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Water Allocation Model for Alberta's Southern Tributaries Irrigation Districts

Author#1

Lloyd Healy

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ABSTRACT A water allocation model using Excel was developed to forecast the amount of available water for use by irrigation districts in Southern Alberta in times of drought. The goal of this development was to enable the program to forecast irrigation district water needs that reflected the improvements that have been made in irrigation district water delivery and also the efficiency improvements made with farm irrigation systems since 1991. Since 1991 irrigation districts in the Waterton, Belly, and St. Mary sub basins (Southern Tributaries) have installed 994 km of buried pipe, 184 km of lined canals, and installed water control structures. This reduced irrigation system losses by 114,300 dam^3 (canal seepage by 112,000 dam^3, and canal evaporation by 2,300 dam^3).

In 2001, reservoir levels were extremely low due to the previous year's high diversion rate, and below average snow pack. This limited water availability had resulted in water license holders deciding to share the water. The Water Allocation Forecasting Model was developed by Alberta Agriculture and Forestry to support this initiative and determined how much each assessed acre could receive in each district. The model uses the Water Supply Forecast produced by Alberta Environment and Parks and irrigation district conveyance efficiencies to determine how much water can be allocated to each assessed irrigation acre in each irrigation district. The model has been used every year since 2001 to provide a water allocation forecast for the irrigation districts, Blood Tribe Irrigation Project, and Private irrigators, and continues to be updated to reflect conveyance efficiency gains the irrigation districts have made.

Keywords: Irrigation District, FarIate Allocation, Forecast, Model, Water Efficiency.

INTRODUCTION The St. Mary River, Waterton River, and Belly River in South Western Alberta are referred to as the Southern Tributaries. These three rivers supply the irrigation water to, municipalities, industry, reserves, private irrigators, and eight irrigation districts with 2850 km of irrigation works (canals and pipelines). The districts have 19 reservoirs with a live storage capacity of 464,470 dam^3 and the province has 5 reservoirs with a capacity of 635,500 dam^3 of live storage.

In the fall of 2000, the on-stream and off-stream reservoir levels that support eight irrigation districts, the Blood Tribe Irrigation Project (BTIP), various amounts of industrial, municipal, and private irrigators was at 30% of their normal carry over winter volumes. The amount of water available is a combination of the expected run-off and the amount of water in stored in on-stream and off-stream reservoirs. In June of 2001, allocations were set at about 60% of licensed volumes. The allocated amount reflected the amount of diversion that a user would receive at their point of diversion (Rood, 2009).

Alberta Agriculture and Forestry developed a water allocation forecasting model using excel software in order to determine how much water could be allocated to the farm gate in each district. The amount of water available at the farm gate of each district depended on how efficient the district was at delivering water. Variables such as seepage, evaporation, and control of the delivery of water play a big role in the amount of water that is eventually available at the farm gate or farm turnout that connects to a farmer's pivot, wheel move, or gravity irrigation system.

This paper will explain all of the variables that are used to forecast the amount of water available at the farm gate in an irrigation district on a monthly basis.

EXPECTED WATER YIELD The amount of water available for irrigation is based on Alberta Environment and Parks water volume supply forecast and then the amounts deducted to account for other licenses, international water agreement, headworks storage and conveyance losses, and river in-stream flow requirements.

Water Volume Supply Forecast Starting in February of each year Alberta Environment and Parks issues a water volume supply forecast each month. The run-off volumes for the Waterton, Belly, and St. Mary Rivers are expressed as the probability of receiving at least a percentage of average run-off volume. The following table is an example of the water volume supply forecast for the St. Mary River from June 1 to September 30.

Table 1. Sample Water Supply Outlook – June 1 to September 30

		90% Chance of this much run-off Reasonable Minimum	75% Chance of this much run-off	50% Chance of this much run-off	25% Chance of this much run-off	Forecast Ranking (Lowest to Highest)
St. Mary River	Volume (dam^3)	265,897	300,769	340,000	379,230	19/99
	Percent of average	61	69	78	87	19/99

In theory the St. Mary River has a 50% chance of receiving 340,000 dam^3 of run-off for the remainder of the irrigation season. There is a 90% chance of receiving at least 265,897 dam^3 of run-off for the remainder of the irrigation season from the St. Mary River. The 90% chance of

receiving this much run-off is referred to as the reasonable minimum amount of water volume that can be expected.

The forecast ranking shows eighteen previous June forecasts had a lower volume of run-off predicted out of the 99 years of run-off data collection. This June forecast is the 19th lowest run-off volume in 99 years of data collection.

International Water Sharing Agreements There is a water agreement with the USA that stipulates how the water of the St. Mary River is to be shared between Canada and the USA. The 1921 Order stipulates that Canada receives 75% of the first 18.86 cms of the natural flow of the St. Mary River at the international boundary and 50% of any excess over 18.86 cms during the irrigation season. For this model it is assumed that 30% of the water from the St. Mary River will be diverted to the USA and only 70% will be available for use in Canada.

Other Licensees There is approximately 65,400 dam^3 of water allocated to other licensees. These include Municipalities, Industry, Commercial, Livestock Watering, and others. The amount of water they receive in the model can be expressed as a percent of their licensed amount. It is normally 100 per cent.

River Allocation Minimum stream flows for the St. Mary (2.75 cms), Waterton River (2.27 cms), and Belly River (0.93 cms) total 5.95 cms. This is a total of 514 dam^3 per day and 77,000 dam^3 over the irrigation season that is unavailable for diversion. Each month into the irrigation season amount is reduced to reflect the volume requirement for the remaining days in the irrigation season.

Headworks Storage and Conveyance Losses Three percent of the watershed yield is assumed to be lost to seepage, evaporation, and conveyance losses.

STORED WATER Table 2 shows the irrigation districts in the southern tributaries have 19 reservoirs with a volume capacity of 464,670 dam^3. Table 3 shows that five provincial reservoirs have a total storage capacity of 635,500 dam^3. This gives a total 1,100,170 dam^3 of live storage available to all uses in the southern tributaries if they were all at full supply level. The volume of water in storage on the first of each month is put in the model.

Table 2 Irrigation District Reservoirs

District/Reservoir	**Live Storage (dam^3)**	**District/Reservoir**	**Live Storage (dam^3)**
RID - Corner Lake	500	SMRID – Forty Mile	100,430
RID - Craddock	620	SMRID – Murray	30,630
RID – Factory Lake	370	SMRID – North East	2,820
TID – Fincastle	3,770	SMRID – Raymond	1,810
TID – Horsefly	6,370	SMRID – Sauder	45,240
TID – Taber Lake	6,410	SMRID – Seven Persons	900
UID – Cochrane Lake	3,100	SMRID – Sherburne	12,190
SMRID – Bullshead	130	SMRID – Stafford	21,790
SMRID – Chin	207,370	SMRID – Yellow Lake	18,130
SMRID – Cross Coulee	2,090	**Total**	**464,670**

Table 3 Provincial Reservoirs			
Provincial Reservoir	**Live Storage (dam^3)**	**Provincial Reservoir**	**Live Storage (dam^3)**
Payne	8,690	St. Mary	369,310
Jensen	19,000	Waterton	111,200
Milk River Ridge	127,300	**Total**	**635,500**

DISTRICT LOSSES District losses consist of return flow, district reservoir seepage and evaporation losses, canal seepage and evaporation losses.

Return Flow Return flow is the amount of water that flows by all farm turn outs and returns to the river. In the model conservative volumes (slightly higher) are used that reflect a district's return flow levels experienced in recent years.

District Reservoir Seepage District reservoir seepage is something that a district cannot control. The model assumes a fixed reservoir seepage rate at full supply level and does not change from year to year.

District Reservoir Evaporation District reservoir evaporation is a value that is calculated in Alberta Agriculture and Forestry's Irrigation Demand Model (IDM). The Morton method is used in the IDM to calculate reservoir evaporation. The reservoir evaporation varies from year to year and is dependent on several factors – temperature, relative humidity, solar radiation, and reservoir surface area which is assumed to be at full supply level. For the purposes of this model an evaporation value 60 to 70% of the maximum evaporation value is chosen to better reflect the lower reservoir areas at normal operating levels which are usually one to two metres below full supply level.

District Canal Seepage District canal seepage values are determined by Alberta Agriculture and Forestry's IDM. Canal seepage losses have been trending down as more canals are converted to pipeline each year, and larger canals are membrane lined.

District Canal Evaporation District canal evaporation is calculated by Alberta Agriculture and Forestry's IDM using the Morton Method. Canal evaporation losses have been trending down as more canals are converted to pipeline each year. Canal evaporation losses in IDM are calculated based on canal operating at full supply level. For the purposes of this model the previous year's canal evaporation values are usually used.

The model was first developed in the fall of 2000. At that time, the best values Alberta Agriculture had for irrigation district losses were the values used in the 1991 regulations (Table 4). From 1991 to 2013 the irrigation districts in the Southern Tributaries had installed 994 km or pipeline and rehabilitated another 184 km of canal as shown in Figure 1. The irrigation infrastructure improvements reduced the district losses significantly as shown in Figure 6. The most significant savings occur from reduced canal seepage. In 2013 there is 112,000 dam^3 less seepage than in 1991. Canal evaporation has also been reduced 2,300 dam^3. District reservoir evaporation has gone up 9,500 dam^3 from the 1991 regulations. Return flow has stayed about the same as a whole, but some districts have reduced their return flow while others are still above the 1991 return flow values. Table 6 shows a present savings of 102,000 dam^3 from the 1991 regulations which translates into 43 mm/ha for the 2013 assessed irrigation area.

Table 4 District Losses - 1991 Regulation Values

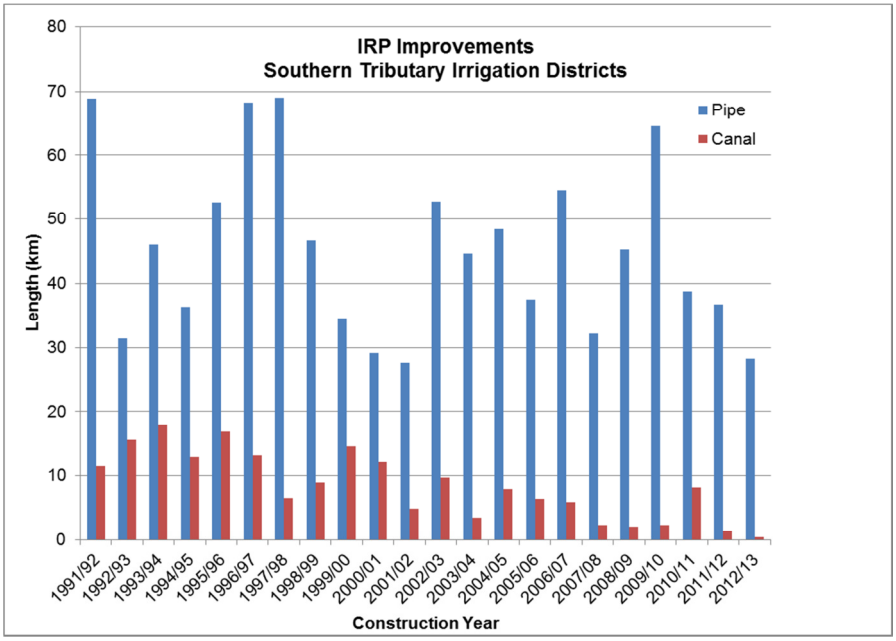
District	Return Flow	Evaporation		Seepage		Total
	(dam^3)	Reservoir (dam^3)	Canal (dam^3)	Canal (dam^3)	Reservoir (dam^3)	(dam^3)
AID	1,306	129	18	3,130	0	3,715
LID	1,764	116	39	3,995	0	4,794
MID	3,836	0	121	5,406	0	7,591
MVID	1,369	135	30	1,317	0	2,311
RID	9,745	0	684	8,092	0	15,015
SMRID	78,007	31,614	5,554	82,799	0	160,498
TID	17,232	3,992	485	14,304	0	27,196
UID	10,904	413	257	9,631	0	17,191
Total	124,163	36,399	7,188	128,674	0	296,424

Table 5 District Losses - Water Allocation Input Values (2013 IDM)

District	Return Flow	Evaporation		Seepage		Total
	(dam^3)	Reservoir (dam^3)	Canal (dam^3)	Canal (dam^3)	Reservoir (dam^3)	(dam^3)
AID	2,000	121	22	72	3	2,218
LID	3,000	121	16	3	3	3,144
MID	9,000	0	76	263	0	9,339
MVID	1,500	121	22	114	3	1,760
RID	17,000	223	174	1,553	2	18,952
SMRID	60,000	40,000	4,000	13,000	400	117,400
TID	25,000	5,000	326	781	42	31,149
UID	9,000	354	265	729	4	10,352
Total	126,500	45,940	4,901	16,515	458	194,315

Table 6 Water Savings - Present Losses vs. 1991 Regulation Losses			
Irrigation District	**Total Losses Current Infrastructure (dam^3)**	**Total Losses 1991 Regulations (dam^3)**	**Water Savings (dam^3)**
AID	2,218	4,583	-2,365
LID	3,144	5,914	-2,770
MID	9,339	9,363	-24
MVID	1,760	2,851	-1,091
RID	18,952	18,521	+431
SMRID	117,400	197,974	-80,574
TID	31,149	36,013	-4,864
UID	10,352	21,205	-10,853
Total	194,315	296,424	-102,109

Figure 1 IRP Improvements



IRRIGATED AREA The forecast model uses two irrigated areas - assessed irrigated area and actual irrigated area.

Assessed Irrigated Area Each irrigation district has assessed irrigation hectares which landowner's pay water rates and are entitled to have water delivered to them by the irrigation district if water is available. In 2013 the Southern Tributary Irrigation Districts had an assessed area

of 232,826 ha. The amount a farmer can expect to receive is based on a depth of water for each irrigated area on the districts assessment roll. This is expressed as mm/ha.

Actual Irrigated Area Not all irrigated areas on an irrigation district assessment roll are irrigated each year. Typically ten percent or more of the irrigated area in an irrigation district is not irrigated in any one year.

DIVERSIONS Each irrigation district has an allowable diversion from one or more of the rivers that make up the Southern Tributaries.

Licensed Diversion Amount The model limits the amount of water that each irrigation district can divert each irrigation season based on its total annual licensed volume. Licensed volumes are listed in Table 7 and 8 for each irrigation district.

Diversion to Date Each month the total amount of water each district has diverted is input into the model. Once an irrigation district diverts its licensed amount, no more water is allocated to that district and it must rely on remaining stored water.

FUTURE CROP REQUIREMENTS The previous year's crop mix is assumed for the current year. The expected remaining crop evapotranspiration requirements are book planning values and do not vary from year to year. They are input into the model to give an indication as to whether or not an irrigation district has enough water to meet the irrigation districts farm water demands for the remaining months of the irrigation season (assuming no rain). The crop mix and the area of each crop in each district are not included in this paper due to space limitations.

MODEL INPUT At the beginning of each month the following data is gathered and entered into the model:

a) Run-off forecast,
b) Volume of stored water in each reservoir,
c) Accumulated diversion of each district to the end of the previous month, and
d) Remaining crop use requirements.

MODEL OUTPUT The following tables show the model outputs with the reasonable minimum forecast. Table 7 shows the farm gate allocation with the current infrastructure. Table 8 shows the farm gate allocation with the losses as per the 1991 regulation.

Not shown in the model output is the gross watershed yield. The gross watershed yield has the US share of 79,769 dam^3, the minimum stream flow of 49,970 dam^3, other license requirements of 52,130 dam^3, and storage and conveyance losses of 8,556 dam^3 give a net watershed yield of 349,111 dam^3.

Table 7 shows that there is 543,316 dam^3 of water stored in the provincial reservoirs, a total of 263,453 dam^3 of shared stored water, and a forecasted net watershed yield of 349,111 dam^3 for a total of 1,155,881 dam^3 of remaining available shared water. The SMRID also has 84,126 dam^3 of non-shared water available. The total amount of watershed yield and shared stored water is divided amongst the irrigation districts based on their share of the total licensed volume share less the amount they have already diverted. For example, the AID has a license for 11,102 dam^3 which is 0.78% of the total licensed volume. This gives the AID 6,941 dam^3 of remaining divertible water and 2,049 dam^3 of remaining shared stored water less 1,796 dam^3 of fixed losses, less 328 dam^3 of previously diverted water for a forecast remaining volume of 7,194 dam^3 of water at the farm gate.

Table 7 Farm Gate Allocation at Reasonable Minimum – Current Infrastructure

Oldman River Basin - Southern Tributaries				Jun-2015	Farm Gate Allocation - Reasonable Minimum					
Headworks Storage =	543,316	dam^3					1,427,258	dam^3		
Shared Non-SMP District Storage	8,000	dam^3						MVID		*From
Shared SMP District Storage =	255,453	dam^3						Without 40-Mile Shared		Book Planning
Currently Diverted Volume =	180,982	dam^3						Dry Year-Minimum 6 CMS		Values
Watershed Yield =	349,111	dam^3		SMRID only water				(J)	(K)	(Q)
				(40 Mile)					ADJUSTED	
Total Available Shared Water =	1,336,862	dam^3	Diverted + Forecast	84,126	dam^3				Diversion per	
Remaining Available Shared Water	1,155,881	dam^3	Forecast						District / Project	Remaining Crop Requirements based on 2014 crop mix
Irrigation District or Project	SSReg Licensed Volume (dam3)	(Licensed Volume) Share %	Remaining Volume of Divertable Water (dam^3)	Remaining Volume of Shared Stored Water (dam^3)	Fixed Losses (dam^3)	Remaining Farm Gate Volume (dam^3)	Remaining Farm Gate Allocation Actual ha (mm/ha)	Remaining Farm Gate Allocation Assessed ha (mm/ha)	to Date # From AESRD (dam^3)	Rain+Irrigation Requirement mm per Assessed Irrigated hectare
AID[8]	11,102	0.78%	6,941	2,049	1,796	7,194	541.2	406.2	328	370.3
LID[8]	14,802	1.04%	9,255	2,732	2,546	9,442	489.8	480.7	281	432.1
MID[8]	41,939	2.94%	26,223	7,741	7,563	26,402	438.8	356.5	3,283	381.8
MVID[8]	9,868	0.69%	6,170	1,822	1,426	6,566	462.4	438.7	185	449.3
RID[7]	99,914	7.00%	62,473	18,443	15,348	65,569	403.3	348.4	10,679	373.4
SMRID[8]	890,588	62.40%	556,862	248,517	95,072	710,306	497.8	451.5	110,237	335.0
TID[8]	194,893	13.66%	121,862	35,975	25,225	132,612	422.4	395.6	23,746	347.0
UID[8]	81,670	5.72%	51,066	15,075	8,383	57,758	610.4	415.0	3,733	366.0
BTIP	49,648	3.48%	31,044	9,164	2,010	38,198	513.5	377.5	0	381.8
Private	32,833	2.30%	4,323	6,061	0	10,384	139.6	102.6	28,510	373.4
TOTAL	1,427,258	100.00%	876,221	347,579		1,064,431			180,982	

Table 8 Farm Gate Allocation at Reasonable Minimum – 1991 Regulations

Oldman River Basin - Southern Tributaries				Jun-2015	Farm Gate Allocation - Reasonable Minimum					
Headworks Storage =	543,316	dam^3					1,427,258	dam^3		
Shared Non-SMP District Storage	8,000	dam^3						MVID		*From
Shared SMP District Storage =	255,453	dam^3						Without 40-Mile Shared		Book Planning
Currently Diverted Volume =	180,982	dam^3						Dry Year-Minimum 6 CMS		Values
Watershed Yield =	349,111	dam^3		SMRID only water				(J)	(K)	(Q)
				(40 Mile)					ADJUSTED	
Total Available Shared Water =	1,336,862	dam^3	Diverted + Forecast	84,126	dam^3				Diversion per	
Remaining Available Shared Water	1,155,881	dam^3	Forecast						District / Project	Remaining Crop Requirements based on 2014 crop mix
Irrigation District or Project	SSReg Licensed Volume (dam3)	(Licensed Volume) Share %	Remaining Volume of Divertable Water (dam^3)	Remaining Volume of Shared Stored Water (dam^3)	Fixed Losses (dam^3)	Remaining Farm Gate Volume (dam^3)	Remaining Farm Gate Allocation Actual ha (mm/ha)	Remaining Farm Gate Allocation Assessed ha (mm/ha)	to Date # From AESRD (dam^3)	Rain+Irrigation Requirement mm per Assessed Irrigated hectare
AID[8]	11,102	0.78%	6,941	2,049	4,583	4,408	331.5	248.9	328	370.3
LID[8]	14,802	1.04%	9,255	2,732	5,914	6,074	315.1	309.2	281	432.1
MID[8]	41,939	2.94%	26,223	7,741	9,363	24,602	408.9	332.2	3,283	381.8
MVID[8]	9,868	0.69%	6,170	1,822	2,851	5,141	362.0	343.5	185	449.3
RID[7]	99,914	7.00%	62,473	18,443	18,521	62,395	383.8	331.6	10,679	335.0
SMRID[8]	890,588	62.40%	556,862	248,517	197,974	607,405	425.7	386.1	110,237	347.0
TID[8]	194,893	13.66%	121,862	35,975	36,013	121,823	388.1	363.5	23,746	366.0
UID[8]	81,670	5.72%	51,066	15,075	21,205	44,936	474.9	322.9	3,733	245.9
BTIP	49,648	3.48%	31,044	9,164	2,010	38,198	513.5	377.5	0	381.8
Private	32,833	2.30%	4,323	6,061	0	10,384	139.6	102.6	28,510	335.0
TOTAL	1,427,258	100.00%	876,221	347,579		925,366			180,982	

The SMRID has an additional 84,126 dam^3 of water available to them and this is added to their shared amount. This is the water in 40 Mile reservoir and must be pumped. In the past it has been shared if the other districts agree to share in the pumping costs.

SMRID has a farm gate allocation of 451.5 mm/ha (Table7) with its current infrastructure and operational procedures. With its old infrastructure it would have only had 386.1 mm/ha (Table 8) of available water remaining. Table 9 shows this is a difference of 65.4 mm/ha. The forecasted crop requirement for the SMRID is 347 mm/ha. In 1991 the SMRID would have only had a surplus of 33.5 mm/ha with the expected water volume forecast, but because of all the improvements in infrastructure and operational procedures this district has made they are forecast to have a surplus of 104.5 mm/ha.

The MID has a farm gate allocation of 356.5 mm/ha (Table 7) with its current infrastructure and operational procedures. With its old infrastructure it would have only had only 332.2 mm/ha (Table 8) available at the farm gate with the water remaining, a difference of 24.3 mm/ha. The MID has saved 5,143 dam^3 of water due to reduced canal seepage (infrastructure improvement), but its return flow has increased 5,164 dam^3.

Table 9 Reasonable Minimum Forecast - Depth of Water Available at Farm Gate

	mm/assessed ha		
Irrigation District	**June 2015 Farm Gate Current Infrastructure**	**June 2015 Farm Gate 1991 Regulations**	**Difference**
AID	406.2	248.9	157.3
LID	480.7	309.2	171.5
MID	356.5	332.2	24.3
MVID	438.7	343.5	95.2
RID	348.4	331.6	16.8
SMRID	451.5	386.1	65.4
TID	395.6	363.5	32.1
UID	415.0	322.9	92.1

Table 10 Available Water Depth at Farm Gate with Current Infrastructure vs. Run-off Probabilities

	mm/assessed ha				
Irrigation District	**90%**	**75%**	**50%**	**25%**	**Remaining Crop Requirement**
AID	406.2	442.4	481.5	532.2	370.3
LID	480.7	524.2	571.2	632.2	432.1
MID	356.5	389.1	424.5	470.3	381.8
MVID	438.7	476.7	517.9	571.3	449.3
RID	348.4	379.0	412.2	455.1	373.4
SMRID	451.5	484.2	519.5	565.3	335.0
TID	395.6	429.1	465.5	512.5	347.0
UID	415.0	448.8	485.4	532.9	366.0

Table 10 shows the farm gate allocations expected at the four run-off probabilities along with the expected remaining crop water requirements for the remainder of the growing season. If there is no rain at all, some of the districts will experience a shortfall. Knowing this irrigation districts and Alberta Environment and Parks can take steps to minimize wastage.

CONCLUSION The model indicates how much water each district can expect to deliver to the farm gate on a monthly basis. The savings due to infrastructure improvements (pipelines and canals) are significant for each district and amount to 114,446 dam^3 for all eight irrigation districts. The amount of return flow has increased in some districts, off-setting the infrastructure gains. As a result these districts see a less than average increase in farm gate available water. Districts that have been able to increase their control of water delivery have seen a greater than average increase in farm gate available water.

The model shows that the biggest variation in how much water is available at the farm gate at this time is due in a large part to the management of water and reducing return flows. In the future irrigation districts need to look at their overall water management and develop strategies to continue to improve. A few potential strategies are:

a) working with the district irrigation farmers and ditch riders to develop and improve water ordering systems,
b) canal structures that will check water to a level under low flows to keep pipeline entrances at full supply level,
c) continue improvement of irrigation district System Control and Data Acquisition (SCADA) systems with appropriate flow control infrastructure to control water flow.

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APPENDIX A Irrigation Districts

Irrigation District	Abbreviation	Irrigation District	Abbreviation
Aetna Irrigation District	AID	Raymond Irrigation District	RID
Leavitt Irrigation District	LID	St. Mary Irrigation District	SMRID
Magrath Irrigation District	MID	Taber Irrigation District	TID
Mountain View Irrigation District	MVID	United Irrigation District	UID