105	7,678
Taber Irrigation District	Fincastle	3,085		185	
	Horsefly	9,250		565	
	Taber Lake	6,415	18,750	405	1,155
United Irrigation District	Cochrane Lake	3,100	3,100	90	90
Western Irrigation District	Chestermere Lake	5,180		260	
	Langdon	7,895	13,075	245	505
Total (all reservoirs)			2,825,288		44,850

The 38 reservoirs owned and operated by the irrigation districts are all offstream reservoirs that depend primarily on canal flows for their water supplies. Reservoir storage is essential to provide water supply security to irrigation water users who would otherwise be dependent on highly variable river flows to meet their needs. Reservoirs within districts provide operational flexibility and reduce response times to meet changes in water demands. Many reservoirs are strategically located to recapture operational spills and return flow, thus improving water use efficiencies within districts. It is expected the continuing need to improve efficiencies will stimulate further reservoir developments within the districts.

2. Canal Seepage

When the 1991 *Regulation* licence volumes were established, seepage was estimated to be 13% of the total volume for all districts. Research conducted since 1996 indicates that the rate of seepage from canals is much lower than estimated in 1991. Substantial progress has been made since 1991 in rehabilitating irrigation district infrastructure and further reducing seepage losses. Seepage from district works has been estimated to be about 89,800 cubic decametres or 2.5 % of the *Regulation* licence volume. This amount will be reduced further with continuing rehabilitation.

Data from 26 ponding tests conducted in various irrigation districts indicated that canal seepage varied from 0.0032 cubic metres per square metre of wetted area per day to 0.1312 cubic metres per square metre per day, with an average of 0.023 cubic metres per square metre per day. The results from the tests and typical cross-sections for various canal sizes were used to derive relationships between seepage rates, canal size (capacity) and soil texture.

Information on soil texture along canals within the irrigation districts was taken from the Agricultural Region of Alberta Soils Inventory Database. Canal lengths, capacities and soil textures were inventoried for each district. Seepage rates for canal segments were derived based on the percentage of each of the three soil texture groups existing along the canal length. Drains were not included in the computations. Many of the drains are natural channels that typically have low seepage rates. Drains that carry a natural flow as well as irrigation return flow would have negligible incremental seepage caused by irrigation water.

Using seepage rates as shown in Figure 29 and canal and soil characteristics, total seepage for each district was computed based on the following assumptions.

- Seepage was zero for all pipelines and lined canals. Compacted earth-lined canals were assumed to have the seepage characteristics of canals with fine textured soils.
- The canals were "checked up" to their maximum hydraulic head regardless of the flow. (Canal check structures are used to assure adequate head at the farm turnouts.)
- The canals would be operated for 150 days each year.

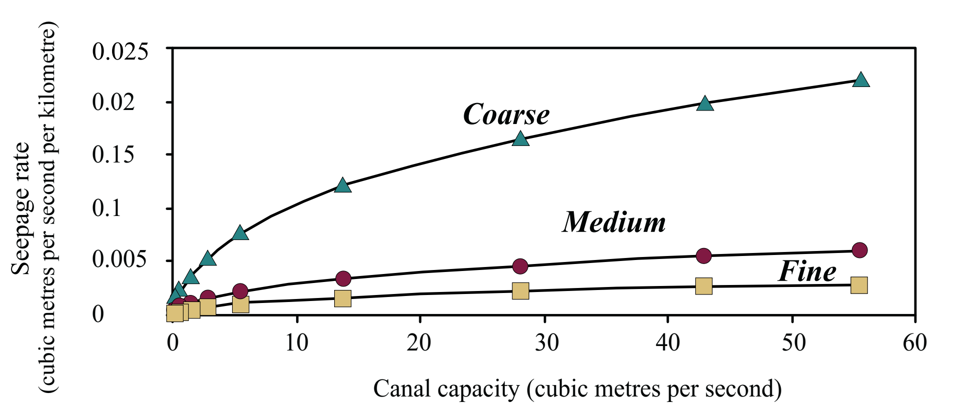


Figure 29. Seepage rates for various soil texture groups and canal capacities.

The total canal seepage for each district is given in Table 15. Note the seepage computed is based on soil texture and infrastructure characteristics in 1999. As such, it is independent of the area irrigated or the gross diversion.

About 5,000 km of canals have the potential to seep. The SMRID, EID and the WID account for two-thirds of this total. The SMRID and EID are Alberta's largest and second largest irrigation districts, respectively. Rehabilitation of conveyance works is well advanced in both these districts; about 69% in the SMRID and about 54% in the EID (Table 13). The WID is the fifth largest irrigation district; only about 18% of its conveyance works have been rehabilitated.

The rate of seepage from the canals varies substantially among the districts, depending on the size of the canals and soil textures. The total annual seepage is estimated to be about 89,753 cubic decametres. The EID has the highest seepage volume, 23,672 cubic decametres, which represents 2.6% of the district's proposed licence volume as established in the 1991 *Regulation*. The WID has a seepage volume similar to the EID. However, this represents a substantially higher portion (6.8%) of the *Regulation* licence volume, in large part due to the low percentage of canals that have been rehabilitated.

Table 15. Summary of seepage losses from irrigation district canals and drains.

Irrigation District	Water Management Study (Based on Ponding Tests)			1991 *Regulation* Seepage Estimates	
	Length of Seepable Canals[2] (km)	Annual Seepage Loss		Volume (dam^3)	Percent of Licence Volume [1]
		Volume (dam^3)	Percent of Licence Volume [1]		
Aetna	17	170	1.5%	3,136	28.2%
Bow River	641	13,799	2.2%	69,939	11.3%
Eastern	1,242	23,672	2.6%	108,548	11.8%
Leavitt	39	238	1.6%	4,001	27.0%
Lethbridge Northern	422	5,346	1.4%	47,379	12.1%
Magrath	62	491	1.2%	5,418	12.9%
Mountain View	26	224	2.3%	1,324	13.4%
Raymond	181	1,971	2.0%	8,030	8.0%
Ross Creek	18	116	3.1%	370	10.0%
St. Mary River	1,003	18,084	2.0%	82,595	9.3%
Taber	94	1,289	0.7%	14,195	7.3%
United	173	1,111	1.3%	9,646	11.5%
Western	1,101	23,242	6.8%	117,183	34.2%
Total or weighted mean	5,019	89,753	2.5%	471,764	13.0%

[1] For the *Regulation* licence volume, see Table 4.
[2] Seepable canals = all canals without membrane or concrete lining.

The seepage losses used for determining the licence amounts for the 1991 *Regulation* limits (Table 4) were based on the Moritz formula, as suggested in the United States Bureau of Reclamation's design manual. The current estimates are only about 19% of the 1991 estimates for two reasons:

- Rehabilitation of irrigation infrastructure has made substantial progress during the past 10 years, eliminating or reducing the rate of seepage from canals. In particular, numerous reaches of small canals have been replaced by pipelines with zero seepage; and
- Ponding tests on unrehabilitated canals indicated a rate of seepage that is much less than the literature values used in the 1991 *Regulation* licence volumes. For instance, the ponding tests indicated an average seepage rate of 0.023 cubic metres per square metre per day. The 1991 estimates were based on a seepage rate of 0.125 cubic metres per square metre per day for all unrehabilitated canals, which is 5.5 times the average rate computed from the ponding tests.

The 1999 estimates of seepage losses represent only 2.5% of the *Regulation* licence volumes. At present, about 54% of the district infrastructure has been rehabilitated (Table 13). Most of the larger canals, and particularly canals with significant seepage, have already been rehabilitated, eliminating a large portion of seepage from the conveyance works. Taber Irrigation District, with 93% of its works rehabilitated, has an annual seepage loss of 0.7% (Table 15). Based on this experience, and with continued rehabilitation in all other districts, it is conservatively estimated seepage losses could be reduced to about 1.5% of the gross diversion, or 54,000 cubic decametres.

3. Evaporation

Canal and reservoir evaporation losses from the current district infrastructure have been estimated to be about 142,016 cubic decametres, or about 3.9% of the proposed licence volume. In establishing the 1999 *Regulation* licence volume, reservoir evaporation was estimated to be 3.6% of the gross diversion. Canal evaporation was not considered in the 1991 estimate. In the future, reservoir evaporation losses would increase if new reservoirs were established within the districts. Canal evaporation would decrease slightly if pipelines continue to replace open channels.

Evaporation of water applied to crops using sprinkler or surface methods is accounted for as a component of on-farm system inefficiencies. Evaporation from open water surfaces of canals and reservoirs owned by the irrigation districts is an additional demand on the districts' water allocations. Evaporation from headworks canals and reservoirs is usually accounted for in the headworks licences issued to AENV and, as such, will not be dealt with in this section.

Evaporation from open water surfaces varies from year to year depending on factors such as temperature, relative humidity, solar radiation and surface areas of canals and reservoirs. Several methods have been developed for estimating evaporation from open water surfaces based on commonly recorded weather parameters. After an extensive study of options, AENV has adopted the Morton method for evaporation computations. The approach was developed in the late 1960s by F.I. Morton, and is based on energy balance and vapour transfer relationships (Morton 1968). The Morton method is being used to compute evaporation in AENV's Water Resources Management Model.

AAFRD examined five equations for computing potential evapotranspiration, primarily using data available in the Gridded Prairie Climate Database. They found the Priestley-Taylor method best replicated research results. This method was selected by AAFRD to compute potential evapotranspiration at the grid sites in southern Alberta.

The Distribution Working Group examined the Morton, Priestley-Taylor, and other methods for computing surface water evaporation. A primary consideration in determining the suitability of the various methods is the availability of the input data for the study period. The working group found that the Priestley-Taylor method provided estimates similar to the Morton method. Since the data for the Priestley-Taylor method were already assembled, that method was selected to provide estimates of canal and reservoir evaporation.

The difference between evaporation and precipitation which falls directly on the water surface is referred to as net evaporation. Net evaporation from canals and reservoirs would be a loss to the distribution system charged against the district licences. Net evaporation from canals was estimated for each district based on an inventory of sizes and lengths of canals, surface areas, and net evaporation estimates for the general locations of the districts. Estimates were based on typical canal geometry, assuming the canals were running full or checked to their full capacity during the irrigation season. Mean annual canal evaporation estimates are shown for each of the 13 districts in Table 16. The total canal net evaporation for all districts was estimated to be 19,245 cubic decametres, or 0.5% of the licence volume. This is a very small component of the total demand within the districts. Canal evaporation was not included in the 1991 computations of the proposed licence amounts.

Evaporation from most reservoirs within the irrigation districts was computed in the WRMM modelling conducted by AENV. The evaporation computations were based on simulated weekly reservoir levels and surface areas. These surface areas were sometimes considerably less than the areas at full supply levels, particularly in critical low runoff, high demand years, when the reservoirs would be drawn down for water supply purposes. The reservoir evaporation demand was variable from year to year. Each scenario of water demands and operational characteristics would have unique reservoir evaporation demands.

In the 1991 computations of the licence volume, evaporation demands for the irrigation district reservoirs were input to the model as a fixed demand on the system. For comparison purposes, the Distribution Working Group computed the mean annual reservoir evaporation for each district based on reservoir surface areas at full supply levels and the mean net evaporation for the general locations of the reservoirs. The estimated reservoir net evaporation loss for each district is given in Table 16. Note these estimates are upper limits of mean annual evaporation. They are probably higher than the evaporation losses computed in the modelling exercise.

The total reservoir net evaporation loss for all districts is estimated to be 122,771 cubic decametres, or 3.4% of the *Regulation* licence volume. This figure compares well with the 1991 estimate of 132,021 cubic decametres. The volume of evaporation loss is primarily a function of district infrastructure characteristics. It will not be significantly modified by changes in the irrigation area or the gross diversion. In the future, canal evaporation will decrease by a small amount as pipelines replace canals. Evaporation would increase with the construction of new reservoirs. While new storage reservoirs can significantly improve district operations and reduce return flows, reservoirs in themselves are water users. This water use should be considered in decisions related to new storage development. Efficient storage sites that maximize the storage capacity to surface area ratio should be given preference.

Table 16. Evaporation from irrigation district canals and reservoirs.

Irrigation District	Irrigation Water Management Study of Evaporation Losses								1991 *Regulation* Evaporation Losses	
	Canals [1]			Reservoirs [1]			Total Net Evaporation		Net Volume (dam^3)	% of Licence Volume
	Total Length (km)	Surface Area (ha)	Net Loss (dam^3)	Number	Surface Area (ha)	Net Loss (dam^3)	Volume (dam^3)	% of Licence Volume [2]		
AID	17	5	18				18	0.2%	131	1.2
BRID	857	648	3,181	4	2,080	10,226	13,407	2.2%	7,771	1.3
EID	1,451	987	4,945	11	13,580	67,132	72.077	7.8%	74,627	8.1
LID	43	11	39				39	0.3%	117	0.8
LNID	529	280	1,242	2	185	777	2,019	0.5%	10,300	2.6
MIF	64	28	121				121	0.3%		0
MVID	27	9	30				30	0.3%	137	1.4
RID	182	161	684	3	57	242	926	0.9%		0
RCID	19	6	31				31	0.8%		0
SMRID	1,192	1,178	5,554	12	7,678	37,239	42,793	4.8%	32,120	3.6
TID	181	109	485	3	1,155	5.128	5,613	2.9%	4,055	2.1
UID	187	75	257	1	90	310	567	0.7%	419	0.5
WID	1,153	627	2,658	2	505	1,717	4,375	1.3%	2,344	0.7
Total	5,902	4,124	19,245	38	25,330	122,771	142,016	3.9%	132,021	3.6

[1] Irrigation district canals and reservoirs only. Does not include headworks canals or reservoirs.
[2] For the *Regulation* licence volume, see Table 4.

4. Return Flow

Irrigation return flow is the quantity of water diverted from a source that exceeds the consumptive requirements of the irrigation project, including losses. This surplus water is returned to the river system – not necessarily the source stream – through drainage channels.

Return flow is an inevitable consequence of operating an irrigation system. It occurs in large part because variable supplies and demands cannot be perfectly matched in a canal distribution system. The irrigation districts are concerned about return flow for several reasons. Uncontrolled spills and sudden changes in canal water levels can damage canals and increase maintenance costs. Inefficient operations could jeopardize expansion of irrigation. They are also concerned about public perceptions of wasteful management practices and impacts on the source streams. During the past decade, the districts and AAFRD have made a concerted effort to better quantify return flow, to understand the factors affecting it, and to identify ways to minimize it. This effort has involved intensive monitoring and study of small irrigation blocks within the BRID and LNID, computer simulation modelling, and extensive monitoring of district return flow.

a) Block Studies

Intensive monitoring of irrigation Block K5 in the BRID and Block J12 in the LNID has helped to track and quantify the water balance within irrigation blocks, and to understand factors affecting return flow. For discussion purposes, return flow can be divided into three primary components – operational spills, base flow and on-farm drainage.

Operational spills usually occur as a result of sudden reductions in demand. Irrigation demands can change suddenly for numerous reasons, such as heavy rains, freezing temperatures, power failures, equipment breakdowns, end gun or corner arm shut-off on pivot systems, and set changes on side-roll systems. Increased return flow will continue until adjustments can be made to the system to restore the supply-demand balance. The need to flush canals and some reservoirs at start-up results in high return flow early in the irrigation season.

During normal operations, **base flow** is required along canals to meet seepage and evaporation losses, to ensure the last users in the system have sufficient water to operate their pumps or turnouts, and to provide a margin of safety to accommodate sudden increases in demand. Base flows and operational spills are not diverted at the farm turnouts – they remain in the laterals to the tailouts. Data from the block studies indicate the average return flow at the tailout of the laterals was 0.07 cubic metres per second. The base flow component is believed to be substantially higher than the operational spills – perhaps about 0.06 cubic metres per second. The number of tailouts in a distribution system has a major effect on return flow. A branched system with numerous laterals and sub-laterals will have higher return flow than a linear system with fewer laterals. The number of tailouts can be reduced by replacing laterals with closed pipelines.

On-farm drainage of surplus applications is usually small for sprinkler systems, but can make a significant contribution to return flow in areas where surface systems are common. Surface irrigation farmers in Block K5 returned about 40% of their total application to drains. The return flow from the irrigation block with a high percentage of surface irrigation was typically 75% to 100% higher than that of the block with only sprinkler systems.

Data from the block studies indicate return flow is primarily a function of infrastructure characteristics, irrigation methods and district management. It appears to be independent of the gross diversion and irrigated area.

b) Recorded Return Flow

Return flow occurs through numerous, often natural, drainage channels. It is often low and intermittent, and is sometimes combined with natural flow. Historically, a relatively small number of return flow channels have been monitored by Water Survey of Canada for the purposes of estimating total annual natural flow of the South Saskatchewan River, downstream of its confluence with the Red Deer River, for interprovincial apportionment purposes. Although the accuracy of return flow estimates so determined is considered to be sufficient for Prairie Provinces Water Board apportionment purposes, additional data are required by the districts to gain a better understanding of the amount of return flow, and its variability, components, and cause and effect relationships. Knowing these characteristics, it may be possible to identify measures to reduce return flow. Return flow is a significant component of the gross diversions and is a major consideration in the quest to make additional water available for expanding the irrigated areas within districts.

In 1994, the EID began a major initiative to monitor flows returning to the Red Deer and Bow rivers. Since then, seven other districts have begun monitoring. In 1999, more than 80 return flow sites were monitored. Daily data for all stations were assembled and reviewed and apparent anomalies in the data were identified and discussed with district and AAFRD staff. Adjustments were made to address anomalies and fill in missing records. District staff estimated the percentage of total return flow that was not gauged.

Six of the 13 districts conducted sufficient monitoring to permit reasonably accurate return flow estimates for all four years. Being the largest, these six districts contain more than 90% of the total irrigated area within all districts. Conclusions drawn from the results of monitoring in the six districts may be considered representative of all district irrigation. Note that the WID did not conduct return flow monitoring during the 1997 to 2000 period. However, Water Survey of Canada stations on the Rosebud River and Crowfoot Creek record about 80% of the return flow for the WID. The WID is therefore included as one of the six districts with reasonably accurate return flow estimates.

The irrigated area, gross diversion and return flow for each district where monitoring was carried out are summarized in Table 17. The EID had the highest volume of return flow, averaging 174,011 cubic decametres for the four years. This amounts to about 35% of the total return flow for the six districts. The EID is the second largest district in terms of irrigated area. It has the longest length of conveyance works, and by far the highest area of surface irrigation, all of which contribute to high return flow. The EID showed a pronounced decrease in return flow during the four-year period. This could be attributed to an improved awareness of return flow and a concerted effort by district managers and operations staff to improve management of the infrastructure and increase irrigation efficiency. The EID began monitoring return flow in 1994, three years before other districts.

Return flow expressed as a percentage of gross diversion varies substantially from district to district. It is highest in the WID, averaging 56.5%, and lowest in the SMRID, averaging 7.2%.

Variations are a function of several factors combined, including the size of the district, water user density and the extent of infrastructure rehabilitation. Return flow, expressed as a percentage of gross diversion, tends to be higher in smaller districts with low densities of irrigation users (area irrigated per km of canal).

Table 17. Irrigation district actual irrigated areas, gross diversions (GD) and return flow.

District	1997					1998				
	Area Irrigated (ha)	Gross Diversion (dam^3)	Return Flow			Area Irrigated (ha)	Gross Diversion (dam^3)	Return Flow		
			dam^3	mm/ha	% of GD			dam^3	mm/ha	% of GD
AID										
BRID	80,092	423,613	126,134	158	29.8%	80,210	374,447	127,844	158	34.1%
EID	111,244	705,748	215,495	195	30.5%	111,269	787,590	186,862	168	23.7%
LNID	58,706	238,774	40,651	70	17.0%	49,527	198,347	37,524	76	18.9%
MID										
RID										
SMRID	138,502	574,811	42,551	30	7.4%	138,709	523,867	44,478	34	8.5%
TID	30,791	142,570	29,007	94	20.3%	31,108	143,456	33,993	110	23.7%
WID	25,273	143,999	87,491	347	60.8%	27,374	175,610	100,321	366	57.1%

District	1999					2000				
	Area Irrigated (ha)	Gross Diversion (dam^3)	Return Flow			Area Irrigated (ha)	Gross Diversion (dam^3)	Return Flow		
			dam^3	mm/ha	% of GD			dam^3	mm/ha	% of GD
AID	757	4,229	3,387	448	78.8%					
BRID	80,155	368,229	109,064	137	29.6%	80,889	515,476	118,057	146	22.9%
EID	112,394	526,443	149,873	134	28.5%	112,893	832,613	143,815	128	17.3%
LNID	58,998	222,014	46,220	79	20.8%	61,514	303,189	49,320	79	16.3%
MID	5,958	25,657	14,571	244	56.8%	6,243	37,202	13,138	210	35.3%
RID	15,770	52,991	6,953	43	13.1%					
SMRID	144,068	507,614	39,006	27	7.7%	142,605	666,337	38,539	27	5.8%
TID	32,038	129,774	40,958	128	31.6%	32,055	172,747	28,673	88	16.6%
WID	20,653	109,054	84,883	411	77.8%	26,067	192,919	78,462	302	40.7%

District	Four-year Means					1991 *Regulation*				
	Area Irrigated (ha)	Gross Diversion (dam^3)	Return Flow			Area Limit (ha)	Licence Volume (dam^3)	Return Flow		
			dam^3	mm/ha	% of GD			dam^3	mm/ha	% of GD
AID						1,429	11,102	1,306	91	11.8%
BRID	80,337	420,443	119,298	148	28.4%	84,984	619,217	69,939	82	11.3%
EID	111,950	713,099	174,011	155	24.4%	111,289	918,958	94,980	85	10.3%
LID						1,930	14,802	1,764	91	11.9%
LNID	57,187	240,581	43,429	76	18.1%	67,583	391,020	35,019	52	9.0%
MID						7,406	41,939	3,836	52	9.1%
MVID						1,497	9,868	1,369	91	13.9%
RCD						486	3,701			
RID						18,818	99,914	9,745	52	9.8%
SMRID	140,972	568,158	41,143	30	7.2%	150,543	890,587	78,007	52	8.8%
TID	31,499	147,137	33,158	107	22.5%	33,265	194,893	17,232	52	8.8%
UID						13,759	83,878	10,904	79	13.0%
WID	24,842	155,395	87,789	354	56.5%	38,445	342,913	37,498	98	10.9%
Totals	446,787	2,244,813	498,828			531,434	3,622,792	361,599		
Weighted Mean				112	22.2%				67	10.0%

Canals with a high density of users have more predictable average demand conditions. As some users are ceasing operations, others are starting up. As rehabilitation progresses within the districts, lateral canals are replaced with pipelines and structures are automated. This increases response times to changes in demand and helps to reduce return flow. The number and location of storage reservoirs in the district can also be a factor in reducing return flow. Storage reservoirs reduce canal travel times, making possible more effective matching of supply and demand. Strategically located reservoirs also enable surplus canal flow to be stored for subsequent use downstream. Timely and accurate communications between water users and district operators are also important aspects of water management to minimize return flow within irrigation districts.

The WID has little internal storage, long canals with low irrigation densities in some areas, a relatively low level of rehabilitation of their conveyance system, and a high traditional dependence on the district works for domestic and municipal water supplies. These factors tend to increase return flow. Rainfall runoff can also affect estimates of return flow for individual districts, particularly in high precipitation years and in districts that normally have higher amounts of natural precipitation, such as the WID.

At the other end of the spectrum, the SMRID, the largest district, has a relatively high density of water users, a high percentage of pipe laterals, and a low percentage of flood irrigation. These characteristics tend to reduce return flow as a percentage of the gross diversion. The SMRID is also unique in its ability to recapture much of its unused irrigation deliveries in reservoirs and subsequently release it for downstream use.

Unit return flow, expressed as millimetres per hectare irrigated, varies markedly from district to district in a ranking pattern similar to return flow expressed as a percentage of gross diversions (Table 17).

The weighted-mean return flow used in the 1991 *Regulation* was 10% of the licence volume. In five of the six districts, average unit return flow is substantially higher than assumed in establishing the 1991 *Regulation* licence volumes. The exception is the SMRID, which returns less flow than was assumed in computing the licence volume.

The monitored return flow within the block studies and within the districts was used to calibrate the IDM. For every scenario of water supply and demand, return flow can be provided as output from the model. The model includes a rainfall-runoff algorithm for determining the amount of natural flow likely to be in the return flow channels. Natural flow is not normally a significant component of total flow in most return flow channels in southern Alberta, although it can be significant for some districts in high precipitation years. Overall, a far more significant impact on return flow is the effect rainfall has on farm operations. Rainfall events often lead to shut down of on-farm irrigation systems and can substantially increase operational spills from district works.

c) PPWB Return Flow Estimates

The Prairie Provinces Water Board (PPWB) estimates annual return flow contributions to river systems from the irrigation districts. The estimates for 1985 through 2000 are given in Table A-1 (Appendix). Some of the estimates are based on Water Survey of Canada provisional hydrometric data. For the WID, April data are excluded from Table A-1. Diversions to the WID do not normally begin until the last few days in April or early May. Including April in the return flow estimates results in unrealistically high return flow in years of high snow melt runoff, such as 1997. Table 18 compares return flow recorded by the districts and that estimated by the PPWB for 1997 to 2000. Estimates prepared by the PPWB include combined return flow from the three foothills districts (MVID, LID and AID) and from the MID, RID, SMRID and TID. The following observations can be made from Table 18.

- The PPWB estimates of return flow for the EID were consistently high, averaging 135% of recorded values for the four years. PPWB estimates for the BRID were consistently low, averaging 63% of recorded values for the four years. Where comparisons can be made for districts other than the BRID and EID, the PPWB estimates are generally within 10% of recorded values.
- PPWB estimates of total return flow for all districts for which comparisons can be made are remarkably consistent with recorded data (within 3%). The best year for comparison is 1999, when eight districts, representing about 98% of the total irrigated area, can be compared. PPWB estimates of the total return flow for the eight districts were 99.8% of the recorded return flow. In 1997, 1998 and 2000, only four districts, representing 58% of the irrigated area, can be compared. For these districts, the PPWB estimates of total return flow averaged 101.9% of the recorded values.

From the comparison of recorded return flow and PPWB estimates, it would appear the PPWB estimates are a good representation of total return flow from all districts. Figure 30 shows the total return flow from all districts for the period 1985 to 2000, based on PPWB estimates, as well as the irrigated areas and gross diversions (AAFRD 2001/a). Observations from Figure 30 include the following.

- There has been a significant variation in year-to-year gross diversion, with major reductions in wet years and increases in dry years. The trend line shows a slight reduction in gross diversion during the 10-year period, in spite of an increase in the irrigated area.
- The irrigated area has steadily increased since 1985. In high precipitation years (1993 and 1995), the irrigated area drops significantly.
- The return flow has consistently been around 600,000 cubic decametres per year for the 16-year period. Return flow appears independent of irrigated area and gross diversion. It is less variable and does not seem to follow the wet-year/dry-year pattern that affect gross diversions and irrigated area.

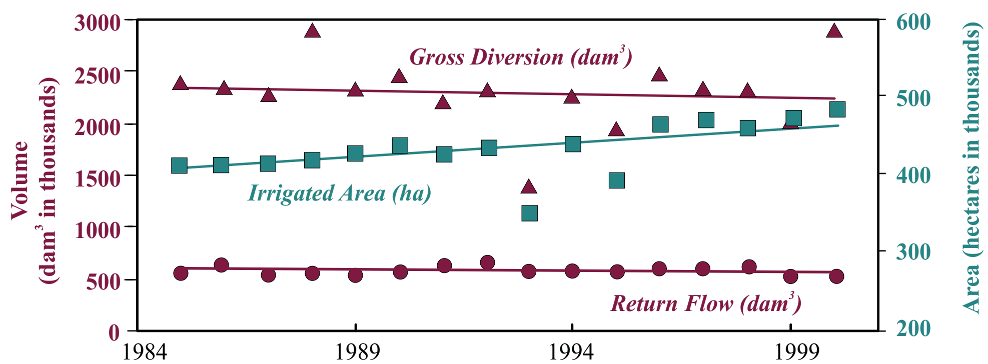


Figure 30. Irrigation district return flows, gross diversions, and irrigated areas. (From PPWB and Water Survey of Canada data, some of which are provisional.)

Table 18. Comparisons between recorded return flow and PPWB estimates (PPWB 1995).[1]

District	1997 Recorded Return Flow (dam^3)	1997 PPWB Return Flow (dam^3)	1997 PPWB Return Flow % of Recorded	1998 Recorded Return Flow (dam^3)	1998 PPWB Return Flow (dam^3)	1998 PPWB Return Flow % of Recorded
BRID	126,134	77,322	61.3%	127,884	76,451	59.8%
EID	215,495	271,340	125.9%	186,862	250,192	133.9%
LNID	40,651	35,600	87.6%	37,524	39,905	106.3%
MVID						
LID		**MVLA[2] 7,141**			**MVLA[2] 9,297**	
AID						
MID		**SMP, MID[3] 103,488**			**SMP, MID[3] 139,616**	
RID						
SMRID	42,551			44,478		
TID	29,007			33,993		
UID		9,002			5,482	
WID[4]	87,491	90,322	103.2%	100,321	93,647	93.3%
Sum[5]	469,771	474,584	101.0%	452,551	460,198	101.7%

District	1999 Recorded Return Flow (dam^3)	1999 PPWB Return Flow (dam^3)	1999 PPWB Return Flow % of Recorded	2000 Recorded Return Flow (dam^3)	2000 PPWB Return Flow (dam^3)	2000 PPWB Return Flow % of Recorded
BRID	109,064	72,439	66.4%	118,057	77,423	65.6%
EID	149,873	199,406	133.1%	143,815	210,648	146.5%
LNID	46,220	41,428	89.6%	49,320	35,500	72.0%
MVID						
LID		**MVLA[2] 10,644**			**MVLA[2] 22,516**	
AID	3,387					
MID	14,571	**SMP, MID[3] 95,593**		13,138	**SMP, MID[3] 67,215**	
RID	6,953					
SMRID	39,006		94.2%	38,539		
TID	40,958			28,673		
UID		13,419			26,678	
WID[4]	84,883	81,885	96.5%	78,462	77,319	98.5%
Sum[5]	491,528	490,751	99.8%	389,654	400,890	102.9%

[1] Data obtained directly from Jim Chen, P.Eng., PPWB. Some return flow estimates may be based on Water Survey of Canada provisional data.
[2] PPWB estimate labeled MVLA is total return flow for MVID, LID and AID.
[3] PPWB estimate labeled SMP, MID is total return flow for SMRID, RID, TID and MID.
[4] For the WID, April data are excluded from the estimates.
[5] Sums for 1997, 1998 and 2000 include the BRID, EID, LNID and WID only. Sums for 1999 include the BRID, EID, LNID, MID, RID, SMRID, TID, and WID only.

d) Future Return Flow

The block studies, district monitoring data and PPWB return flow estimates all suggest that return flow is primarily a function of district layout and infrastructure characteristics, on-farm irrigation methods and district operational characteristics. Return flow appears to be independent of the gross diversion and irrigated area.

Reductions in return flow are possible through measures such as continued replacement of laterals with closed pipelines, new storage at strategic locations, automation of structures, increased irrigation densities, on-farm method shifts from surface irrigation to sprinklers, as well as district operations more focused on minimizing return flow. A future total return flow of 500,000 cubic decametres per year, or 13.8% of the licence volume, is achievable. This is a conservative value that could be used for planning purposes. Reductions beyond this amount are believed to be possible and should be set as a goal.

C. WATER DEMAND SUMMARY BASED ON KEY FINDINGS

Following establishment of the 1991 *Regulation*, AENV and AAFRD worked together to determine the volume of water that would be sufficient for irrigating the areas specified in each irrigation district. However, there was insufficient data to make reliable estimates with regard to on-farm irrigation management and efficiencies, district water losses and return flow. Many assumptions were necessary. Research conducted by the irrigation districts and AAFRD from 1996 to 2000 provides much-needed information. This has made it possible to improve the estimates of current and future water requirements, and to evaluate the estimates and assumptions made in 1991.

Table 19 provides a simplified water demand analysis for the 13 irrigation districts. The analysis was prepared using a methodology and format similar to that used in 1991. For comparison purposes, three scenarios are presented:

1) **The *Regulation* limit.** Estimates and assumptions inherent in determination of the proposed licence volume for the *Regulation* are given in Chapter II. Section C. The licence volume was based on 90th percentile irrigation demands for ultimate water demand conditions in the 13 districts. This scenario reflects the 1991 understanding of what the future might be for irrigation in Alberta.

2) **The 1999 state of irrigation in Alberta.** The results of research conducted from 1996 to 2000 were used to estimate water demands that reflect 1999 conditions within the irrigation districts.

3) **Projected future conditions.** Projections reflect trends and up-to-date judgements on where the irrigation industry appears to be headed in the next 10 to 20 years.

The most significant difference in factors used to estimate on-farm requirements was the level of irrigation management considered in the three scenarios. The 1991 *Regulation* licence volume was based on 100% of crop water requirements. From 1996 through 2000, irrigation water users met, on average, about 84% of the crop water requirement. Irrigation practitioners in Alberta believe that meeting, on average, 90% of the crop water requirement represents the upper limit of irrigation management in the future. This upper limit is based on the crops grown, and the cultural and harvesting practices in southern Alberta. Primarily as a result of the difference in the irrigation management factor, the projected future farm gate delivery requirement has been estimated to be about 430,000 cubic decametres less than estimated for the 1991 *Regulation*.

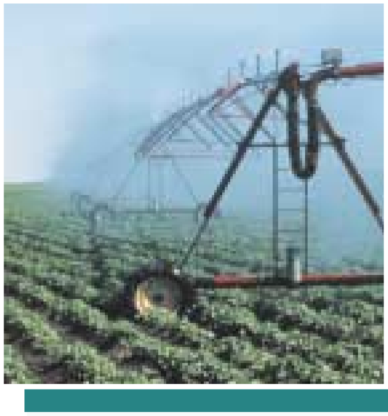


Table 19. Simplified analysis of irrigation water demand for the 13 irrigation districts.

Water Demand Component	1991 *Regulation* Licence Volume	1999 Conditions	Projected Future Conditions
On-farm Water Requirements			
Crop water requirement (90th percentile)		498 mm	507 mm
Irrigation management factor (1996-2000 mean)	100%	84%	90%
Water applied to crop		418 mm	456 mm
Precipitation (10th percentile, growing season)		140 mm	140 mm
Crop irrigation requirement	375 mm	278 mm	316 mm
On-farm efficiency	75%	71%	75%
Farm gate delivery requirement (90th percentile)	500 mm	392 mm	421 mm
Irrigation District Water Requirements			
Case 1: Assume 531,434 hectares, as per 1991 *Regulation*			
Farm gate delivery requirement	2,657,402 dam^3	2,083,221 dam^3	2,226,714 dam^3
Seepage losses	471,759 dam^3	89,753 dam^3	54,000 dam^3
Evaporation losses	132,021 dam^3	142,016 dam^3	140,000 dam^3
Return flow	361,610 dam^3	574,966 dam^3	500,000 dam^3
Gross diversion demand (90th percentile)	3,622,792 dam^3	2,889,956 dam^3	2,920,714 dam^3
Case 2: Assume gross diversion of 3,622,792 dam^3, as per *Regulation* licence volume			
Gross diversion	3,622,792 dam^3	3,622,792 dam^3	3,622,792 dam^3
Seepage losses	471,759 dam^3	89,753 dam^3	54,000 dam^3
Evaporation losses	132,021 dam^3	142,016 dam^3	140,000 dam^3
Return flow	361,610 dam^3	574,966 dam^3	500,000 dam^3
Farm gate delivery (90th percentile)	2,657,402 dam^3	2,816,057 dam^3	2,928,792 dam^3
Farm gate delivery requirement (90th percentile)	500 mm	392 mm	421 mm
Total area that could be irrigated[1]	531,434 ha	718,382 ha	695,675 ha

[1] Based on the *Regulation* licence volume and water demand only. Water supply factors have not been considered.

With regard to irrigation district infrastructure, seepage losses appear to have been greatly over-estimated in 1991, evaporation losses were under-estimated (canal evaporation was not included in the computations), and return flow was under-estimated. All things considered, it is now estimated that the projected future 90th percentile demand for the 1991 *Regulation* limit of 531,434 hectares (Table 4) is 2,920,714 cubic decametres. This is a reduction of 702,078 cubic decametres or about 19% of the *Regulation* licence volume of 3,622,792 cubic decametres.

Assuming a 90th percentile gross diversion equal to the *Regulation* licence volume of 3,622,792 cubic decametres (Case 2), it is estimated about 695,675 hectares could be irrigated. This area is 164,241 hectares greater than the *Regulation* limit, an increase of almost 31%.

This simplified analysis of water demand does not consider any aspects of water supply, including the availability of water in the source streams, the needs and water licence priorities of other users, capacity limitations on district infrastructure, and effects on individual irrigation blocks within the districts. All these factors are considered in the simulation modelling that is discussed in the following chapter of this report. The analysis in Table 19 serves to indicate that, considering all districts as a whole, a substantial amount of expansion beyond the 531,434 hectares in the 1991 *Regulation* could be considered without a water allocation beyond the collective *Regulation* licence volume. This conclusion does not apply equally to all districts.

D. CONCLUSIONS

The following conclusions have been drawn from the key research findings, based on four years of field research, data collection, and analysis.

The crop mix within the irrigation districts has changed during the past 10 years, and will likely continue to change in the future.

It is projected that the future crop mix for irrigated agriculture will evolve toward an increased area of forage to support the expanding livestock industry, increased area of specialty crops to support value-added processing, and a decreased area of cereal grains. This will result, overall, in slightly higher water requirements than the current crop mix.

For the foreseeable future, an on-farm application efficiency of 75% is considered to be reasonable for planning purposes.

The average, overall on-farm application efficiency within the irrigation districts in 1999 was estimated to be 71%. Significant gains in on-farm application efficiencies have been realized during the past four decades, as irrigation methods have changed and system technology has advanced. Additional gains should occur in the future.

Improved on-farm irrigation management will result in future water applications meeting 90% of optimum crop water requirements for the types of crops grown and the cultural practices in southern Alberta.

It is estimated that farmers are irrigating to meet, on average, about 84% of the water required to obtain optimum crop yields. This level of irrigation management, or water application, has increased during the past 10 years, and is projected to continue to increase.

Seepage from district works will be reduced with continuing rehabilitation.

Substantial progress has been made in rehabilitating irrigation district infrastructure and reducing seepage losses during the past 10 years. Seepage losses are estimated to be about 2.5% of licence volume. Seepage losses from canals appear to have been greatly overestimated in 1991. Continued reduction in seepage losses will occur in the future as more canals are rehabilitated.

In the future, canal evaporation may decrease slightly as more conveyance channels are replaced with pipelines. Reservoir evaporation losses are expected to increase if new reservoirs are developed within the districts.

Canal and reservoir evaporation losses from the 1999 district infrastructure are estimated to be about 142,016 cubic decametres or almost 4% of the *Regulation* licence volume. Evaporation losses were slightly underestimated in the development of the 1991 *Regulation* as canal evaporation was not included in the original computations.

Return flow is projected to decline by as much as 17% with continued rehabilitation of the water distribution infrastructure, improved on-farm and district water management, and potential development of offstream reservoirs.

Field data recorded from 1997 to 2000 indicate return flow, expressed as a percentage of actual gross diversion, varies substantially from district to district – from a low of 7.2% to a high of 56.6%. In five of the six largest districts, average unit return flows are substantially higher than those assumed in establishing the 1991 *Regulation* licence volumes. The exception is the SMRID, which returns less flow than was assumed in 1991. Annual return flow volumes from all irrigation districts have consistently totalled around 600,000 cubic decametres per year for the period 1985 through 2000. However, they are projected to decrease to 500,000 cubic decametres with continued water management efficiency gains. The addition of new storage facilities could not only increase the upstream supply of available water, but could also reduce return flow volume, as water is recaptured for further use.

A comparative water demand analysis for the 13 irrigation districts indicates the projected future gross diversion demands for the 1991 *Regulation* limits are significantly less than those estimated in 1991. Considering all districts as a whole and the gains in water management made through the 1990s, a substantial amount of expansion beyond the 1991 *Regulation* limits could be considered within the *Regulation* licence volumes.

The research program provided an updated and more scientifically sound database than was available in 1991 when the *Regulation* licence volumes were established. Using a methodology similar to that used in 1991, gross diversion demand for the 1991 *Regulation* limit of 531,434 hectares was estimated to be about 19% less than originally estimated.