FIRI Analysis and Tailwater Return Flow Study on the Fort Lyon Canal

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Lower Arkansas Valley Water Conservancy District

Farm Boy Engineering, LLC

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Executive Summary

The relative lack of variation amongst Maximum Farm Efficiency (MFE) values between water-long ditches and water-short ditches has been viewed as a deficiency of the Hydrologic Institutional (H-I) Model. In Kansas v. Colorado testimony concerning on-farm efficiency, Colorado cited deficit irrigation and tailwater reuse as two factors that justified its argument that higher MFE values should be implemented in the H-I Model for water-short ditches, such as the Fort Lyon, Amity, Colorado, Holbrook, and Otero canals.

MFE, as used in the H-I Model, is a function of on-farm ditch loss (FDL), tailwater fraction (TWF) and initial deep percolation fraction (DPF) and is defined as:

$$MFE = 100\% - FDL\% - TWF\% - DPF\%$$

For the Fort Lyon Canal, MFE, FDL, and TWF have assigned values of 65%, 3.5%, and 9.65% respectively in the H-I Model. DPF has a resulting value of 21.9%.

The Farm Irrigation Rating Index (FIRI) method was developed by the USDA-Natural Resources Conservation Service (NRCS) as a way to uniformly evaluate water savings resulting from on-farm irrigation improvements. For surface irrigation systems, FIRI combines specific factors related to potential farm irrigation efficiency, irrigation management and irrigation system design. Combined, these elements provide a composite farm irrigation efficiency value.

The objectives of this study are as follows:

1) Measure actual TWF on a section of the Fort Lyon Canal (study area) to determine if the assumed value of TWF used in the H-I Model is accurate.
2) Utilize the NRCS Farm Irrigation Rating Index (FIRI) to evaluate the same section of the Fort Lyon Canal to determine if the model is applicable for use in estimating MFE factor for the H-I Model.
3) Determine whether measured TWF values from this study justify a more detailed and extensive irrigation efficiency study under the Fort Lyon Canal.

Results and Conclusions:

1) The average measured TWF for the study area during 2015 and 2016 was 5.30% and 4.07% respectively as opposed to an assumed value of 9.65% in the H-I Model. These TWF levels were achieved in two relatively wet years under the Fort Lyon Canal.

2) The FIRI method does not appear to be applicable in estimating MFE for use in the H-I Model due to the subjectivity of irrigation factors used in FIRI and initial estimation of the Potential Efficiency factor in the model.

3) Measured TWF values that are significantly lower than assumed values may be an indication that MFE is underestimated for the Fort Lyon Canal in the H-I Model. For this reason it is recommended that a more detailed irrigation efficiency evaluation take place within the Fort Lyon Canal to gain a full understanding of the interaction between tailwater, deep percolation, and farm efficiency in order to verify the accuracy of all three factors in the H-I model.

Table of Contents

I. Background and Introduction

I.a. Models and Flood Irrigation

The Hydrologic Institutional (H-I) model is used to assess compliance of the Arkansas River Compact between Colorado and Kansas. This model utilizes monthly canal diversions, crop evapotranspiration (ET), and precipitation measurements from irrigated farm land in the Arkansas River Valley east of Pueblo, CO, along with several canal-specific factors to estimate total Arkansas River flows at the Colorado/Kansas state line.

The Irrigations Systems Analysis Model (ISAM) is used by the Colorado Division of Water Resources in the administration of compact-related rules to estimate depletions/accretions to the Arkansas River within Colorado caused by irrigation improvements that have the potential to alter return flow patterns to the river, such as lining of off-farm earthen ditches and conversion from flood irrigation to sprinkler systems. The ISAM model replicates the monthly consumptive use and soil moisture accounting of the H-I Model and therefore utilizes H-I Model canal-specific parameters and factors. Some of the canal-specific factors utilized in the two models include:

- Canal Seepage Loss
- Off-Farm Lateral Loss
- Tailwater Fraction
- On-Farm Ditch Loss
- Maximum Farm Efficiency
- Deep Percolation Fraction
- Secondary Evapotranspiration Loss
- Available Water Capacity
- Crop Root Zone Depth.

The Maximum Farm Efficiency (MFE) factor as used in the H-I and ISAM Models acts as an upper limit to the percentage of irrigation water applied to a crop that can be consumed by the crop. This limit is used in the soil-water budgeting procedure to account for the non-uniform distribution of irrigation water associated with flood irrigation practices. The MFE factor was adjusted in initial versions of the H-I Model developed prior to the final Kansas v. Colorado decree, and because state line depletions are particularly sensitive to the value of this factor, it is often the subject of debate amongst irrigation experts.

During the typical flood irrigation process, irrigation water is diverted from the Arkansas River by canal companies through earthen canals to farmers who then divert water from the canal through a headgate structure to their farms. For farms immediately adjacent to the canal, irrigation water is usually diverted from the canal directly onto the farm. For farms not adjacent to the canal, irrigation water is transported via a private or shared off-farm lateral to the farm. Off-farm laterals can be constructed of plastic pipe, concrete channel, or earthen channel. Once irrigation water arrives at the farm, it is delivered to individual fields through earthen ditch, concrete ditch, or pipe. At the field, irrigation water is applied using gated pipe, concrete ditch (with cutouts or siphon tubes), or earthen ditch (with cutouts or siphon tubes).

Flood irrigation is characterized by “sets” in which water is applied to a single section of the field - generally encompassing a specific number of cutouts, siphon tubes, or gates applying water - at any one time. A single set is typically allowed to distribute water onto a field section for a certain number of hours or until the advancing water front reaches the tail end of the field (set duration). At this point, water leaves the field area and contributes to the irrigation supply of adjacent fields or is conveyed back to the river system through a tributary. Once a set is finished, a new set is made, either by moving check dams upstream (or downstream) in the ditch to new cutouts or by opening a new set of gates (in gated pipe irrigation systems). Flood irrigation sets often start at one end of the field and are moved toward the opposite end until the field is completely irrigated.

The H-I and ISAM Models account for the inefficiencies of flood irrigation through the factors listed previously. On a farm-scale analysis, the tailwater fraction, deep percolation fraction, on-farm ditch loss, and maximum farm efficiency are used within the water-budget process to determine the amount of water consumed by a crop and the amount that can potentially return to the river system.

The MFE Factor has been the subject of debate, not only because of its effect on state line depletions but also because of: 1) the difficulty in measuring the value across entire canal systems and 2) the differences in definition among experts. In the H-I and ISAM Models, MFE is the maximum amount of field application made available for crop use over each canal system on a monthly basis. MFE values for flood irrigation on canals within the H-I Model domain have been assigned values of 65% to 70%.

From a modeling perspective, MFE is a function of on-farm ditch loss (FDL), tailwater fraction (TWF), and deep percolation fraction (DPF) and defined in the H-I Model as:

$$MFE = 100\% - FDL\% - TWF\% - DPF\%$$

where:

$$FDL = \frac{On\ Farm\ Ditch\ Loss\ Amount}{Amount\ Delivered\ to\ Farm}$$

$$TWF = \frac{Tailwater\ Amount}{Applied\ Amount}$$

$$DPF = \frac{Deep\ Percolation\ Amount}{Applied\ Amount}$$

with FDL, TWF, and DPF considered on a canal-wide basis with a monthly time step.

TWF is generally a function of management practices (including set size and set duration) and water sediment loads (clearer water tends to advance more slowly across a field producing less tailwater). TWF has an assigned value of 9.65% in the H-I Model while FDL is assigned a value of 3.5%.

DPF is also influenced by the same factors as TWF as well as crop rooting depth and soil-water content within the crop root zone prior to irrigation. DPF is not assigned an explicit value in the H-I Model, but for the Ft Lyon Canal is 21.9% based on the assigned MFE of 65%. In the H-I Model, irrigation application exceeding the amount required for crop consumption or soil storage (within the crop root zone) is assumed to deep percolate.

In Kansas v. Colorado testimony concerning on-farm efficiency, Colorado cited deficit irrigation and tailwater reuse as two factors that justified its argument that higher MFE values should be implemented in the H-I Model for water-short ditches such as the Fort Lyon, Amity, Colorado, Holbrook, and Otero canals. Deficit irrigation is the practice of applying an irrigation supply that is less than the amount required by a crop for optimum yield. The primary irrigation practice that differs between full-irrigation and deficit irrigation scenarios is set duration. During deficit irrigation, set durations are often shortened resulting in less tailwater and less total infiltrated amount over an irrigated area. This scenario also tends to reduce deep percolation losses and increase irrigation efficiency.

Tailwater reuse is the practice of controlling and reapplying tailwater either through mechanical means such as tailwater ponds and pumps or simply utilizing down gradient ditches to distribute tailwater as a supply for other fields, farms, or even canals. Tailwater reuse has the potential to cause an increase in irrigation efficiency over the entire tailwater production/reuse area depending on the amount of tailwater reused and the soil-water content in the crop root zone before tailwater application. Because of the relationship between TWF and MFE, field observation of TWF values lower than previously estimated could signify that MFE values are underestimated in the H-I and ISAM Models.

I.b. Goals of the Study

Estimates of MFE and TWF as used in the H-I Model are the result of several field trips taken through the area by experts from Kansas and Colorado during 1996[1]. These field trips yielded opinions on achievable irrigation efficiencies through observations of soil types, field slopes, tailwater, tailwater reuse, and MFE. Soil types and general field slope data were confirmed with Natural Resource Conservation Service (formerly Soil Conservation Service) data. Tailwater, tailwater reuse, and MFE opinions, however, appear to have been estimated through visual inspection only.

The objectives of this study are as follows:

1) Measure actual TWF on a section of the Fort Lyon Canal (study area) to determine if the assumed value of TWF used in the H-I Model is accurate.
2) Utilize the NRCS Farm Irrigation Rating Index (FIRI) to evaluate the same section of the Fort Lyon Canal to determine if the model is applicable for use in estimating MFE factor for the H-I Model.
3) Determine whether measured TWF values from this study justify a more detailed and extensive irrigation efficiency study on the Fort Lyon Canal.

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[1]Littleworth, A. Second Report, Kansas vs. Colorado, U.S. Supreme Court, Section VI. September 1997

II. Study Area

II.a. Site Selection

The relative lack of variation amongst MFE values between water-long ditches and water-short ditches has been viewed as a deficiency in the H-I Model. The Fort Lyon Canal, which irrigates approximately 94,000 acres, is the largest canal in Colorado and is oftentimes considered a water-short system. Water is delivered to shareholders on a rotational basis using 48 hour "runs" beginning at the top of the canal near La Junta and moving downstream near Lamar before starting over. Table 1 illustrates the variation in annual Fort Lyon Canal water supplies, number of runs, and precipitation from 2012 thru 2016.

Table 1: Recent Fort Lyon Canal Water Supply and Precipitation

Year	[1]FLCC Water Supply (ac ft)	[1]FLCC #Runs	[1,2]FLCC Precipitation (in)
2012	74,466	7	8.2
2013	139,035	12	9.8
2014	212,389	22	13.6
2015	253,046	30	18.8
2016	245,052	32	8.34

[1]From 2016 Annual Reports of the Officers of the Fort Lyon Canal Company
[2]Average of Lamar and Las Animas rainfall measurements, FLCC

Over the last 15 years, the Fort Lyon Canal system has experienced a substantial conversion from flood irrigation acreage to center-pivot sprinkler irrigated acreage. Currently, about 16,500 acres under this system utilize sprinkler irrigation. This transition has left few large sections of irrigated farm ground under the Fort Lyon Canal that utilize traditional flood irrigation practices that involve tailwater reuse and multiple farmers.

Figure 1: Location of the Fort Lyon Canal in Colorado

The study area chosen for this project encompasses about 2,000 flood irrigated acres near the town of McClave. Farm ground within the study area is owned by seven different landowners and actively farmed by six different tenants who each granted permission to allow research activities to be conducted on their farms.

Irrigation supply for the study area is diverted from the Fort Lyon Canal through two lateral ditches – the McClave Lateral and the Sunflower Lateral – which follow ridge lines on the western and eastern boundaries of the study area respectively. The McClave Drain channel dissects the study area from north to south and carries any tailwater return flows, groundwater seep, and precipitation runoff back to the Arkansas River.

Farm identification for the study was based on whether irrigation supply was derived from the McClave Lateral (denoted with letter M in the study farm naming convention) or Sunflower Lateral (denoted with letter S) and the order in which the farm diverted water from the lateral (numbered 1 through 5). Farm M3B shared a divide box diversion with Farm M3.

Figure 2: Location of the Study Area on the Fort Lyon Canal

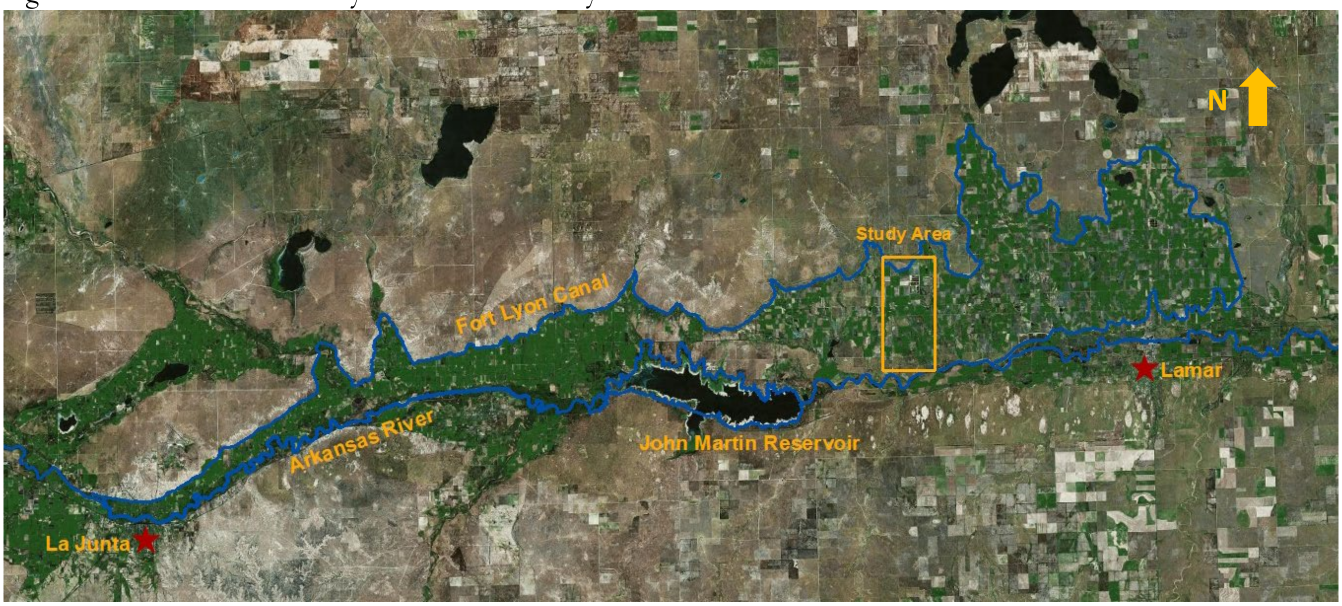
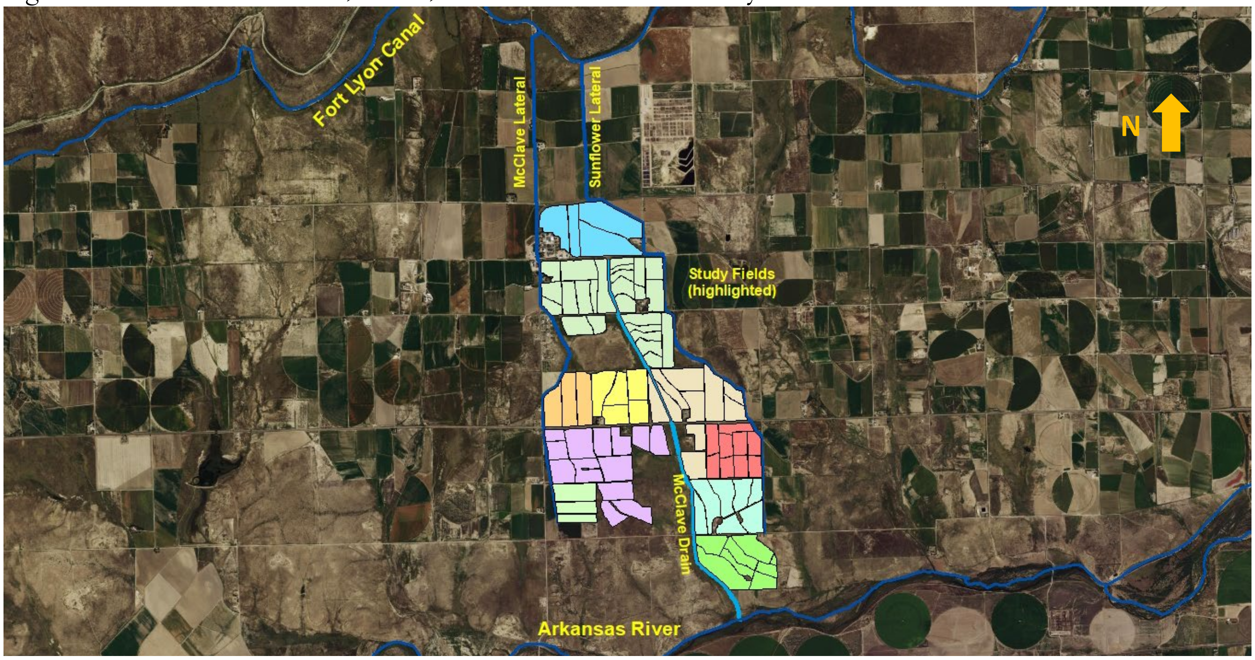


Figure 3: Location of Laterals, Drain, and Farms within the Study Area



II.b. Study Area Characteristics

Soil types within the study area are predominantly Rocky Ford clay loams.

Table 2: Soil Types in the Study Area

NRCS-WSS Dominant Soil Types in Study Area			
Soil Symbol	**Soil Name**	**Acres in Study Area**	**% of Study Area**
RfB	Rocky Ford clay loam, 1 to 3 percent slopes	1201.4	54.55%
RfA	Rocky Ford clay loam, 0 to 1 percent slopes	730.9	33.19%
NmB	Numa clay loam, 1 to 3 percent slopes	134.3	6.10%
RkB	Rocky Ford loam, wet, 1 to 3 percent slopes	58.7	2.67%
RkA	Rocky Ford clay loam, wet, 0 to 1 percent slopes	32.1	1.46%
Ca	Cascajo soils and gravelly land	17.8	0.81%
MeC	Minnequa loam, 1 to 5 percent slopes	16	0.73%
ToC	Travessilla-Olney sandy loam, 1 to 9 percent slopes	8.9	0.40%
HaC	Harvey loam, 1 to 9 percent slopes	1.4	0.06%
WlB	Wilid silt loam, 0 to 3 percent slopes	0.6	0.03%
NuB	Numa clay loam, wet, 0 to 3 percent slopes	0.1	0.00%
TOTAL Acres in Study Area		**2202.2**	**100.00%**

Source: NRCS Web Soil Survey

Irrigated field gradients within the study area vary from about 0.5% to 3.5% with an average of 1.35%. Field slopes west of the McClave Drain channel tend to follow downward gradients to the south and east while fields east of the channel tend to follow downward slopes to the south and west.

Table 3: Topography Statistics for the Study Area

Topography Statistics for Study Area[1]	
Average Gradient across Study Area:	1.35%
Highest Gradient in Study Area:	3.57%
Farm ID with Highest Gradient:	M2
Lowest Gradient in Study Area:	0.54%
Farm ID with Lowest Gradient:	M5
McClave Lateral Highest Elevation (ft) (Flume Floor at Headgate):	3,934
McClave Lateral Lowest Elevation (ft) (McBox6):	3,837
McClave Lateral Length (ft) (Flume to McBox6):	19,827
McClave Lateral Gradient (%):	0.49%
Sunflower Lateral Highest Elevation (ft) (Flume Floor at Headgate):	3,932
Sunflower Lateral Lowest Elevation (ft) (SunBox5):	3,806
Sunflower Lateral Length (ft) (Flume to SunBox5):	4,576
Sunflower Lateral Gradient (%):	0.51%

[1]Gradients measured only on irrigated ground in the study area.
Source: USA Topo maps.

Crops grown within the study area are predominantly alfalfa but also include winter wheat, grain sorghum, corn, and forage sorghum. During 2015, all farms in the study area utilized flood irrigation which included both furrow irrigation and corrugation and involved the use of earthen ditches, concrete ditches, and plastic pipe. Prior to the 2016 irrigation season, one farm in the study area (Farm M5) was converted from flood irrigation to center pivot sprinkler irrigation. Subsequently, this farm was removed from the 2016 analysis.

Table 4: Crop Type Distribution by Year for the Study Area

2015 Crop Type	Sum of Acres	% of Total Acres
ALFALFA	**1102**	**52%**
SORGHUM (ALL)	**473**	**22%**
Other	**286**	**13%**
WHEAT	**161**	**8%**
CORN (GRAIN)	**106**	**5%**
TOTAL	**2127**	**100%**

2016 Crop Type	Sum of Acres	% of Total Acres
ALFALFA	**1082**	**53%**
SORGHUM (ALL)	**736**	**36%**
WHEAT	**87**	**4%**
Other	**84**	**4%**
CORN (GRAIN)	**58**	**3%**
TOTAL	**2047**	**100%**

Table 5: Length of Irrigation Conveyance/Distribution Systems in Study Area during 2015 and 2016

		Earthen Ditch	Concrete Ditch	Gated Pipe	Underground Pipe
2015	Length (mi)	35.34	2.87	0.46	2.93
	% of Total	85%	7%	1%	7%
2016	Length (mi)	34.57	2.53	0.46	2.43
	% of Total	86%	6%	1%	6%

Source: ArcMap 10.3

III. Tailwater Return Flow Measurements and Results

III.a. Flow Measurement Stations

TWF is defined as the ratio of tailwater amount to the application amount and can be applied on a field-level, farm-level, or canal-wide basis. Tailwater reuse has historically been a common practice in the study area and includes reuse from field to field within an individual farm as well as from one farm to another. In order to account for tailwater reuse within the study area as a whole, tailwater measurement stations were installed at all surface water entry points into the McClave Drain where tailwater return flows were expected to occur[2]. Tailwater flumes were sized based upon expected tailwater flow rates; this was determined in part by the number of canal shares associated with each farm along with communicated prior experience from the farmers.

Table 6: Flow Measurement Stations

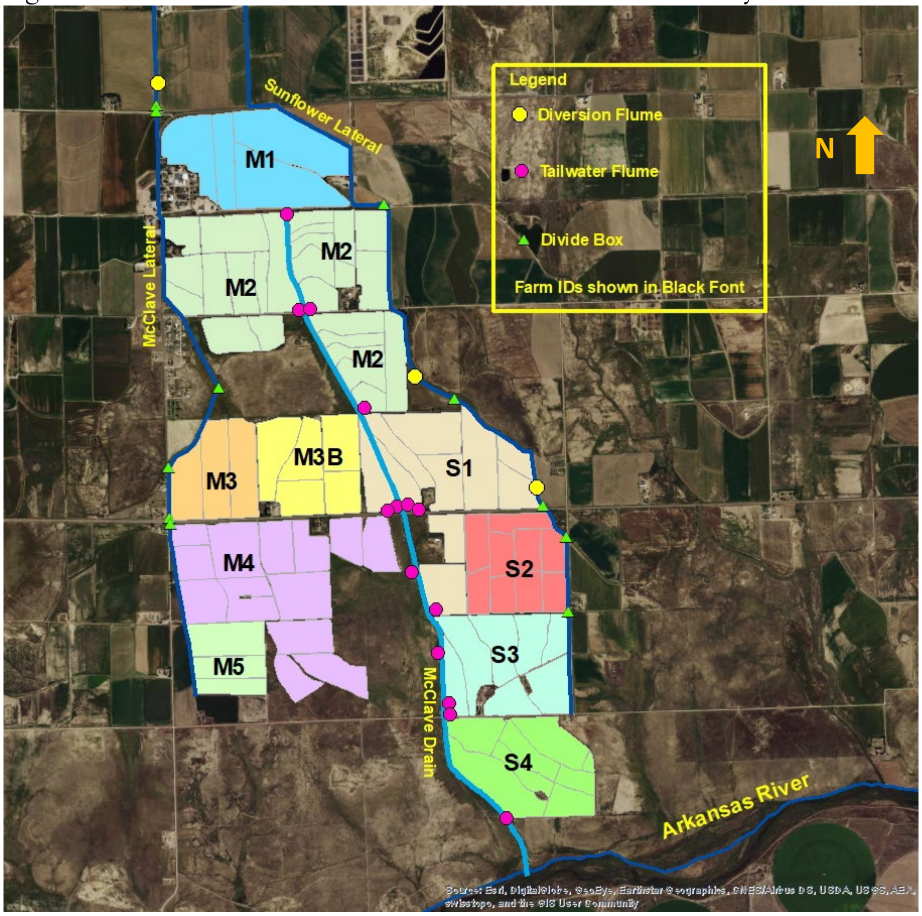
Station ID	Installation Date	Flume Type	Throat Width (in)	Measurement Type	Farms Measured	Date Verified	% Error
MCDIV1[1]	4/16/2015	Parshall	48	Diversion	M1,M2,M3,M3B,M4,M5		
MCDIV2	4/15/2015	Parshall	48	Diversion	M1,M2,M3,M3B,M4,M5	10/1/2015	0.2%
MCDIV3[2]	5/13/2015	Parshall	36	Diversion	M3,M3B,M4,M5	7/28/2015	-2.1%
SUNDIV1[1]	4/16/2015	Parshall	36	Diversion	S1,S2,S3,S4		
SUNDIV2	5/11/2015	Parshall	36	Diversion	S1,S2,S3,S4	8/16/2015	2.2%
SUNDIV3	5/29/2015	Parshall	36	Diversion	S2,S3	7/9/2015	-4.3%
TWM1	4/17/2015	Parshall	9	Tailwater	M1	8/11/2015	0.7%
TWM2A	4/21/2015	Cutthroat	12	Tailwater	M2	4/7/2017	0.0%
TWM2B	5/18/2015	Cutthroat	12	Tailwater	M2	10/12/2015	0.0%
TWM2C	4/20/2015	Parshall	6	Tailwater	M2	9/16/2015	-1.7%
TWM3	6/16/2015	Parshall	9	Tailwater	M3,M3B	10/3/2017	-4.3%
TWM4	4/23/2015	Cutthroat	8	Tailwater	M4,M5	5/1/2016	4.5%
TWM4B	10/9/2015	Cutthroat	8	Tailwater	M4	10/12/2015	-3.6%
TWS1A	6/17/2015	Parshall	9	Tailwater	S1	8/7/2015	-0.9%
TWS1B	6/17/2015	Cutthroat	12	Tailwater	S1	7/31/2015	3.4%
TWS1C[5]	6/18/2015	Cutthroat	8	Tailwater	S1		
TWS1D[5]	7/29/2016	Parshall	9	Tailwater	S1		
TWS2[3]	4/25/2015	Cutthroat	12	Tailwater	S2,S3	8/6/2015	-4.6%
TWS2[4]	8/21/2015	Parshall	18	Tailwater	S2,S3	8/29/2015	-4.9%
TWS3	4/24/2015	Parshall	9	Tailwater	S3	9/24/2015	-3.9%
TWS4[5]	5/3/2016	Cutthroat	8	Tailwater	S4		

[1]FLCC flume; unable to verify consistent flume shift; data discarded.
[2]Removed after 2015 irrigation season due to sediment problems; data not used due to submerged conditions during several irrigation events.
[3]Removed after 2015 Run #19 due to higher than anticipated tailwater flowrate.
[4]Installed prior to 2015 Run #20.
[5]All 2015 Farm S4 diversions applied to Farm S3.

Irrigation application amounts were derived from diversion measurement stations located in the McClave and Sunflower Laterals. Diversion flumes measured total lateral flow rate prior to division and distribution to individual farms.

[2]Interviews with farmers prior to beginning the study provided locations of tailwater entry points and expected tailwater flow rates.

Figure 4: Location of Flow Measurement Structures within Study Area



Each diversion and tailwater measurement station includes a flume, stilling well with equipment box, and Sutron® Stage Discharge Recorder (SDR) with solar panel and battery.

Figure 5: Diversion Flume

Figure 6: Tailwater Flume

Flumes were installed according to Colorado Division of Water Resources publication "Standard Operating Procedures: Discharge Measurement at Parshall Flumes." Flume measurement accuracy was checked using a USGS Pygmy Current Meter in combination with AquaCalc Pro Plus Stream Flow Computer (JBS Instruments).

Figure 7: Flume Accuracy Verification

III.b. Lateral Divide Boxes

Lateral divide boxes are water regulation structures that serve the purpose of dividing off-farm lateral flows into the appropriate flow rates for diversion to individual farms.

Figure 8: Divide Box

Divide boxes are typically constructed of a concrete floor and walls with a divide wall located in the channel parallel to water flow. The length of each section adjacent to the divide wall is proportional to the number of shares passing through that section. Table 7 summarizes the proportion of flow through flumes MCDIV2 and SUNDIV2 that each farm receives (bottom two rows). These values are determined through dimensional analysis of each divide box within the two laterals.

Table 7: Divide Box Diversion Splits

Flume	MCDIV2	MCDIV2	MCDIV2	MCDIV2	MCDIV2	MCDIV2	MCDIV2	MCDIV2	SUNDIV2	SUNDIV2	SUNDIV2	SUNDIV2	SUNDIV2	SUNDIV2	TOTAL
Farm ID	**M1**	**M2**	**M3**	**M3B**	**M4**	**M5**	**PT**	**ITI**	**S1**	**S2**	**S3**	**S4**	**RT**	**BN**	
Divide Box ID															
MCBOX1	40%	40%	60%	60%	60%	60%	60%	60%							
MCBOX2	43%	57%													
MCBOX3			10%	13%	77%	77%	77%	77%							
MCBOX4					70%	70%	70%	30%							
MCBOX5					76%	76%	24%								
MCBOX6					72%	28%									
SUNBOX2									32%	68%	68%	68%	68%	68%	
SUNBOX3										41%	59%	59%	59%	59%	
SUNBOX4											50%	50%	25%	25%	
SUNBOX5											51%	49%			
% of MCDIV2 Diversions	**17%**	**23%**	**6%**	**8%**	**18%**	**7%**	**8%**	**13%**							100%
% of SUNDIV2 Diversions									**32%**	**28%**	**10%**	**10%**	**10%**	**10%**	100%

PT, ITI, RT, BN are farms that divert water from McClave or Sunflower Laterals that are not included in study.

Lateral divide boxes are founded on the assumption that flow depth and velocity are uniform throughout the entire divide box cross section. Several divide box cross-sections were analyzed using a USGS pygmy current meter and AquaCalc Pro Plus Stream Flow Computer to check flow velocity distribution. Non-uniform lateral velocity profiles were accounted for by applying a weighted flow fraction through each divide section.

Table 8: Divide Box Velocity

	[1]Left Channel Width (in)	[1]Left Channel Velocity (ft/s)	[1]Left Channel Velocity Weighted Fraction of Flow through Box	[1]Left Channel Farm IDs	[1]Right Channel Width (in)	[1]Right Channel Velocity (ft/s)	[1]Right Channel Velocity Weighted Fraction of Flow through Box	[1]Right Channel Farm IDs	Total Box Width (in)	Total Velocity (ft/s)
Divide Box ID										
MCBOX1	63.00	2.68	0.92	M1,M2	81.00	3.08	1.06	M3,M3B,M4, M5,PT,ITI	144.00	2.91
MCBOX2	47.25	1.81	0.99	M1	60.75	1.84	1.01	M2	108.00	1.83
MCBOX3	33.50	2.06	0.93	M3,M3B	99.00	2.28	1.03	M4,M5,PT,ITI	132.50	2.22
MCBOX4	71.50	1.00	1.00	M4,M5,PT	30.00	1.00	1.00	ITI	101.50	1.00
MCBOX5	80.00	2.04	0.98	M4,M5	23.00	2.18	1.05	PT	103.00	2.07
MCBOX6	49.00	2.43	1.03	M4	21.00	2.18	0.93	M5	70.00	2.36
SUNBOX2	132.00	1.00	1.00	2,S3,S4,RT,B	61.00	1.00	1.00	S1	193.00	1.00
SUNBOX3	50.50	2.11	0.98	S3,S4,RT,BN	34.00	2.19	1.02	S2	84.50	2.14
SUNBOX4	35.00	1.00	1.00	RT,BN	35.50	1.00	1.00	S3,S4	70.50	1.00
SUNBOX5	32.50	1.00	1.00	S4	34.25	1.00	1.00	S3	66.75	1.00

[1]Looking downstream through divide box.
PT, ITI, RT, BN are farms that divert water from McClave or Sunflower Laterals that are not included in study.
Yellow highlighted cells are assumed values.

III.c. Irrigation Ditch Seepage Losses

In order to calculate TWF, it is necessary to know the amount of irrigation water applied at the field. The Moritz[3] equation was used to estimate ditch seepage losses between diversion measurement stations (located in off-farm laterals) and each field.

Moritz equation:

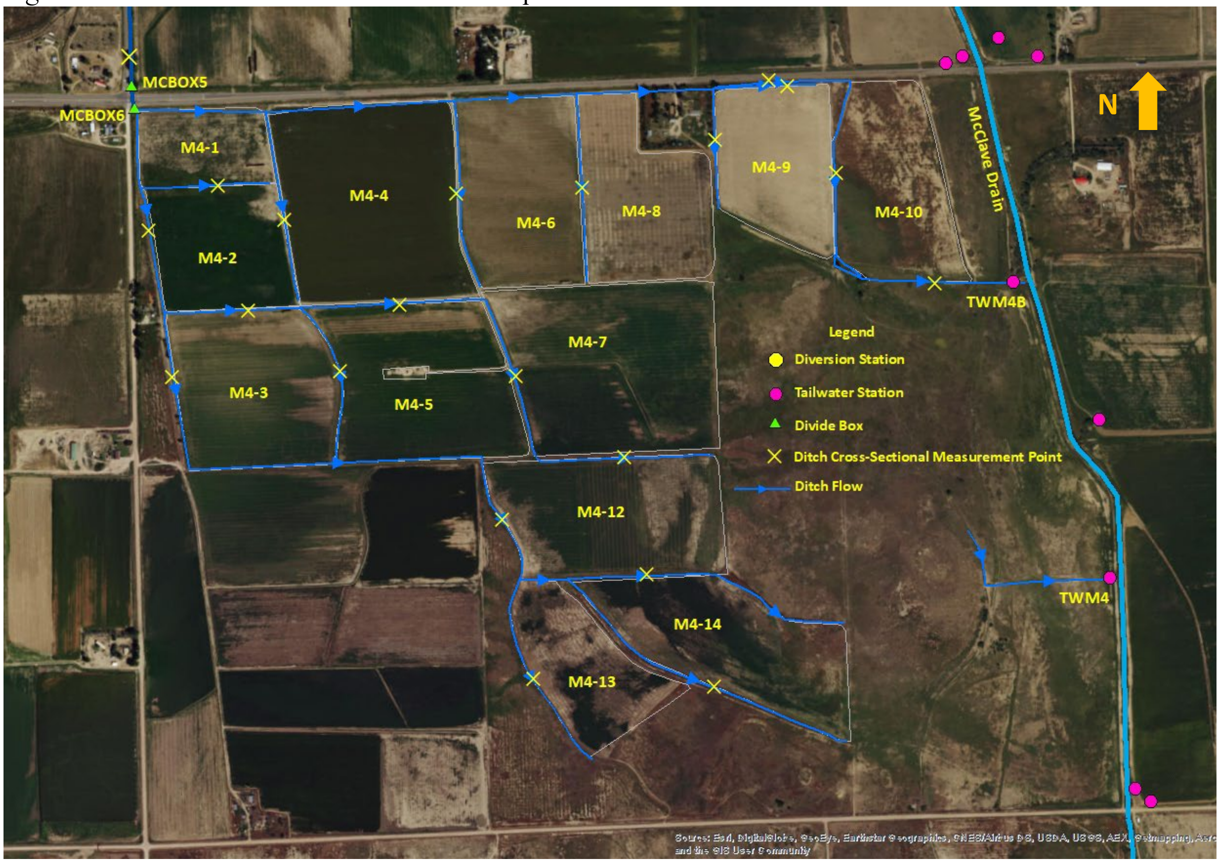
$$S = 0.2 * C * \left(\frac{Q}{V}\right)^{1/2}$$

where:
S = ditch seepage loss (cfs/mi)
C = saturated hydraulic conductivity (ft/day)
Q = flow rate in ditch (cfs)
V = flow velocity in ditch (ft/s)

Field measurements of ditch cross-sectional dimensions were collected at 207 points within the study area (during non-irrigation season) and included on-farm ditches as well as off-farm laterals.

[3]Source: Department of Interior, Bureau of Reclamation, Design Standards No. 3, Canals and Related Structures

Figure 9: Cross-Section Dimension Point Map for Farm M4



Lateral cross-sectional profiles were observed as rectangular in shape while on-farm ditch cross sections were assumed trapezoidal with equal side lengths. Saturated hydraulic conductivity values were determined for each cross-section measurement point using NRCS Web Soil Survey data. For on-farm ditches, Q was calculated by dividing diversion volumes on each farm per run (48 hours long) and selecting the median value over the entire season. This process yielded a median Q value for each farm per year. For off-farm laterals, Q was calculated by subtracting divide box splits for each lateral segment from diversion measurement station data. Average flow velocity, V, was calculated by a combination of Manning's Equation and Mass Balance:

Manning's Equation:

$$V = \left(\frac{1.486}{n}\right) * R^{\frac{2}{3}} * S^{\frac{1}{2}}$$

where

n = Manning's roughness coefficient = 0.03 for earthen ditches

R = Hydraulic Radius of ditch flow = $\left(\frac{cross\ sectional\ area}{wetted\ perimeter}\right)$

S = ditch slope

Mass Balance:

$V = Q/A$
where

Q = ditch flow rate
A = ditch flow cross-sectional area

These two equations were set equal while solving for flow depth at each point. This process, used with the Moritz equation, yielded a seepage loss value (cfs/mi ditch) for each ditch cross-sectional measurement point.

For each study field, average seepage loss volume (in acre feet) was calculated by averaging Moritz S values for each point that irrigation water traveled through to reach the field and multiplying by the length of earthen ditch. Earthen ditch lengths for headland ditches were assumed to equal half of total headland ditch length since irrigation water sets typically start at one end (where $L =$ total headland L) and finish at the opposite end (where $L = 0 *$ total headland L).

Total ditch seepage loss for each farm (in acre feet) was calculated by averaging seepage loss values for each field within a farm and adding average off-farm lateral loss for each farm. This method assumes equal distribution of irrigation water amongst all fields within a farm during the year and yields a single average volumetric seepage loss value for each farm per year.

Table 9: Average Ditch Seepage Loss by Farm

2015 Total Avg Ditch Seepage Loss per Farm During 48 hr Run (ac ft)

McClave Lateral Farms					Sunflower Lateral Farms			
M1	M2	M3/M3B	M4	M5	S1	S2	S3	S4
0.19	0.209	0.685	0.903	0.249	0.360	0.361	0.986	N/A

2016 Total Avg Ditch Seepage Loss per Farm During 48 hr Run (ac ft)

McClave Lateral Farms					Sunflower Lateral Farms			
M1	M2	M3/M3B	M4	M5	S1	S2	S3	S4
0.19	0.210	0.688	0.908	N/A	0.356	0.355	0.438	0.593

III.d. Precipitation Amounts and Timing

The effect of precipitation on runoff through tailwater measurement stations during irrigation events was accounted for using the runoff equation developed by the NRCS, incorporating the runoff curve number (CN). The curve number affects runoff by accounting for hydrologic conditions as well as soil types and surface conditions.

$$Q = \frac{(P - 0.05S_{0.05})^2}{P + 0.95S_{0.05}} \; for\ P > 0.05S\ or\ Q = 0\ for\ P \leq 0.05S$$

where

Q = runoff in inches
P = rainfall in inches
S = the potential maximum soil moisture once runoff begins in inches. S incorporates CN as:

$$S = \frac{1000}{CN} - 10$$

Measured precipitation amounts were collected from three rain gauges in the study area after each rain event throughout the 2015 and 2016 irrigation seasons. Additionally, data from a nearby CoAgMet station was utilized as necessary. These measurements yielded P for each irrigation run at each field.

To determine S, CN values were selected from Table 10 based upon cover type, treatment and hydrologic condition for each farm. Cover type and treatment of the study fields were determined by observed crop types and residue coverage in each field each year. Hydrologic conditions were identified as "Good." Soil types in the study area were determined at each identification point (Point ID) using the NRCS Web Soil Survey. The majority of Point ID soil types had resulting saturated hydraulic conductivity values (K_{SAT}) of 0.2 in/hr, corresponding with the NRCS Hydrologic Soil Group B.

Table 10: NRCS Runoff Curve Number (CN) Values for Cultivated Agricultural Lands

Cover description			**Curve Numbers for Hydrologic Soil**			
Cover type	**Treatment**[A]	**Hydrologic condition**	**A**	**B**	**C**	**D**
Fallow	**Bare soil**	—	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	**Straight row (SR)**	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T + R	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	**SR**	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T + R	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	**SR**	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C&T	Poor	63	73	80	83
		Good	51	67	76	80

Source: https://en.wikipedia.org/wiki/Runoff_curve_number

Resulting *CN*s utilized in the study runoff calculation are listed in Table 11. When crop rotation created two different crop types in a field within a year, the *CN*s of the crop types were averaged for the field. A *CN* value for each farm was calculated using a weighted average of field *CN*s within the farm by acres per field. This weighted average *CN* was then used to calculate *S* in the runoff equation.

Table 11: Curve Number (CN) Values for Study Area

Cover Type	Curve Number (CN)
Alfalfa	72
Fallow	83
Grain Corn	75
Sorghum	72
Wheat	72

Finally, *Q* was calculated for each field and correlated to corresponding irrigation runs by date of precipitation event to determine if the tailwater amount of the run was affected. If an effect of the precipitation was determined, the amount was subtracted from the total runoff measured through the tailwater flume during the run.

Table 12: Precipitation Contribution to Tailwater Amount

2015 Total Precip Contribution to TW Flume Amounts per Farm (ac ft)

McClave Lateral Farms					Sunflower Lateral Farms			
M1	M2	M3/M3B	M4	M5	S1	S2	S3	S4
10.48	0.705	0.263	0.000	0.000	5.727	7.454	4.189	N/A

2016 Total Precip Contribution to TW Flume Amounts per Farm (ac ft)

McClave Lateral Farms					Sunflower Lateral Farms			
M1	M2	M3/M3B	M4	M5	S1	S2	S3	S4
6.64	3.570	1.894	8.558	N/A	5.734	3.866	2.251	2.321

III.e. Irrigation Monitoring

Irrigation monitoring began in May 2015 and continued through mid-November 2016. Diversion and tailwater measurement stations were generally visited one to four times per irrigation event and once afterward. Monitoring activities during the course of irrigation included equipment inspection, SDR calibration (if necessary), observation of flow conditions and farm diversion verification. Post-irrigation monitoring activities included equipment inspection, SDR data retrieval and inspection of channel conditions (including sediment removal if necessary). In 2015, 25 irrigation events were monitored with 1244 measurement station checks. During 2016, 32 irrigation events were monitored with 1538 measurement station checks.

III.f. Verification of Flume Accuracy

In order to confirm the accuracy of flow measurement in flumes, each structure was checked using a USGS Pygmy Current Meter in combination with AquaCalc Pro Plus Stream Flow Computer (JBS Instruments). The flume verification procedure that was utilized for this study was identical to the procedure used by Colorado Division of Water Resources, Division 2 hydrographers during a training trip to the study area in June 2015. Consistent with

DWR practice, any flume showing less than ± 5% error (as compared to current meter analysis) was assumed to be measuring accurately and no shift was applied to SDR stage data. Table 6 on page 8 shows the date that each flume was verified and the percent error.

III.g. SDR Data Analysis

Sutron® Stage Discharge Recorders were used to measure and record upstream (at staff gauge) flow depth (stage) values in flumes. SDRs were initially programmed to record stage values every 15 minutes but were reprogrammed to five-minute intervals on July 30, 2015. During 2015, in-field calibration of SDRs took place when staff gauge reading and SDR value differed by 0.02 feet or more. In 2016, this limit was lowered to 0.01 feet; subsequently this limit was also applied to 2015 data during processing. SDRs were typically downloaded following each irrigation event and converted to Microsoft Excel files for further processing.

III.h. TWF Calculations

Net application amount on each farm was calculated in acre/feet as follows:

$$\begin{aligned} &\mathit{Net\ Farm\ Application\ Amount} \\ &\qquad = (\mathit{Lateral\ Diversion\ Measured\ Amount} * \mathit{Box\ Split\ Fraction}) \\ &\qquad - \mathit{Off\ Farm\ Lateral\ Seepage\ Loss} - \mathit{On\ Farm\ Ditch\ Seepage\ Loss} \end{aligned}$$

Net tailwater amount from each farm was calculated in acre/feet as follows:

$$\mathit{Net\ Tailwater\ Amount} = \mathit{Tailwater\ Flume\ Measured\ Amount} - \mathit{Precipitation\ Runoff}$$

TWF values were calculated as follows on a farm basis as well as for the entire study area:

$$\mathit{Farm\ Tailwater\ Fraction} = \frac{(\mathit{Net\ Farm\ Tailwater\ Amount})}{(\mathit{Net\ Farm\ Application\ Amount})}$$

$$\mathit{Study\ Area\ Tailwater\ Fraction} = \frac{(\mathit{Net\ Study\ Area\ Tailwater\ Amount})}{(\mathit{Net\ Study\ Area\ Application\ Amount})}$$

III.i. Tailwater Results

Results of diversion and tailwater amounts are provided in Tables 13 through 16 for 2015 and Tables 17 through 20 for 2016.

Table 13: 2015 Tailwater Fractions by Farm

2015 Tailwater Fractions by Farm

McClave Lateral Farms					Sunflower Lateral Farms		
M1	M2	M3/M3B	M4	M5	S1	S2	S3
12.45%	0.07%	0.55%	0.35%	0.00%	16.39%	8.92%	7.36%

Table 14: 2015 Net Diversion Amount by Farm per Irrigation Run

2015 Net Diversion Amount by Farm Per Run (ac ft)

	McClave Lateral Farms						Sunflower Lateral Farms			
RUN #	M1	M2	[1]M3	[1]M3B	M4	M5	S1	[2]S2	[3]S3	[3]S4
6		36.91			27.95	10.85				
7		32.80			24.76	9.62			25.70	
8		32.20			24.29	9.44			21.13	
9		30.32	7.98	9.98	22.83	8.88	22.17			
10	24.28	31.77	8.37	10.47	23.96	9.31	23.95		22.29	
11	23.91	31.29	8.24	10.31	23.59	9.17	24.98		23.28	
12	24.98	32.69	8.62	10.78	24.67	9.58	24.90	30.11	23.21	
13	24.18	31.64	8.34	10.43	23.86	9.27	23.50	28.42	21.86	
14		33.29	8.78	10.99	25.15	9.77	27.97	33.81	26.14	
15	23.65	30.94	8.15	10.19	23.31	9.06	29.04	35.10	27.16	
16	24.14	31.58	8.32	10.41	23.81	9.25	28.71	34.71	26.85	
17	23.99	31.39	8.27	10.34	23.66	9.20	27.90	33.74		
18	23.63	30.92	8.14	10.18	23.30	9.05	27.12	32.79		
19	26.87	35.15	9.28	11.62	26.59	10.32	29.59	35.77		
20	25.33	33.14	8.74	10.94	25.02	9.72	27.91	33.74	26.08	
21		32.74	8.63	10.80	24.71	9.60	27.40	33.13	25.60	
22		33.07	8.72	10.91	24.97	9.70	25.70	31.07	23.97	
23		31.66	8.34	10.43	23.88	9.28	26.96	10.63	25.18	
24		33.86	8.94	11.18	25.58	9.93	32.63	39.43	30.60	
25		30.83	8.12	10.15	23.23	9.03	19.52	23.62	18.05	
26		31.98	8.43	10.54	24.13	9.37	18.67	22.60	17.24	
27		32.24	8.50	10.63	24.32	9.45	17.65	13.22	16.26	
28		28.09	7.38	9.22	21.10	8.21	20.06	24.28	18.57	
29		22.10	5.77	7.17	16.44	6.42	9.23	11.21	8.20	
30		25.03	6.56	8.17	18.72	7.29	1.38	1.74	0.68	
TOTAL	**244.95**	**787.61**	**180.65**	**225.84**	**593.83**	**230.77**	**516.96**	**509.12**	**428.07**	

Table 15: 2015 Net Tailwater Amount by Farm per Irrigation Run

2015 Net Tailwater Amount by Farm per Run (ac ft)

	McClave Lateral Farms					Sunflower Lateral Farms			
RUN #	**M1**	**M2**	**[1]M3/M3B**	**M4**	**M5**	**S1**	**[2]S2**	**[3]S3**	**[3]S4**
6	0.00	0.03		0.00	0.00				
7	0.00	0.22		0.00	0.00			2.17	
8	0.00	0.00		0.00	0.00			1.33	
9	0.00	0.00	0.00	0.00	0.00	6.05		0.00	
10	2.27	0.00	0.00	0.00	0.00	5.57		1.07	
11	4.12	0.00	1.53	0.00	0.00	1.90		0.05	
12	0.03	0.00	0.00	0.00	0.00	0.05	0.00	0.70	
13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.48	
14	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.20	
15	0.00	0.00	0.10	0.00	0.00	9.96	0.00	2.13	
16	0.00	0.00	0.19	0.00	0.00	5.60	7.04	0.00	
17	8.58	0.00	0.00	0.00	0.00	6.11	8.97	0.00	
18	11.05	0.00	0.00	0.00	0.00	6.63	2.80	0.00	
19	4.44	0.00	0.00	0.00	0.00	3.63	9.79	0.00	
20	0.00	0.00	0.23	0.00	0.00	4.48	3.98	0.00	
21	0.00	0.00	0.02	0.00	0.00	3.60	8.25	0.00	
22	0.00	0.00	0.00	0.00	0.00	4.64	1.78	0.00	
23	0.00	0.24	0.00	0.00	0.00	8.61	0.00	0.80	
24	0.00	0.07	0.00	0.00	0.00	9.80	1.22	3.12	
25	0.00	0.00	0.00	0.00	0.00	0.03	1.61	3.15	
26	0.00		0.00	2.05	0.00	0.00	0.00	0.59	
27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
28	0.00	0.00	0.00	0.00	0.00	7.11	0.00	6.09	
29	0.00	0.00	0.00	0.00	0.00	0.89	0.00	6.94	
30	0.00	0.00	0.15	0.00	0.00	0.00	0.00	2.67	
TOTAL	**30.50**	**0.56**	**2.23**	**2.05**	**0.00**	**84.71**	**45.43**	**31.51**	

[1]Irrigation diversions for Farms M3, M3B applied together to either Farm M3 or M3B during 2015. Water not divided.
[2]Irrigation diversions for Farms S2, BN applied together during 2015. Water not divided.
[3]Irrigation diversions for Farms S3, S4, RT applied together to either Farm S3 or RT during 2015; no water applied to Farm S4 during 2015.
*Blank cells indicate irrigation runs when water was diverted to another farm outside of study area or prior to equipment installation.
**BN, RT are farms that are not included in study that divert water from Sunflower Lateral.

Table 16: 2015 Tailwater Statistics

2015 Study Area Tailwater Statistics

Total Net Diversion Amount (ac ft)	3717.81
Total Net Tailwater Amount (ac ft)	196.99
Average Tailwater Fraction (TWF) (%)	**5.30%**
Highest Annual Average TWF by a Farm (%)	16.39%
Lowest Annual Average TWF by a Farm (%)	0.00%

Table 17: 2016 Tailwater Fractions by Farm

2016 Tailwater Fractions by Farm (ac ft)

McClave Lateral Farms					Sunflower Lateral Farms			
M1	M2	M3/M3B	M4	[2]M5	S1	S2	S3	S4
2.37%	0.83%	0.31%	0.84%	N/A	14.71%	4.37%	4.59%	6.19%

Table 18: 2016 Net Diversion Amount by Farm per Irrigation Run

2016 Net Diversion Amount by Farm Per Run (ac ft)

	McClave Lateral Farms						Sunflower Lateral Farms			
RUN #	M1	M2	[1]M3	[1]M3B	M4	[2]M5	S1	S2	S3	S4
1		36.48	9.64	12.08	52.03		22.74	27.51	7.16	
2		32.34	8.52	10.66	46.05		24.17	29.24	7.63	
3		32.32	8.52	10.66	46.02		24.83	30.02	7.85	
4	25.03	32.75	8.64	10.80	46.64		23.74	28.71	7.49	
5		32.29	8.51	10.64	34.96		24.18	29.25	7.64	
6		32.62	8.60	10.76	35.33		24.69	29.86	7.80	
7		31.91	8.41	10.52	34.54		23.14	27.99	7.30	6.75
8		32.96	8.69	10.88	35.70		23.89	28.89	7.54	6.98
9	25.16	32.91	8.68	10.86	24.84		25.56	30.91	8.09	7.50
10	25.46	33.32	8.79	11.00	25.16		24.50	29.62	7.74	7.17
11		29.98	7.89	9.86	22.56		25.38	30.69	8.03	7.44
12	22.71	29.72	7.82	9.77	22.36		27.67	33.45	8.78	8.16
13		16.50	4.26	5.26	12.08		23.61	28.56	7.45	6.89
14		1.31	0.16	0.07	0.27		2.60	3.22	0.54	0.33
15	24.62	32.21	8.49	10.62	24.30		24.51	29.64	7.74	7.17
16	24.70	32.32	8.52	10.66	24.38		25.70	31.08	8.14	7.55
17	22.54	29.49	7.76	9.69	22.18		26.26	31.75	8.32	7.72
18	20.84	27.27	7.16	8.93	20.45		26.13	31.60	8.28	7.68
19	22.86	29.91	7.87	9.83	22.51		20.59	24.92	6.46	5.95
20		30.85	8.12	10.15	23.24		23.94		7.56	6.99
21	23.39	30.61	8.06	10.07	23.05		24.50		7.74	7.17
22	23.73	31.05	8.18	10.22	23.40		23.52	28.45	7.42	6.86
23	25.08	32.81	8.65	10.82	24.76		24.68	29.85	7.80	7.23
24	23.70	31.01	8.17	10.21	23.37		27.92	33.76	8.87	8.24
25	24.68	32.29	8.51	10.65	24.36		25.29	30.58	8.00	7.42
26	24.61	32.20	8.49	10.62	24.29		25.12	30.38	7.95	7.36
27	24.88	32.55	8.58	10.73	24.56		24.70	29.87	7.81	7.23
28	24.49	32.04	8.45	10.56	24.17		24.37	29.47	7.70	7.13
29	24.31	31.81	8.38	10.48	23.98		23.69	28.65	7.48	6.92
30	23.49	30.73	8.09	10.11	23.15		23.63	28.58	7.46	6.90
31	19.94	26.10	6.84	8.53	19.55		23.93	28.94	7.56	
32	10.52	13.78	3.53	4.33	9.97		10.42	12.64	3.11	
TOTAL	**486.73**	**946.43**	**249.00**	**311.05**	**844.20**		**749.61**	**848.06**	**236.43**	**166.72**

Table 19: 2016 Net Tailwater Amount by Farm per Irrigation Run

2016 Net Tailwater Amount by Farm per Run (ac ft)

	McClave Lateral Farms					Sunflower Lateral Farms			
RUN #	M1	M2	[1]M3/M3B	M4	[2]M5	S1	S2	S3	S4
1	0.00	0.08	0.00	0.00		5.08	0.64	0.88	0.00
2	0.00	0.00	0.00	0.00		0.10	0.00	0.12	0.00
3	0.00	0.89	0.00	0.00		0.00	0.00	0.00	0.00
4	0.00	0.69	0.00	0.00		0.00	5.16	1.31	0.00
5	0.00	0.08	0.00	0.00		2.86	2.24	0.55	0.00
6	0.00	0.27	0.00	0.77		6.35	2.17	0.54	0.00
7	0.00	0.01	0.00	0.09		0.00	0.05	0.76	0.00
8	0.00	0.54	0.00	0.85		2.21	0.00	0.48	0.00
9	0.26	0.25	0.00	0.92		3.89	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00
11	0.00	0.65	0.00	0.00		0.00	0.00	0.00	0.00
12	0.55	0.55	0.00	0.00		3.99	0.95	0.38	0.00
13	0.00	2.16	1.01	0.10		3.81	1.96	3.24	0.02
14	0.00	0.88	0.00	0.00		0.36	0.20	0.44	4.18
15	0.49	0.27	0.00	0.00		1.55	0.00	0.00	0.00
16	0.46	0.05	0.00	0.01		4.26	0.00	0.31	0.00
17	0.00	0.00	0.00	0.00		11.44	0.00	0.00	0.00
18	0.00	0.00	0.00	0.00		5.75	0.00	0.00	6.11
19	0.00	0.00	0.00	0.99		3.72	0.00	0.00	0.00
20	0.00	0.18	0.08	0.45		0.00	0.00	0.00	0.00
21	1.14	0.00	0.27	0.18		2.40	0.00	0.15	0.00
22	3.07	0.00	0.00	0.00		7.23	0.22	0.00	0.00
23	0.00	0.00	0.34	1.74		7.87	6.66	0.00	0.00
24	0.00	0.00	0.00	0.00		10.32	0.14	0.00	0.00
25	0.08	0.00	0.00	0.01		8.13	1.04	0.00	0.00
26	1.19	0.00	0.00	0.00		12.06	2.20	0.00	0.00
27	2.41	0.00	0.00	0.24		1.83	3.13	0.00	0.00
28	0.69	0.26	0.00	0.77		5.04	6.28	0.00	0.01
29	0.95	0.00	0.00	0.00		0.00	4.03	0.00	0.00
30	0.00	0.01	0.00	0.00		0.00	0.00	0.56	0.00
31	0.00	0.00	0.00	0.00		0.00	0.04	1.13	0.00
32	0.24	0.00	0.00	0.00		0.00	0.00	0.00	0.00
TOTAL	**11.52**	**7.81**	**1.71**	**7.13**		**110.26**	**37.10**	**10.85**	**10.31**

[1]Irrigation diversions for Farms M3, M3B applied together to either Farm M3 or M3B during 2016. Water not divided.
[2]Farm M5 converted to center pivot sprinkler prior to 2016 irrigation season. Diversions not used for 2016 tailwater calculations.
*Blank cells indicate irrigation runs when water was diverted to another farm outside of study area or prior to equipment installation.

Table 20: 2016 Tailwater Statistics

2016 Study Area Tailwater Statistics	
Total Net Diversion Amount (ac ft)	4838.22
Total Net Tailwater Amount (ac ft)	196.69
Average Tailwater Fraction (TWF) (%)	**4.07%**
Highest Annual Average TWF by a Farm (%)	14.71%
Lowest Annual Average TWF by a Farm (%)	0.31%

III.j. Tailwater Conclusions

The average measured TWF for the study area during 2015 and 2016 was 5.30% and 4.07% respectively as opposed to an assumed value of 9.65% in the H-I and ISAM models.

Diversions by the FLCC during these two years were 253,046 ac ft and 245,052 ac ft respectively compared to the 5-year average of 184,797.6 ac ft. This suggests that the hydrologic conditions during the study period were wetter than the short-term average and that TWF during years of lower diversions could prove to be smaller yet.

IV. Farm Irrigation Rating Index Method (FIRI)

IV.a. Background of the FIRI Method

The Farm Irrigation Rating Index (FIRI) method was developed by the USDA-Natural Resources Conservation Service (NRCS formerly SCS) in the 1980s as a way to uniformly evaluate water savings resulting from on-farm irrigation improvements. FIRI is designed to quantify changes in on-farm irrigation water use from both a management and system design standpoint and can be applied to surface, sprinkler or drip irrigation systems. FIRI is a relative rating method that can be used for comparison between different farms and different years. FIRI is not intended to replace on-site irrigation evaluations nor is it intended to represent field application efficiencies, tailwater amounts or deep percolation amounts[4]. For surface irrigation systems, FIRI combines specific factors related to potential farm irrigation efficiency, irrigation management and irrigation system design. Combined, these elements provide a composite farm irrigation efficiency value.

IV.b. Index Description

The FIRI equation is as follows:

$$FIRI = PE * (1 - \left(\sqrt{((1-M_d)^2 + (1-S)^2 + (1-I)^2 + (1-M)^2 + (1-D)^2 + (1-S_c)^2 + (1-W_c)^2 + (1-C_e)^2 + (1-L)^2)}\right) * R$$

where:

$FIRI$ = farm irrigation efficiency (%)
PE = potential farm irrigation efficiency (%)
M_d = Water measurement factor
S = Soil moisture monitoring and scheduling factor
I = Irrigation skill and action factor
M = Maintenance factor
D = Water delivery factor
S_c = Soil condition factor
W_c = Water Distribution Control Factor
C_e = Conveyance Efficiency Factor
L = Land Leveling Factor
R = Tailwater Reuse Factor

[4]Source: Klamm, D., Brenner, J. Farm Irrigation Rating Index. ET & Irr. Eff. Seminar. 1995

Potential Farm Irrigation Efficiency (PE) - The PE component of the FIRI method is a measure of the optimum efficiency associated with a specific irrigation system type. This optimum efficiency assumes that all system and management related factors are maximized and equal to a value of 1. FIRI PE values are obtained through NRCS literature and are specific to each irrigation system type as shown below.

Table 21: Potential Farm Irrigation Efficiency

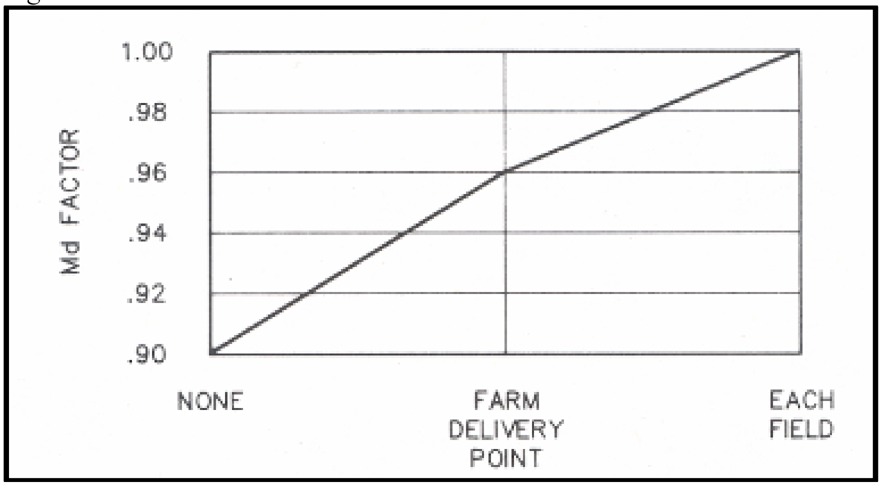
SYSTEM	POTENTIAL EFFICIENCY	SYSTEM	POTENTIAL EFFICIENCY
Borders	%	Sprinkler	%
Level or Basin	90	Big gun or boom	60
Graded	80	Hand line or wheel line	70
Guide	70	Solid set (above canopy)	75
Contour - level		Solid set (below canopy)	80
Field crop	70	Center - pivot	80
Rice	80	Center - pivot (LEPA)	85
Border Ditch	60	Lateral move	85
Furrow		Trickle	
Level or Basin	90	Point source	90
Graded	75	Spray emitters	85
Contour	75	Continuous tape	90
Corrugations	75		
Surge	85		
Subirrigated	75		
Flood Irrigation			
Controlled	60		
Uncontrolled	50		
Contour Ditch	60		

* NOTE: Use these values of potential efficiency if site specific design efficiency for the field being evaluated is not available.

For farms included in the study, a PE value of 75% was chosen based on the prevalence of furrow-corrugation and furrow-graded irrigation systems in the study area.

Water Measurement Factor (M_d) - The Water Measurement Factor describes if and how irrigation water is measured on a particular farm.

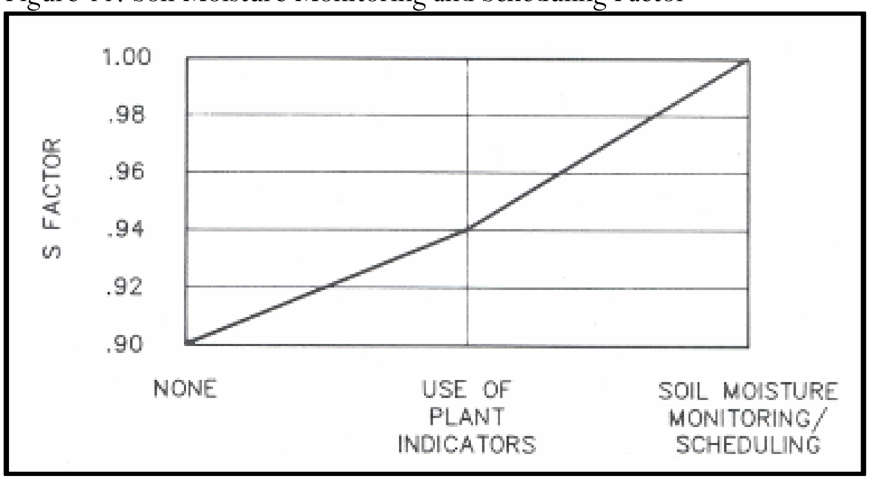
Figure 10: Water Measurement Factor



All farms included in this study measured irrigation flows using flumes (w/o automatic recorders) located at lateral diversion points.

Soil Moisture Monitoring and Scheduling Factor (S) - The Soil Moisture Monitoring/Scheduling Factor describes if and how soil moisture content is monitored and used to schedule irrigation on a farm.

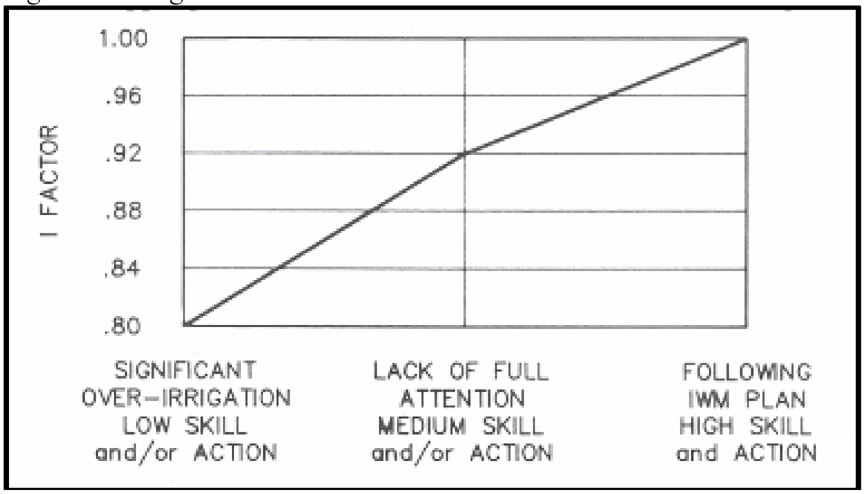
Figure 11: Soil Moisture Monitoring and Scheduling Factor



Soil moisture monitoring/irrigation scheduling for farms included in this study was typically achieved by observation of crop stress and/or soil feel method.

Irrigation Skill and Action Factor (I) - The Irrigation Skill/Action Factor evaluates 1) whether an Irrigation Water Management (IWM) plan is in place, and 2) whether an irrigator changes irrigation water sets frequently enough to prevent over-irrigation.

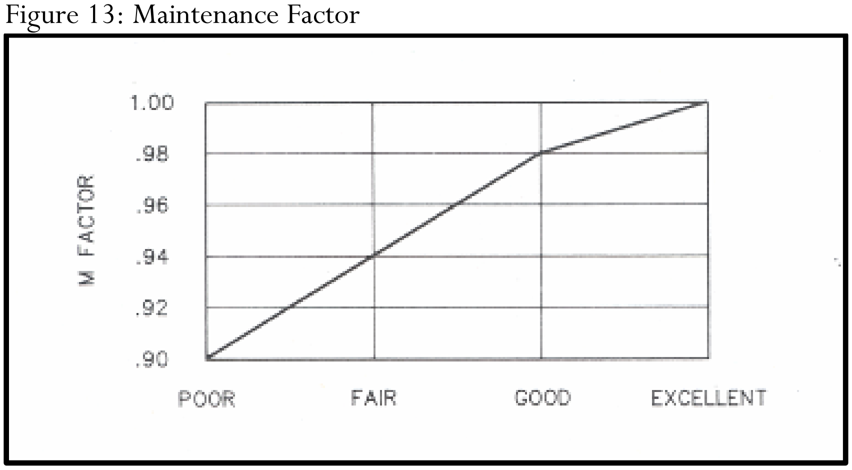
Figure 12: Irrigation Skill and Action Factor



For farms included in this study, no written IWM plans were in place. Irrigation Skill Factor, I, was considered "Medium Skill" if an irrigator changed irrigation sets at least two times daily.

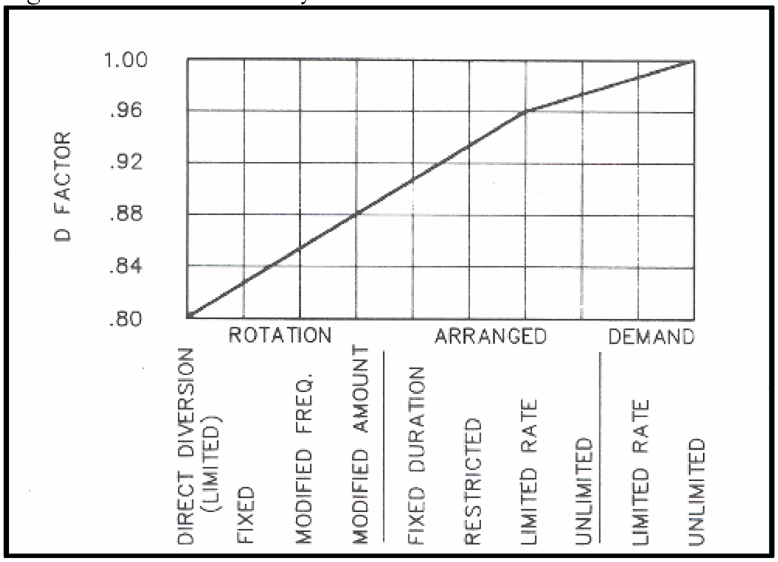
Maintenance Factor (M) - The Maintenance factor is used to assess a farmer's attention to regularly required irrigation system maintenance activities including removal of sediment from ditches and smoothing of land. For farms included in this study, the following assumptions were used for each maintenance factor grade:
Poor – Farms where earthen ditches were never cleaned and where land smoothing activities never occurred.
Fair – Farms where either ditch cleaning or land smoothing occurred at least once per year.
Good – Farms where both ditch cleaning and land smoothing occurred at least once during the year.
Excellent – Farms where ditch cleaning occurred on a regular basis and land smoothing occurred during the year.

Figure 13: Maintenance Factor



Water Delivery Factor (D) - The Water Delivery Factor addresses the timing (frequency, duration) and amount of irrigation water supplied to a farm.

Figure 14: Water Delivery Factor

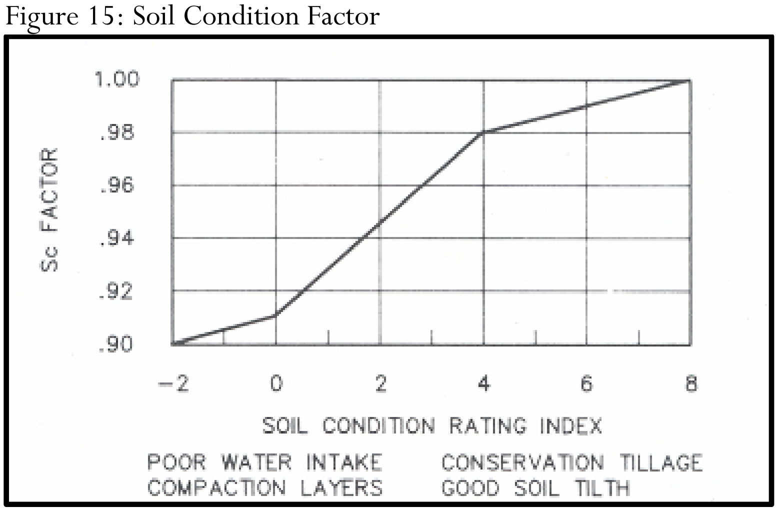


Farms in this study were defined as Rotation-Modified Frequency due to the following practices:

- Fort Lyon Canal Company utilizes a rotational water delivery method with a fixed duration to FLCC shareholders,
- Frequency of irrigation events is variable due to fluctuating river flows as well as demand from other water rights and other shareholders on the Fort Lyon Canal.

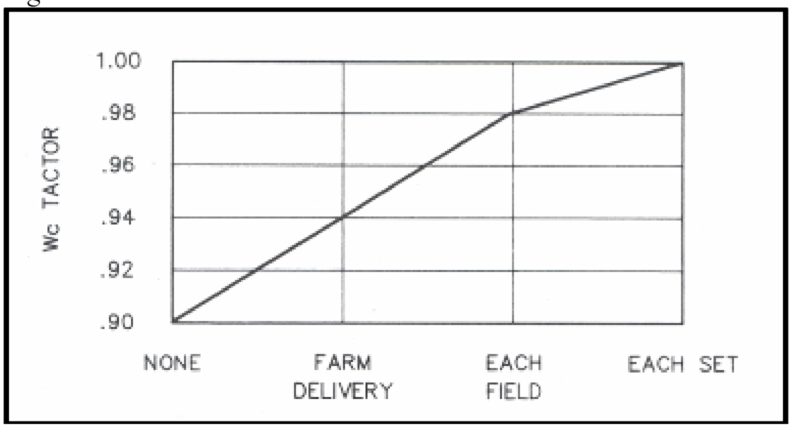
Soil Condition Factor (S_c) - The Soil Condition Factor is used to correlate tillage/conservation practices with water intake rate for soils on a farm. The Soil Condition Factor increases in value for farming practices that promote high water intake and retention. Farms in this study were assigned S_C values ranging from 0.97 to 0.99 based on type of tillage performed and amount of crop residue retained.

Figure 15: Soil Condition Factor



Water Distribution Control Factor (W_c) - The Water Distribution Control Factor assesses whether adequate flow control structures (including division boxes and check dams) are in place to regulate the flow of water to the farm, the fields and each set.

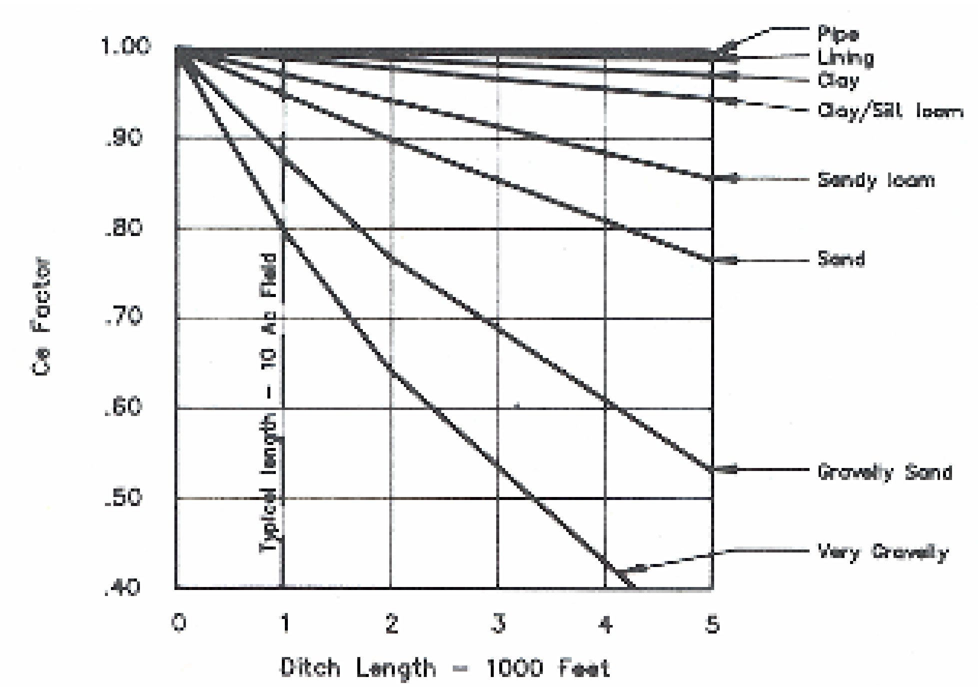
Figure 16: Water Distribution Control Factor



All farms in the study utilized on-farm division boxes and check dams to regulate water to each set. Additionally, irrigation flow to each farm was regulated at the lateral division point by FLCC personnel at least twice daily.

Conveyance Efficiency Factor (C_e) - The Conveyance Efficiency Factor is an estimate of seepage losses through on-farm irrigation ditches. The FIRI model can estimate the C_e factor based on farm channel length and type of channel bed (lined/unlined, soil type). For the farms in this study, the appropriate lengths of lined channel (pipe, concrete ditch) and unlined ditch were entered into the FIRI model for each farm. For unlined channels, a clay soil type was used.

Figure 17: Conveyance Efficiency Factor



Material	EFF
Very Gravelly	0.80
Gravelly Sand	0.88
Sand	0.95
Sandy Loam	0.97
Clay/Silt Loam	0.99
Clay	0.995
Lining (Conc & Pipe—coupled)	0.998
Pipe (cemented, welded)	0.999

Conveyance Efficiency maybe computed by the following:

C_e = (EFF)power in 1000's feet of length

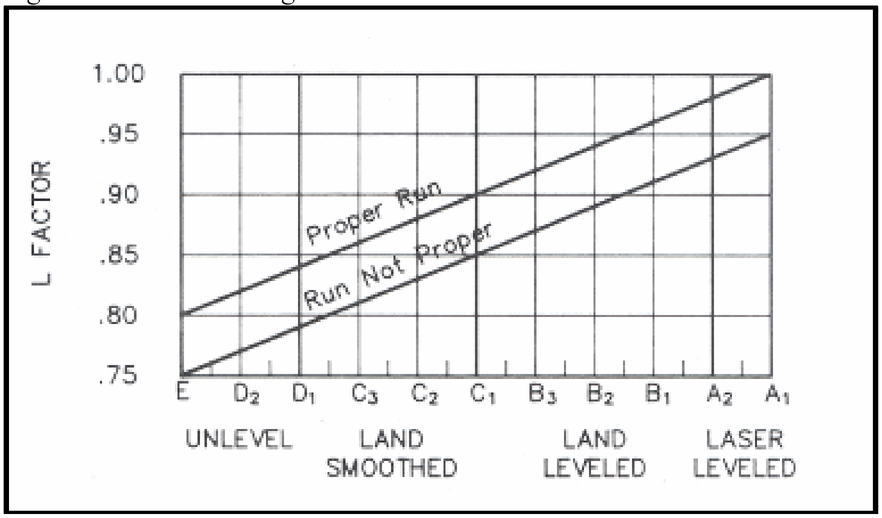
Example:

1500 LF in Gravelly Sand

$C_e = (0.88)^{1.5} = \underline{.82}$

Land Leveling Factor (L) - The Land Leveling Factor is used to represent the uniformity of irrigation application through evaluation of farm slopes and run lengths (distances).

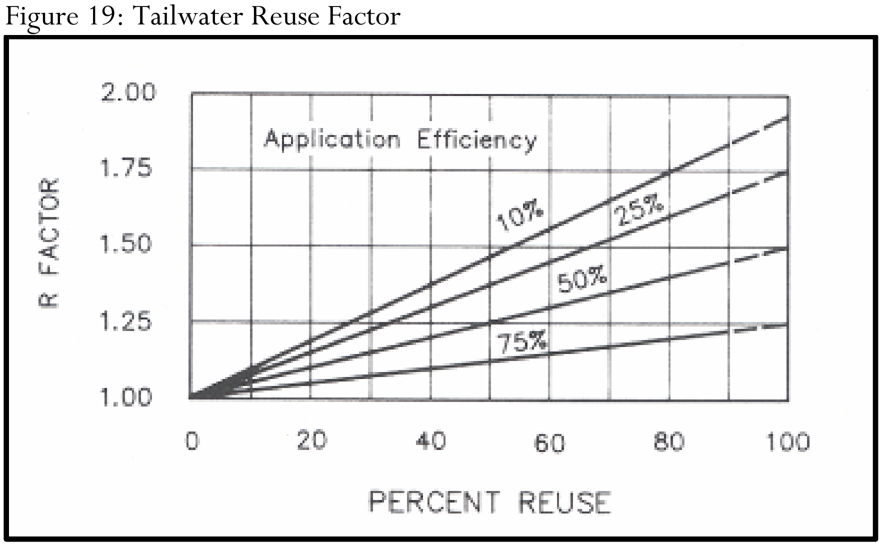
Figure 18: Land Leveling Factor



The FIRI model quantifies the Land Leveling Factor by classifying the irrigation slope (as >.05% or <=.05%) and cross slope (as <.3%, between .3% and .5%, and >=.5%) as well as proper length of set run which is defined as an advance time of 1/4 to 1/3 of the set time. All study farms were considered as uniform irrigation slope (>.05%) and uniform cross slope (>=.05%) with improper run lengths and surface category of C3.

Tailwater Reuse Factor (R) - The Tailwater Reuse Factor is used to account for the fraction of tailwater a field or farm produces that can be reused. For study farms this reuse generally occurred on down-gradient, adjacent fields and farms. The percentage of farm acres where tailwater reuse could occur was tabulated and multiplied by PE and TW (assumed as 9.65% from the H-I model). This value was rounded to the nearest 10% value and applied to the FIRI model to produce Tailwater Reuse Factor R. Percent reuse on study farms ranged from 7.4% to 20.2% resulting in R factors ranging from 1.05 to 1.09.

Figure 19: Tailwater Reuse Factor



IV.c. FIRI Results

The Management and System Design Factors that were estimated for each study farm along with calculated FIRI Rating Values are shown in Table 22 below.

Table 22: FIRI Factors and Results

			FARM ID									
			M1	M2	M3	M3B	M4	M5	S1	S2	S3	S4
System	Potential Efficiency		75%	75%	75%	75%	75%	75%	75%	75%	75%	75%
Mgmt. Factors	Measurement	M_d	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93
	Scheduling	S	0.95	0.94	0.95	0.95	0.95	0.95	0.95	0.95	0.94	0.94
	Skill	I	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
	Maintenance	M	1.00	0.90	0.98	0.98	1.00	1.00	1.00	1.00	0.94	0.94
	Delivery	D	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
	Soil	S_c	0.99	0.97	0.98	0.98	0.99	1.00	0.99	0.99	0.97	0.97
System Design Factors	Water Distribution Control	W_c	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Conveyance	C_e	0.98	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98
	Land Leveling	L	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81
	Tailwater reuse	R	1.09	1.09	1.05	1.05	1.09	1.05	1.05	1.09	1.09	1.05
FIRI Rating Value			**59.7%**	**58.2%**	**57.2%**	**57.2%**	**59.7%**	**57.3%**	**57.3%**	**59.7%**	**59.0%**	**56.5%**

IV.d. FIRI Conclusions

While the FIRI method appears to be a useful tool in comparing irrigation evaluation factors from year to year on a single farm, application of the method to the H-I or ISAM models for use as Maximum Farm Efficiency seems inappropriate due to the following reasons:

1) MFE acts as an upper limit to irrigation water consumption in the soil-water budget while FIRI values reflect average, yearly irrigation efficiencies.
2) FIRI is subjective in nature in that it involves the estimation of eleven independent factors (for flood irrigation systems) while MFE can be measured/modeled using known amounts of application and tailwater and estimated deep percolation.
3) FIRI is very sensitive to Potential Irrigation Efficiency Factor (PE) which requires an initial estimation of MFE.
4) FIRI does not take into account crop rooting depths or crop evapotranspiration which are necessary in understanding deep percolation amounts. The lack of crop type/root depth in FIRI suggests that FIRI is ultimately intended for year-to-year comparison on a single farm where cropping patterns are assumed to remain constant and have no effect on irrigation efficiency.

V. Evaluation of Potential Phase II of Project

While quantification of MFE requires an understanding of both tailwater fraction and deep percolation, measured TWF values that are significantly lower than assumed values may be an indication that MFE is underestimated for the Fort Lyon Canal in the H-I and ISAM models. Measured TWF values of 5.30% and 4.07% during 2015 and 2016 are less than the 9.65% used within the H-I model domain and occurred during years of above average diversions by the Fort Lyon Canal.

For these reasons, it is recommended that a more detailed irrigation efficiency evaluation take place within the Fort Lyon Canal to gain a full understanding of the interaction between tailwater, deep percolation, and farm efficiency in order to verify the accuracy of all three factors in the H-I and ISAM models.

VI. Appendices

VI.a. Appendix A: FIRI Factor Reasoning and Notes by Farm

Farm ID:	**M1**
Factor	**Factor Reasoning and Notes**
PE	Alfalfa fields corrugated using 22" Muth marker; milo fields planted in shallow rows on 10" spacing.
$\mathbf{M_d}$	Flow measurement occurs at beginning of lateral near headgate. Manual readings taken daily.
S	Irrigation scheduling based on combination of delivery records, daily crop water use values from local radio, and observation of crop stress.
I	Irrigator checks sets several times daily and typically changes sets within one hour following advance to field bottom. No defined IWM plan in place.
M	On-farm conveyance ditches are frequently mowed and cleaned of sediment during irrigation season.
D	Water delivered on a rotational basis with fixed flow rate, fixed duration, and variable frequency during irrigation season.
$\mathbf{S_c}$	Cons. tillage utilized with approx. 25% former crop residue remaining on soil surface. Disk-ripper used annually on spring crops to shatter any subsurface soil hard pan layer.
$\mathbf{W_c}$	Concrete divide boxes utilized on farm to regulate diversions amongst fields. Steel drop-checks and canvas dams used to regulate and divert water onto fields through earthen cutouts.
$\mathbf{C_e}$	Conveyance factors calculated for both open ditch-lined (concrete) and open ditch-clay soils by averaging shortest and longest ditch length for each scenario.
L	Irrigation slope and cross-slopes fairly uniform with slopes >0.05% and >0.5% respectively. Advance time often 75% to 100% of set time in order to minimize tailwater runoff.
R	%TW Reuse = Recapturable Amount/(Deep Perc Amount + TW Amount)
	**H-I Model assumptions used for Deep Perc Amount (25%) and TW Amount (9.5%)
	**Tailwater reuse occurs on approximately 72% of farm acreage by recapture through down-gradient ditches.
	**Recapturable Amount assumed to equal 72% times 75% (Application Efficiency).

Farm ID:	**M2**
Factor	**Factor Reasoning and Notes**
PE	Alfalfa fields corrugated using 30" Muth marker; sorghum fields planted in shallow 10" furrows.
M_d	Flow measurement occurs at beginning of lateral near headgate. Manual readings taken daily.
S	Irrigation scheduling based on observation of crop stress.
I	Irrigator checks sets several times daily and typically changes sets within one hour following advance to field bottom. No defined IWM plan in place.
M	On-farm conveyance ditches are occasionally mowed and cleaned of sediment during irrigation season.
D	Water delivered on a rotational basis with fixed flow rate, fixed duration, and variable frequency during irrigation season.
S_c	Moderate tillage techniques (disking) utilized with small amount of former crop residue remaining on soil surface.
W_c	Concrete divide boxes utilized to regulate diversions amongst fields. Steel drop-checks and canvas dams used to regulate water onto fields through earthen cutouts.
C_e	Conveyance efficiency factor calculated for open ditch-clay soils by averaging shortest and longest ditch length.
L	Irrigation slope and cross-slopes fairly uniform with slopes >0.05% and >0.5% respectively. Advance time 75% to 100% of set time to minimize tailwater runoff.
R	%TW Reuse = Recapturable Amount/(Deep Perc Amount + TW Amount)
	**H-I Model assumptions used for Deep Perc Amount (25%) and TW Amount (9.5%)
	**Tailwater reuse occurs on approximately 64% of farm acreage by recapture through down-gradient ditches.
	**Recapturable Amount assumed to equal 64% times 75% (Application Efficiency)

Farm ID:	M3
Factor	**Factor Reasoning and Notes**
PE	Alfalfa fields corrugated using 30" Muth marker; Milo fields planted in 30" furrows.
M_d	Flow measurement occurs at beginning of lateral near headgate. Manual readings taken daily.
S	Irrigation scheduling based on combination of delivery records, daily crop water use values from local radio, and observation of crop stress.
I	Irrigator checks sets several times daily and typically changes sets within one hour following advance to field bottom. No defined IWM plan in place.
M	On-farm conveyance ditches are periodically mowed and cleaned of sediment during irrigation season.
D	Water delivered on a rotational basis with fixed flow rate, fixed duration, and variable frequency during irrigation season.
S_c	Moderate tillage utilized with small amount of crop residue left on soil surface. Ripper used on spring crop ground to shatter subsurface soil hard pan layer.
W_c	Concrete divide boxes utilized to regulate diversions amongst fields. Steel drop-checks and canvas dams used to regulate water onto fields through earthen cutouts.
C_e	Conveyance efficiency factor calculated for open ditch-clay soils by averaging shortest and longest ditch length.
L	Irrigation slope and cross-slopes fairly uniform with slopes >0.05% and >0.5% respectively. Advance time 75% to 100% of set time to minimize tailwater runoff.
R	%TW Reuse = Recapturable Amount/(Deep Perc Amount + TW Amount)
	**H-I Model assumptions used for Deep Perc Amount (25%) and TW Amount (9.5%)
	**Tailwater reuse occurs on approximately 60% of farm acreage by recapture through down-gradient ditches.
	**Recapturable Amount assumed to equal 60% times 75% (Application Efficiency)

Farm ID:	M3B
Factor	**Factor Reasoning and Notes**
PE	Alfalfa fields corrugated using 30" Muth marker; Milo fields planted in 30" furrows.
M_d	Flow measurement occurs at beginning of lateral near headgate. Manual readings taken daily.
S	Irrigation scheduling based on combination of delivery records, daily crop water use values from local radio, and observation of crop stress.
I	Irrigator checks sets several times daily and typically changes sets within one hour following advance to field bottom. No defined IWM plan in place.
M	On-farm conveyance ditches are periodically mowed and cleaned of sediment during irrigation season.
D	Water delivered on a rotational basis with fixed flow rate, fixed duration, and variable frequency during irrigation season.
S_c	Moderate tillage utilized with small amount of crop residue left on soil surface. Ripper used on spring crop ground to shatter subsurface soil hard pan layer.
W_c	Concrete divide boxes utilized to regulate diversions amongst fields. Steel drop-checks and canvas dams used to regulate water onto fields through earthen cutouts.
C_e	Conveyance efficiency factor calculated for open ditch-clay soils by averaging shortest and longest ditch length.
L	Irrigation slope and cross-slopes fairly uniform with slopes >0.05% and >0.5% respectively. Advance time 75% to 100% of set time to minimize tailwater runoff.
R	%TW Reuse = Recapturable Amount/(Deep Perc Amount + TW Amount)
	**H-I Model assumptions used for Deep Perc Amount (25%) and TW Amount (9.5%)
	**Tailwater reuse occurs on approximately 62% of farm acreage by recapture through down-gradient ditches.
	**Recapturable Amount assumed to equal 62% times 75% (Application Efficiency)

Farm ID:	M4
Factor	**Factor Reasoning and Notes**
PE	Alfalfa and wheat fields corrugated using 22" Muth marker; Milo fields planted in shallow rows on 10" spacing
M_d	Flow measurement occurs at beginning of lateral near headgate. Manual readings taken daily.
S	Irrigation scheduling based on combination of delivery records, daily crop water use values from local radio, and observation of crop stress.
I	Irrigator checks sets several times daily and typically changes sets within one hour following advance to field bottom. No defined IWM plan in place.
M	On-farm conveyance ditches are frequently mowed and cleaned of sediment during irrigation season.
D	Water delivered on a rotational basis with fixed flow rate, fixed duration, and variable frequency during irrigation season.
S_c	Conservation tillage utilized with approx. 25% crop residue remaining on soil surface. Disk-ripper used annually on spring crops. No-till often used on wheat.
W_c	Concrete divide boxes utilized to regulate diversions amongst fields. Steel drop-checks and canvas dams used to regulate water onto fields through earthen cutouts.
C_e	Conveyance factors calculated for open ditch-lined, open ditch-clay soils, and closed conduit pipeline by averaging shortest and longest length for each scenario.
L	Irrigation slope and cross-slopes fairly uniform with slopes >0.05% and >0.5% respectively. Advance time 75% to 100% of set time to minimize tailwater runoff.
R	%TW Reuse = Recapturable Amount/(Deep Perc Amount + TW Amount)
	**H-I Model assumptions used for Deep Perc Amount (25%) and TW Amount (9.5%)
	**Tailwater reuse occurs on approximately 98% of farm acreage by recapture through down-gradient ditches.
	**Recapturable Amount assumed to equal 98% times 75% (Application Efficiency)

Farm ID:	M5
Factor	**Factor Reasoning and Notes**
PE	Alfalfa fields corrugated using 30" Muth marker; Corn fields planted at 30" spacing using strip-till beds.
M_d	Flow measurement occurs at beginning of lateral near headgate. Manual readings taken daily.
S	Irrigation scheduling based on combination of delivery records, daily crop water use values from local radio, and observation of crop stress.
I	Irrigator checks sets several times daily and typically changes sets within one hour following advance to field bottom. No defined IWM plan in place.
M	On-farm conveyance ditches are frequently mowed and cleaned of sediment during irrigation season.
D	Water delivered on a rotational basis with fixed flow rate, fixed duration, and variable frequency during irrigation season.
S_c	Strip-till techniques utilized on all ground with approximately 75% former crop residue remaining on soil surface.
W_c	Concrete divide boxes utilized to regulate diversions amongst fields. Steel drop-checks and canvas dams used to regulate water onto fields through earthen cutouts.
C_e	Conveyance factors calculated for both open ditch-lined (concrete) and open ditch-clay soils by averaging shortest and longest ditch length for each scenario.
L	Irrigation slope and cross-slopes fairly uniform with slopes >0.05% and >0.5% respectively. Advance time 75% to 100% of set time to minimize tailwater runoff.
R	%TW Reuse = Recapturable Amount/(Deep Perc Amount + TW Amount)
	**H-I Model assumptions used for Deep Perc Amount (25%) and TW Amount (9.5%)
	**Tailwater reuse occurs on approximately 56% of farm acreage by recapture through down-gradient ditches.
	**Recapturable Amount assumed to equal 56% times 75% (Application Efficiency)

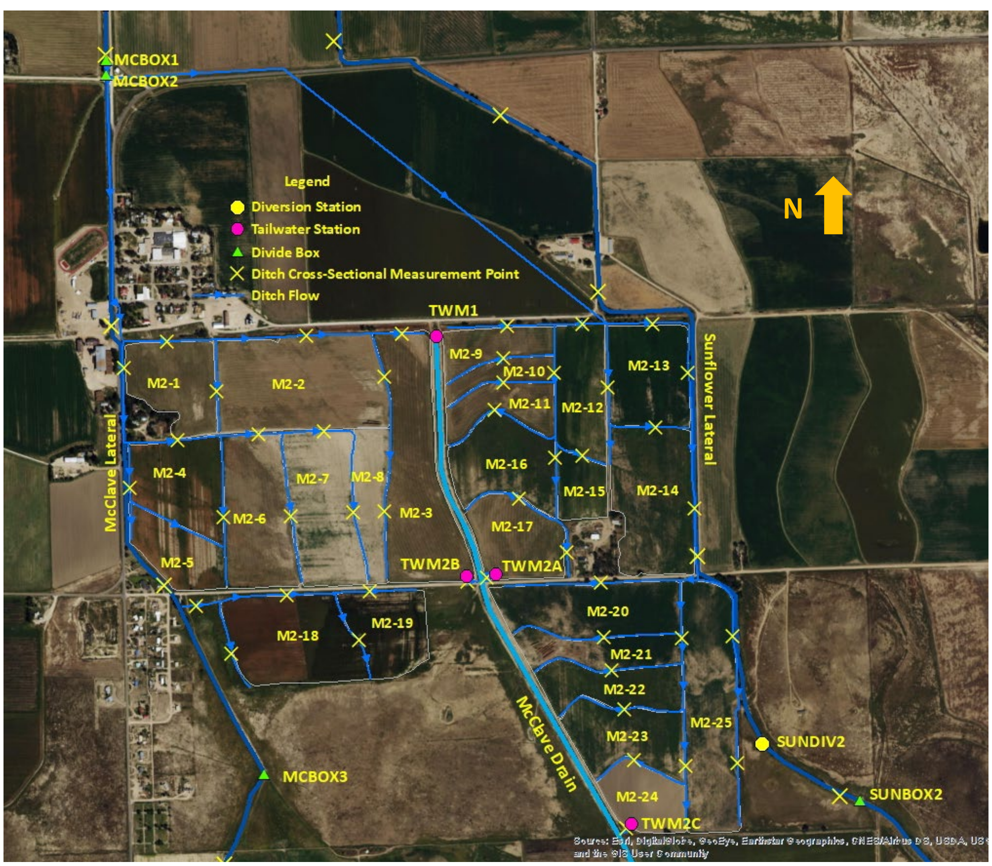
Farm ID:	S1
Factor	**Factor Reasoning and Notes**
PE	Alfalfa fields corrugated using 22" Muth marker; Milo fields planted in shallow rows on 10" spacing
M_d	Flow measurement occurs at beginning of lateral near headgate. Manual readings taken daily.
S	Irrigation scheduling based on combination of delivery records, daily crop water use values from local radio, and observation of crop stress.
I	Irrigator checks sets several times daily and typically changes sets within one hour following advance to field bottom. No defined IWM plan in place.
M	On-farm conveyance ditches are frequently mowed and cleaned of sediment during irrigation season.
D	Water delivered on a rotational basis with fixed flow rate, fixed duration, and variable frequency during irrigation season.
S_c	Conservation tillage utilized with approximately 25% crop residue remaining on soil surface. Disk-ripperused annually on spring crops.
W_c	Concrete divide boxes utilized to regulate diversions amongst fields. Steel drop-checks and canvas dams used to divert water onto fields through earthen cutouts.
C_e	Conveyance factors calculated for both open ditch-lined (concrete) and open ditch-clay soils by averaging shortest and longest ditch length for each scenario.
L	Irrigation slope and cross-slopes fairly uniform with slopes >0.05% and >0.5% respectively. Advance time 75% to 100% of set time to minimize tailwater runoff.
R	%TW Reuse = Recapturable Amount/(Deep Perc Amount + TW Amount)
	**H-I Model assumptions used for Deep Perc Amount (25%) and TW Amount (9.5%)
	**Tailwater reuse occurs on approximately 80% of farm acreage by recapture through down-gradient ditches.
	**Recapturable Amount assumed to equal 80% times 75% (Application Efficiency)

Farm ID:	S2
Factors	**Factor Reasoning and Notes**
PE	Alfalfa fields corrugated using 22" Muth marker; Milo fields planted in shallow rows on 10" spacing
M_d	Flow measurement occurs at beginning of lateral near headgate. Manual readings taken daily.
S	Irrigation scheduling based on combination of delivery records, daily crop water use values from local radio, and observation of crop stress.
I	Irrigator checks sets several times daily and typically changes sets within one hour following advance to field bottom. No defined IWM plan in place.
M	On-farm conveyance ditches are frequently mowed and cleaned of sediment during irrigation season.
D	Water delivered on a rotational basis with fixed flow rate, fixed duration, and variable frequency during irrigation season.
S_c	Conservation tillage utilized with approximately 25% crop residue remaining on soil surface. Disk-ripper used annually on spring crops.
W_c	Concrete divide boxes utilized to regulate diversions amongst fields. Steel drop-checks and canvas dams used to divert water onto fields through earthen cutouts.
C_e	Conveyance factors calculated for both open ditch-lined (concrete) and open ditch-clay soils by averaging shortest and longest ditch length for each scenario.
L	Irrigation slope and cross-slopes fairly uniform with slopes >0.05% and >0.5% respectively. Advance time 75% to 100% of set time to minimize tailwater runoff.
R	%TW Reuse = Recapturable Amount/(Deep Perc Amount + TW Amount)
	**H-I Model assumptions used for Deep Perc Amount (25%) and TW Amount (9.5%)
	**Tailwater reuse occurs on approximately 80% of farm acreage by recapture through down-gradient ditches.
	**Recapturable Amount assumed to equal 80% times 75% (Application Efficiency)

Farm ID:	S3
Factors	**Factor Reasoning and Notes**
PE	Alfalfa fields corrugated using 30" Muth marker; Sorghum fields planted in shallow 10" furrows
M_d	Flow measurement occurs at beginning of lateral near headgate. Manual readings taken daily.
S	Irrigation scheduling based on observation of crop stress.
I	Irrigator checks sets several times daily and typically changes sets within one hour following advance to field bottom. No defined IWM plan in place.
M	On-farm conveyance ditches are occasionally mowed and cleaned of sediment during irrigation season.
D	Water delivered on a rotational basis with fixed flow rate, fixed duration, and variable frequency during irrigation season.
S_c	Moderate tillage techniques (disking) utilized with small amount of former crop residue remaining on soil surface.
W_c	Concrete divide boxes utilized to regulate diversions amongst fields. Steel drop-checks and canvas dams used to divert water onto fields through earthen cutouts.
C_e	Conveyance efficiency factor calculated for open ditch-clay soils by averaging shortest and longest ditch length.
L	Irrigation slope and cross-slopes fairly uniform with slopes >0.05% and >0.5% respectively. Advance time 75% to 100% of set time to minimize tailwater runoff.
R	%TW Reuse = Recapturable Amount/(Deep Perc Amount + TW Amount)
	**H-I Model assumptions used for Deep Perc Amount (25%) and TW Amount (9.5%)
	**Tailwater reuse occurs on approximately 73% of farm acreage by recapture through down-gradient ditches.
	**Recapturable Amount assumed to equal 73% times 75% (Application Efficiency)

Farm ID:	S4
Factors	**Factor Reasoning and Notes**
PE	Alfalfa fields corrugated using 30" Muth marker; Sorghum fields planted in shallow 10" furrows
M_d	Flow measurement occurs at beginning of lateral near headgate. Manual readings taken daily.
S	Irrigation scheduling based on observation of crop stress.
I	Irrigator checks sets several times daily and typically changes sets within one hour following advance to field bottom. No defined IWM plan in place.
M	On-farm conveyance ditches are occasionally mowed and cleaned of sediment during irrigation season.
D	Water delivered on a rotational basis with fixed flow rate, fixed duration, and variable frequency during irrigation season.
S_c	Moderate tillage techniques (disking) utilized with small amount of former crop residue remaining on soil surface.
W_c	Concrete divide boxes utilized to regulate diversions amongst fields. Steel drop-checks and canvas dams used to divert water onto fields through earthen cutouts.
C_e	Conveyance efficiency factor calculated for open ditch-clay soils by averaging shortest and longest ditch length.
L	Irrigation slope and cross-slopes fairly uniform with slopes >0.05% and >0.5% respectively. Advance time 75% to 100% of set time to minimize tailwater runoff.
R	%TW Reuse = Recapturable Amount/(Deep Perc Amount + TW Amount)
	**H-I Model assumptions used for Deep Perc Amount (25%) and TW Amount (9.5%)
	**Tailwater reuse occurs on approximately 64% of farm acreage by recapture through down-gradient ditches.
	**Recapturable Amount assumed to equal 64% times 75% (Application Efficiency)

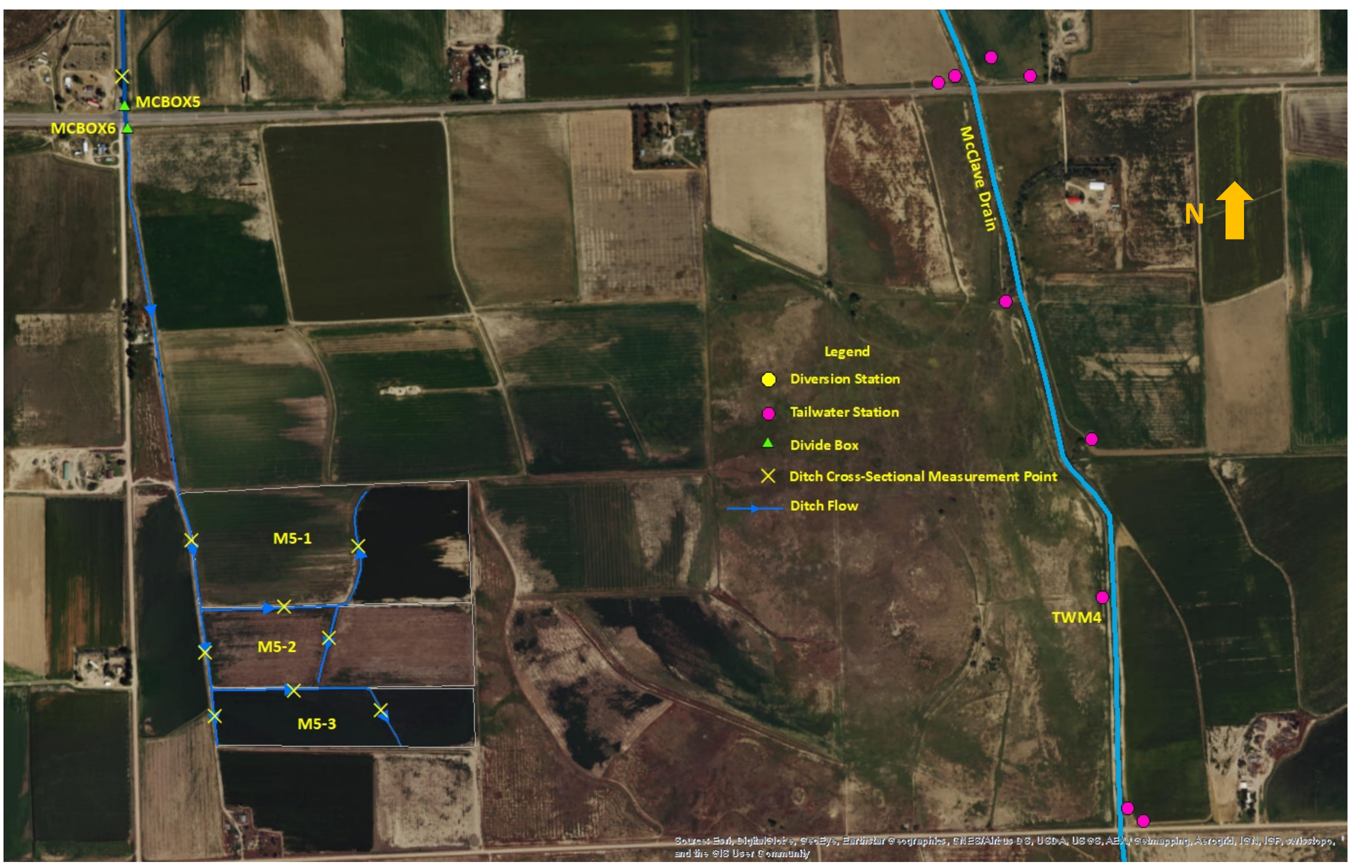
VI.b. Appendix B: Farm Maps

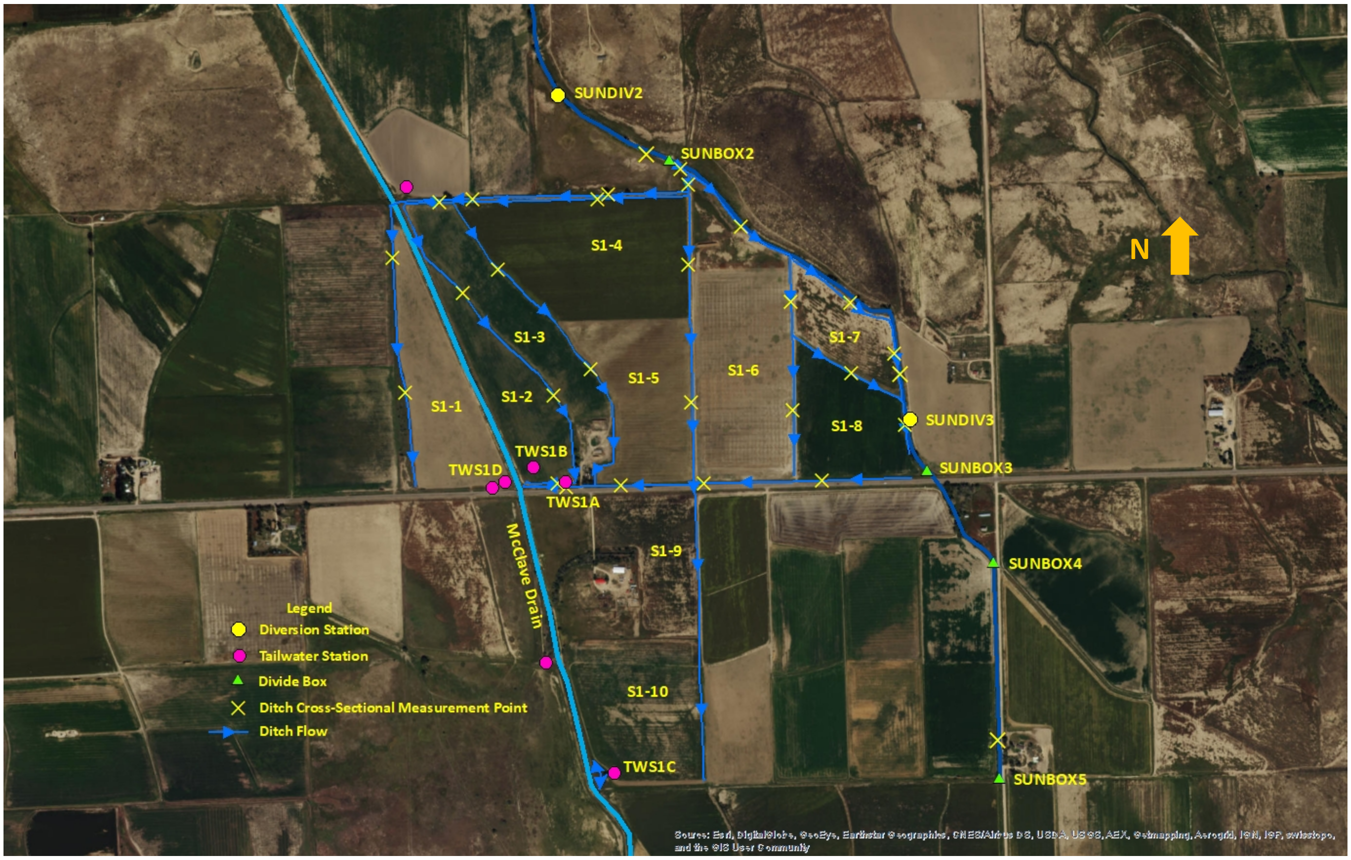


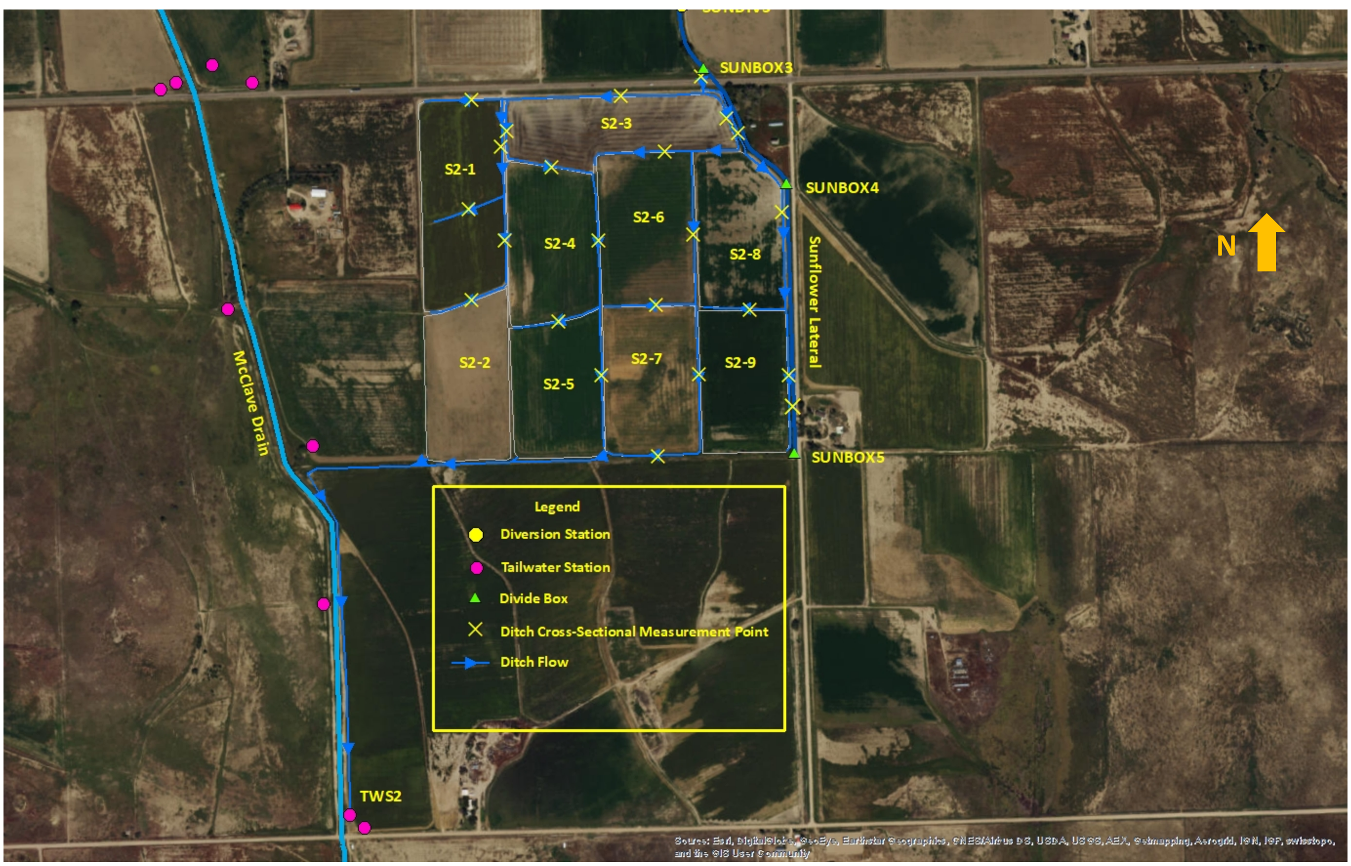

MCBOX3
MCBOX4
MCBOX5
MCBOX6
M3-1
M3-2
M3-3
McClave Drain
N
TWM3
Legend
Diversion Station
Tailwater Station
Divide Box
Ditch Cross-Sectional Measurement Point
Ditch Flow

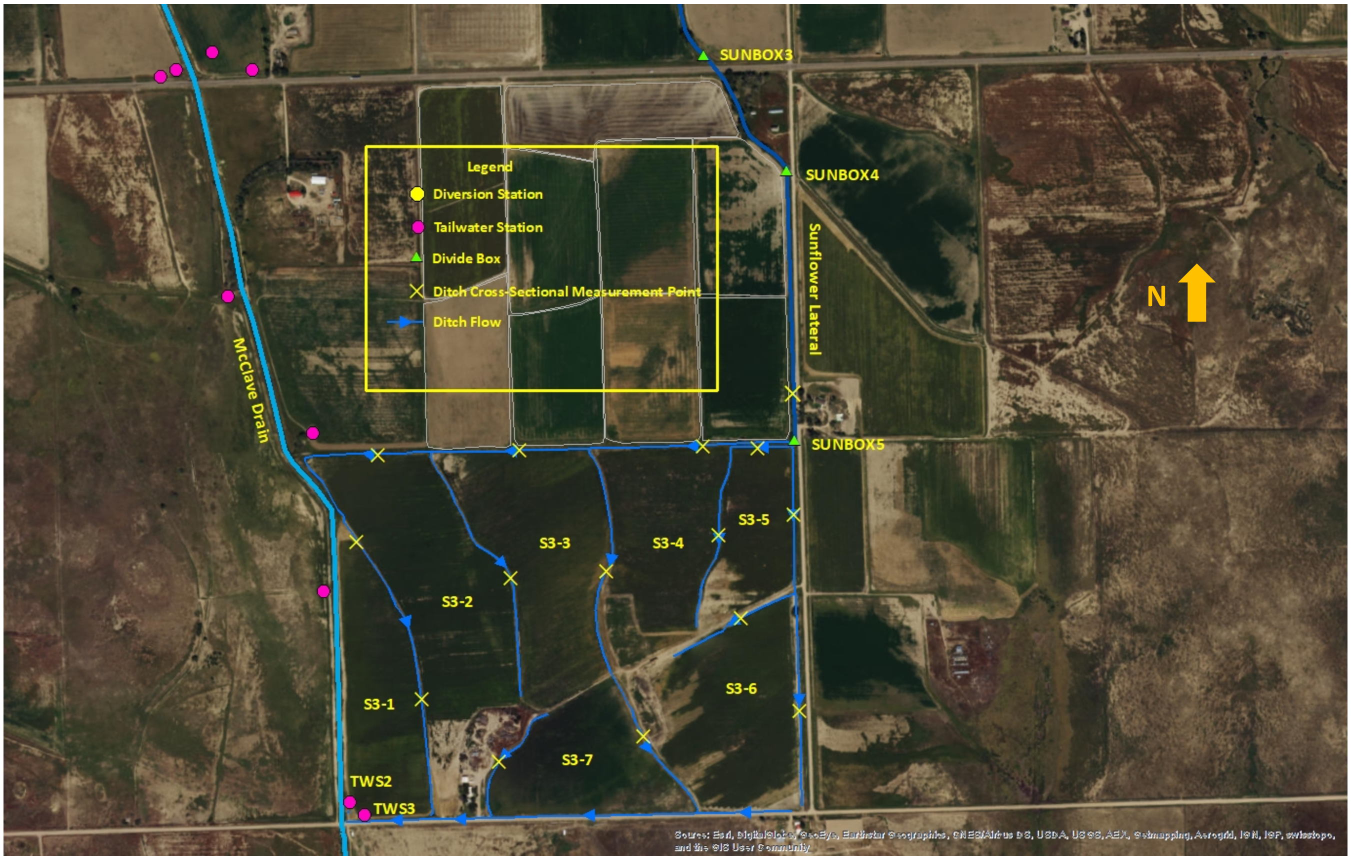

MCBOX3
MCBOX4
MCBOX5
MCBOX6
M3-2
M3-3
M3B-1
M3B-2
M3B-3
M3B-4
M3B-5
McClave Drain
N
TWM3
Legend
Diversion Station
Tailwater Station
Divide Box
Ditch Cross-Sectional Measurement Point
Ditch Flow

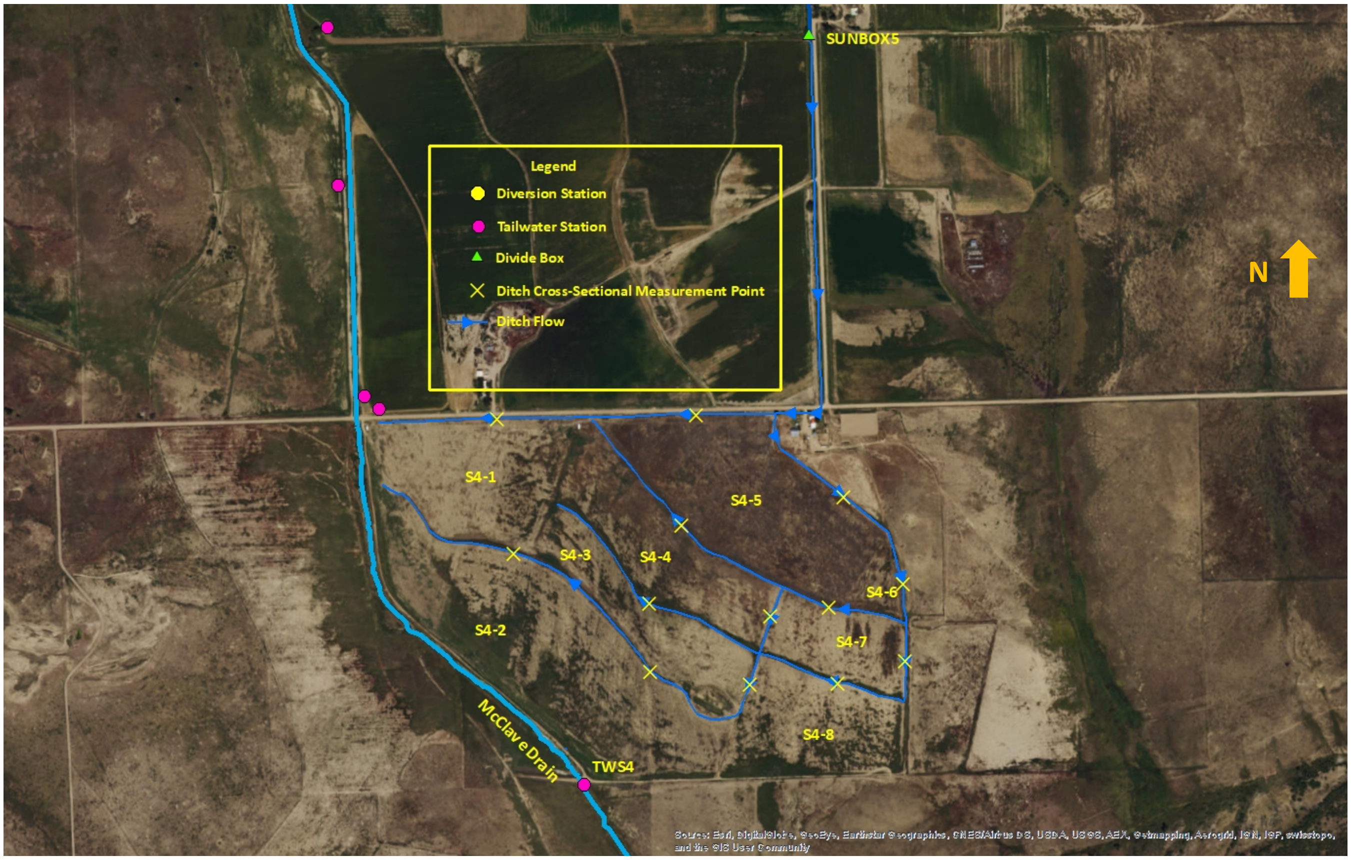

MCBOX5
MCBOX6
M4-1
M4-2
M4-3
M4-4
M4-5
M4-6
M4-7
M4-8
M4-9
M4-10
M4-12
M4-13
M4-14
McClave Drain
TWM4B
TWM4
S2-1
S2-2
N
Legend
Diversion Station
Tailwater Station
Divide Box
Ditch Cross-Sectional Measurement Point
Ditch Flow


MCBOX5
MCBOX6
M5-1
M5-2
M5-3
McClave Drain
TWM4
N
Legend
Diversion Station
Tailwater Station
Divide Box
Ditch Cross-Sectional Measurement Point
Ditch Flow


SUNDIV2
SUNBOX2
N
S1-4
S1-3
S1-5
S1-6
S1-7
S1-1
S1-2
S1-8
SUNDIV3
TWS1B
TWS1D
SUNBOX3
TWS1A
McClave Drain
S1-9
SUNBOX4
Legend
Diversion Station
Tailwater Station
Divide Box
Ditch Cross-Sectional Measurement Point
Ditch Flow
S1-10
TWS1C
SUNBOX5
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community


SUNBOX3
S2-3
S2-1
SUNBOX4
S2-6
S2-4
S2-8
N
Sunflower Lateral
McClave Drain
S2-2
S2-7
S2-9
S2-5
SUNBOX5
Legend
Diversion Station
Tailwater Station
Divide Box
Ditch Cross-Sectional Measurement Point
Ditch Flow
TWS2
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community


SUNBOX3
SUNBOX4
Legend
Diversion Station
Tailwater Station
Divide Box
Ditch Cross-Sectional Measurement Point
Ditch Flow
Sunflower Lateral
McClave Drain
N
SUNBOX5
S3-5
S3-3
S3-4
S3-2
S3-6
S3-1
S3-7
TWS2
TWS3


SUNBOX5
Legend
Diversion Station
Tailwater Station
Divide Box
Ditch Cross-Sectional Measurement Point
Ditch Flow
N
S4-1
S4-5
S4-3
S4-4
S4-6
S4-2
S4-7
S4-8
McClave Drain
TWS4