AGRICULTURAL WATER MANAGEMENT PLAN

2020 Update

FOR THE

MODESTO IRRIGATION DISTRICT

Prepared Pursuant to Water Code Section 10826

Adopted March 23, 2021

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List of Abbreviations & Acronyms

AB	Assembly Bill
AF	acre-feet
ASO	Airborne Snow Observatory
AWMP	Agricultural Water Management Plan
CCR	California Code of Regulations
CCSF	City and County of San Francisco
cfs	cubic feet per second
CIMIS	California Irrigation Management Information System
CNF	Computed natural flow
CVRWQCB	Central Valley Regional Water Quality Control Board
CWRMP	Comprehensive Water Resources Management Plan
DPRA	Don Pedro Recreation Agency
DSS	Decision Support System
DWR	Department of Water Resources
ET	Evapotranspiration
ET_c	Crop evapotranspiration
ET_o	Reference evapotranspiration
EWMP	Efficient Water Management Practice
FERC	Federal Energy Regulatory Commission
JPL	Jet Propulsion Laboratory
GIS	Geographic Information System
GSA	Groundwater Sustainability Agency
GSP	Groundwater Sustainability Plan
ID	Improvement District
ILRP	Irrigated Lands Regulatory Program
IRGWMP	Integrated Regional Groundwater Management Plan
ITRC	Irrigation Training and Research Center
M&I	Municipal and Industrial
METRIC	Mapping of ET with Internal Calibration
MID	Modesto Irrigation District
MRWTP	Modesto Regional Water Treatment Plant
NPDES	National Pollution Discharge Elimination System
O&M	Operation and Maintenance
OID	Oakdale Irrigation District
PEIR	Programmatic Environmental Impact Report
PRMS	Precipitation Runoff Modeling System
QC/QA	Quality Control/Quality Assurance
SB	Senate Bill
SBx7-7	Water Conservation Act of 2009
SCADA	Supervisory Control and Data Acquisition
SFPUC	San Francisco Public Utility Commission
SGMA	Sustainable Groundwater Management Act
SSJID	South San Joaquin Irrigation District
STRGBA	Stanislaus and Tuolumne Rivers Groundwater Basin Association
SWRCB	State Water Resources Control Board
TDS	Total Dissolved Solids
TID	Turlock Irrigation District
USACE	U.S. Army Corps of Engineers
USGS	United States Geological Survey
UWMP	Urban Water Management Plan
VAMP	Vernalis Adaptive Management Plan
WSID	West Stanislaus Irrigation District

Section I: Introduction

This Modesto Irrigation District (MID or District) Agricultural Water Management Plan (AWMP) is an update of the District's 2015 AWMP and has been prepared in accordance with the requirements of the Water Conservation Act of 2009 (SBx7-7), the associated Agricultural Water Management Planning Act (Section 1, Part 2.8, Division 6 of the Water Code), the Agricultural Water Measurement Regulation (Title 23 California Code of Regulations, AB 1668 Water Management Planning (Friedman, Statute of 2018), and conforms to the framework presented in *A Guidebook to Assist Agricultural Water Suppliers to Prepare a 2020 Agricultural Water Management Plan* (2020 Guidebook) that was issued by the California Department of Water Resources (DWR) as a draft document in August 2020. The District is located in Stanislaus County, east of the San Joaquin River and between the Tuolumne and Stanislaus Rivers, as shown in **Figure 1**.

The 2020 Guidebook includes new requirements for AWMPs pursuant to AB 1668. These new requirements include an annual water budget, identification of water management objectives based on the water budget, quantification of water use efficiency, and detailed drought management plan.

The requirements introduced by SBx7-7 and later by AB 1668 are intended to encourage agricultural water suppliers to assess current efficient water management practices (EWMP), to evaluate additional practices that may conserve water, and to require accurate measurement of water delivered to customers. The AWMP process also presents an opportunity for water suppliers to demonstrate existing accomplishments in water use efficiency as well as anticipated water use efficiency measures.

Included in Section VII of this AWMP is an analysis of each of the EWMPs to be addressed as part of SBx7-7 and as outlined in the 2020 Guidebook prepared by DWR. The EWMPs are grouped into the following categories:

- Critical Efficient Water Management Practices

1. Measure the volume of water delivered to customers with sufficient accuracy to comply with subdivision (a) of California Water Code Section 531.10 and to implement paragraph (2) of the legislation.
2. Adopt a pricing structure for water customers based at least in part on quantity delivered.

- Conditional Efficient Water Management Practices

1. Facilitation of alternative land use for lands with exceptionally high-water duties or whose irrigation contributes to significant problems, including problem drainage.

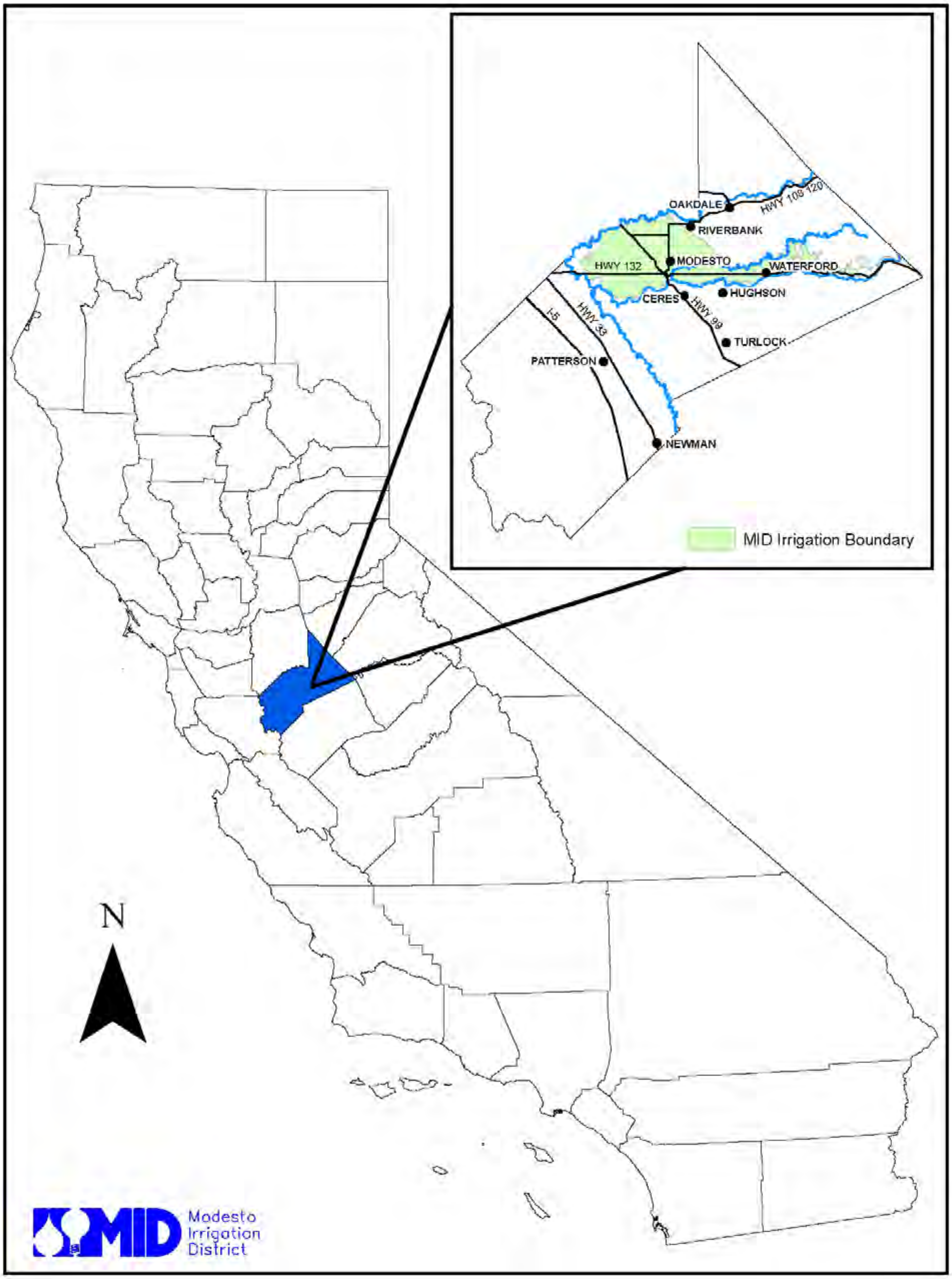


Figure 1 – Location Map of MID and Stanislaus County

2. Facilitation of use of available recycled water that otherwise would not be used beneficially, meets health and safety criteria, and does not harm crops or soils. The use of recycled urban wastewater can be an important element in overall water management.
3. Facilitate the financing of capital improvements for on-farm irrigation systems.
4. Implement an incentive pricing structure that promotes one or more of the following goals:
   A. More efficient water use at the farm level such that it reduces waste;
   B. Conjunctive use of groundwater;
   C. Appropriate increase of groundwater recharge;
   D. Reduction in problem drainage;
   E. Improved management of environmental resources; and
   F. Effective management of all water sources throughout the year by adjusting seasonal pricing structures based on current conditions.
5. Expand lined or piped distribution systems, construct regulatory reservoirs to increase distribution system flexibility and capacity, decrease maintenance, and address seepage when negative impacts exist.
6. Increase flexibility in water ordering by, and delivered to, water customers within operational limits.
7. Construct and operate supplier operational outflow and tailwater systems.
8. Increase planned conjunctive use of surface water and groundwater within the supplier service area.
9. Automate canal control devices.
10. Facilitate or promote customer pump testing and evaluation.
11. Designate a water conservation coordinator who will develop and implement the water management plan and prepare progress reports.
12. Provide for the availability of water management services to water users. These services may include, but are not limited to, the following:
    A. On-farm irrigation and drainage system evaluations;
    B. Normal year and real-time irrigation scheduling and crop evapotranspiration (ETc) information;
    C. Pilot Program for online water ordering;
    D. Surface water, groundwater, and drainage water quantity and quality data; and
    E. Agricultural water management educational programs and materials for irrigators.

13. Evaluate the policies of agencies that provide the supplier with water to identify the potential for institutional change to allow more flexible water deliveries and storage.
14. Evaluate and improve the efficiencies of the suppliers' pumps.
15. Evaluate and streamline operations as necessary.
16. Seek potential external funding sources for District projects.

1. Description of Previous Water Management Activities

MID and its agricultural water users have implemented many of the EWMPs described in the District's 1999, 2012 and 2015 AWMP's. In addition, numerous water conservation measures beyond those identified in the 1999, 2012 and 2015 AWMP's have been implemented.

A central consideration in the District's determination of how best to implement a program of EWMPs is the District's goal of providing flexible, reliable service to its agricultural water users. Irrigators in MID are transitioning from producing field crops such as alfalfa and grains to permanent crops such as trees and vines. As irrigators transition from field crops to permanent crops and shift toward pressurized, low-volume drip and micro-sprinkler systems, the requirements of customer service are changing.

In addition, regardless of crop mix and on-farm irrigation practices, the District remains committed to maintaining a balance between surface water and groundwater as sources of supply and has pursued pricing policies and operational practices that support conjunctive management. The effort required to sustain groundwater levels and retain the ability to tap this resource during periods of prolonged drought has served the District well and, as discussed later in this AWMP, may serve as an effective mechanism for meeting requirements of the Sustainable Groundwater Management Act (SGMA) and responding to the effects of climate change.

For the reasons described above, when evaluating EWMPs, MID assesses the value of EWMPs as part of a comprehensive package of practices that assist the District in providing a high level of customer service and support conjunctive management. As a result, the District may implement individual EWMPs that are not cost-effective in a narrow sense. However, providing reliable, responsive customer service is essential for maintaining a stable customer base and meeting the changing needs of MID's agricultural water users.

The following section describes some of the practices implemented by the District that are consistent with the principles of the District's AWMP planning efforts:

- Financial Grants: For over 30 years, MID has provided financial support to agricultural water users for the replacement of on-farm water supply ditches and concrete cast-in-place pipelines. The District developed the MID Conservation Program (Program), which provides up to 50% of the cost of eligible projects and also provides low interest loans for the other 50% of the projects' costs to qualifying MID landowners for projects that conserve water and improve water management after the eligible project is completed.

Projects must meet certain eligibility criteria and be pre-approved by MID. The Guidelines (**Appendix F**) provide information on eligible projects, applicant eligibility, available funding, the application process, project ranking criteria, contractual obligations, and the anticipated annual schedule. The Program has occurred annually but is subject to funding and approval by the Board of Directors (Board) on an annual basis.

- Water Measurement Pilot Program. MID has been testing several water measurement devices to determine which are the most suitable and accurate for its irrigation system. The results of the Pilot Program, which collected field data from 2015 to 2018 and is now monitoring the longevity of the devices, are discussed herein. This information will help the District to make an informed decision on appropriate delivery point measurement devices or methods necessary to comply with the measurement requirements of SBx7-7.

- Financial Contributions: MID has made financial contributions to a Mobile Irrigation Lab, operated by the East Stanislaus Resource Conservation District, to evaluate the performance and efficiency of grower's on-farm irrigation systems (MID has paid up to 75 percent of the cost of the irrigation system evaluation). MID has been a partner in the mobile lab project for the past 5 years.

- In-lieu Groundwater Recharge: Historically the City of Modesto relied solely on groundwater to meet its municipal and industrial (M&I) needs. Since 1995, MID has delivered up to 36,600 acre-feet (AF) of treated Tuolumne River water per year to the City of Modesto for M&I uses. With completion of Phase II in 2018, MID can deliver up to to 67,204 AF of treated surface water annually to the City of Modesto or nearly 82% of the City of Modesto's estimated 2045 demand as published in the City of Modesto/MID 2020 Joint Urban Water Management Plan (UWMP).

- Automatic SCADA Controls: Automatic Supervisory Control and Data Acquisition (SCADA) systems have been installed at most of the District's water distribution diversion and operational outflow facilities. The automation of water distribution diversion and operational outflow facilities gives the District greater flexibility to manage the water distribution system and increases the reliability of on-farm water deliveries.

- Crop Water Use Information: MID makes data from the California Irrigation Management Information System (CIMIS) available to water users. CIMIS daily and seasonal crop water use information is available by computer at cimis.water.ca.gov or through MID's website at www.mid.org.

- U.S Geological Survey (USGS) Groundwater Study: MID, through its involvement with the Stanislaus and Tuolumne Rivers Groundwater Basin Association (STRGBA), was instrumental in contracting with the USGS to conduct a basin groundwater study. The 2004 study, entitled "*Hydrogeologic Characterization of the Modesto Area, San Joaquin Valley, California*", provided the District and the other basin water users and suppliers with information regarding the hydrologic structure of the basin. The USGS completed an update to the study in 2015 entitled "*Hydrologic Model of the Modesto Region, California, 1960-2004*". The update includes a three-dimensional groundwater model for the Modesto Groundwater Sub-basin called the MERSTAN model.

- Airborne Snow Observatory: Recent drought conditions and increased regulatory requirements have increased the need for water managers in the Tuolumne River watershed to make better and earlier predictions of inflow patterns. In an attempt to better understand the variability in upcountry snow storage, MID along with TID and the City and County of San Francisco (CCSF) have partnered with the Airborne Snow Observatory, Inc (ASO) and the California Department of Water Resources (DWR). ASO, Inc. uses technology developed by NASA's Jet Propulsion Laboratory (JPL) wherein a LiDAR instrument and imaging spectrometer are mounted on an airplane and flown over the Tuolumne River watershed to measure snow depth, snow water equivalent and snow albedo. The resulting snow depth maps are then coupled with snow density modeling to give snow water equivalent patterns over the Tuolumne River watershed. This technology provides better coverage of the watershed, especially in the higher elevations, than previous snow measurement methods, providing a more accurate runoff forecast. Depending on the amount of snowfall, the ASO has been making bi-weekly or monthly flights usually beginning in early spring through the end of runoff season since 2015.

- Water Quality Monitoring and Sampling: MID has a water quality monitoring program and successfully complies with the statewide general NPDES permit for discharge of aquatic herbicides. MID also participates in a water monitoring and sampling program in compliance with the Irrigated Lands Regulatory Program (ILRP) as adopted by the Central Valley Regional Water Quality Control Board (CVRWQCB) as a member of the East San Joaquin Water Quality Coalition. In addition, MID performs annual monitoring of select District groundwater wells.

- Rim Fire Water Quality Monitoring: In August 2013 the Rim Fire (3rd largest in California history) burned approximately 400 square miles of the Tuolumne River watershed. MID and TID partnered with the United States Geological Survey (USGS) to establish a stream gage at Wards Ferry Bridge and conduct extensive water quality monitoring of inflow at Don Pedro Reservoir. Documenting the quantity and quality of water entering the Don Pedro Reservoir, and modeling streamflow changes in response to the fire, gives water managers the tools to understand the cumulative effects of the Rim Fire on future water supplies. Water quality monitoring began in late fall of 2013 and was completed in 2016. USGS published their study in 2019 and can be found at the following link: https://pubs.er.usgs.gov/publication/70203606

- UC Davis Water Quality Study: The MID Domestic Water Treatment Plant entered into an agreement (January 14, 2014) with the University of California Davis (UCD) Watershed Science Center to conduct water quality monitoring and perform laboratory treatability studies to identify the constituents and parameters of greatest concern for the efficacy of water treatment processes and the quality of treated water. This project was completed in 2015 and a report was submitted to MID.

- Water Allocation and Pricing: Consistent with MID's goals, the MID Board of Directors (Board) reviews irrigation water service pricing on an annual basis. The Board’s goal is to maintain a price that encourages surface water use over private groundwater pumping while encouraging efficient water use. The Board elected to increase prices in 2014, 2015 and 2016. The most recent change has included conversion to a pricing structure, based at least in part on the quantity delivered, to encourage water conservation.

- 2020 Urban Water Management Plan (UWMP): MID and the City of Modesto are currently preparing a joint 5-year update to the UWMP in compliance with the Urban Water Management Planning Act. The updated plan will be submitted to DWR by July 2021.

- Well Field Optimization Project: This project by MID and OID, in cooperation with STRGBA, was developed using a DWR-funded grant. The project involved the design and implementation of a computer-aided Decision Support System (DSS) to operate irrigation wells. The DSS was developed as a management tool for implementing the District’s conjunctive use program.

- Comprehensive Water Resources Management Plan: Beginning in 2007, MID embarked on a Comprehensive Water Resources Management Plan (CWRMP) consisting of a variety of recommendations for policy and facility improvements to accommodate current and future water demands. The District’s CWRMP is a multi-phase effort intended to incorporate elements of prior planning efforts, new information, and creative ideas into a comprehensive plan to guide future water management decisions. Decision makers, stakeholders, consultants, and staff benefit from a comprehensive picture of the issues and impacts related to water management in the district. The District’s goals in developing the CWRMP were to:

    1. Address discharge water quality and regulatory risks;
    2. Improve operations efficiency and customer service;
    3. Plan for aging system replacement;
    4. Adapt to technology change;

5. Plan for Federal Energy Regulatory Commission (FERC) relicensing so that the District can provide evidence to support its renewal application and minimize any negative impacts that might result from relicensing decisions; and
6. Understand the options and opportunities available to the District for addressing current and future needs.

MID completed a Programmatic Environmental Impact Report (PEIR) for the CWRMP under a contract with CH2MHill, now Jacobs Engineering Group, Inc. The PEIR is intended to provide a high-level analysis of the potential CWRMP impacts and set the stage for focused individual project specific environmental review as projects warrant and as resources allow. MID completed the PEIR in 2016. While implementation of the CWRMP is contingent upon funding, MID sees benefits in the CWRMP as an effort to identify better methods to manage the District's water resources. Potential funding mechanisms to implement the CWRMP are identified in the PEIR. The CWRMP is currently undergoing CEQA review and is expected to be released for public review in early 2021.

- Main Canal Reservoir Project: In 2020, MID completed the Main Canal Reservoir (MCR) Project, a nearly 300 acre-foot (AF) regulating reservoir located at MID's Lower Main Canal and Lateral 3 Headworks. This facility allows for faster responses to imbalances in the irrigation supplies and customer water demands downstream of Lateral 3 and the Lower Main Canal bifurcation-which accounts for nearly three-quarters of the MID's irrigated acreage.
- Groundwater Replenishment Program: In above-average water years when MID determines that surplus water supplies are available, the District desires to deliver surplus water to actively farmed agricultural lands that are outside of the District service area, but within its sphere of influence (SOI). The groundwater replenishment program is intended to allow some landowners to utilize the surplus surface water in lieu of pumping groundwater, which will increase the beneficial use of the surface water in the area and assist with meeting the requirements of the Sustainable Groundwater Management Act (SGMA). No new District facilities have been constructed as part of this program. Landowners use temporary pipelines, temporary portable pumps, and generators to convey the water from the MID canals to their land.
- As a member of the Stanislaus and Tuolumne Rivers Groundwater Basin Association Groundwater Sustainability Agency (STRGBA GSA), MID is actively participating in efforts toward SGMA compliance. Development of the Modesto Subbasin Groundwater Sustainability Plan is currently the main focus of STRGBA GSA and MID plays a lead role in plan development.

2. Coordination Activities

a) Notification of AWMP Preparation

SBx7-7 requires that each city or county within which the supplier provides water supplies be notified that the AWMP is being prepared but doesn't specifically identify how much advance time is required for notification of cities and counties of the AWMP preparation. SBx7-7 also doesn't require notification to any other agency(s) and doesn't require that comments from any city, county or other agency must be solicited and considered. The District, however, did notify local agencies and the public that the AWMP was being updated as shown in **Table 1. Appendix A** includes documentation on the public noticing of the AWMP preparation and adoption.

b) Public Participation

Public participation activities associated with preparation of the updated AWMP are presented in **Table 1**.

3. AWMP Adoption and Submittal

The purposes of this updated AWMP are to assess MID's current water management operations, provide background with respect to actions taken since the 2015 AWMP, to respond to the provisions of SBx7-7 and AB 1668, and to discuss future actions that may be taken within the next planning horizon. The AWMP adoption and submittal process follows that outlined in the 2020 Guidebook.

a) AWMP Adoption

This 2020 AWMP update has been adopted by the District Board of Directors. **Appendix B** of this document includes a Resolution of AWMP Adoption.

b) AWMP Submittal

The District followed the steps that are described in the 2020 Guidebook for submittal of the AWMP and the process that was followed is outlined in **Table 1**.

c) AWMP Availability

In preparing this AWMP, MID solicited public input by holding a public hearing and inviting oral and written comments prior to adoption of the AWMP at a Board of Director's meeting on March 23rd, 2021. The public hearing was advertised in the Modesto Bee newspaper on March 9th, and March 16th, 2021. A copy of the newspaper notice is found in **Appendix A**. **Table 1** shows the state and local interested parties who were notified about preparation of the updated AWMP. The public hearing was also advertised on the District website. Written comments provided on the AWMP are found in **Appendix H**.

Table 1 – Summary of Coordination, Adoption and Submittal Activities

Potential Interested Parties	Notified of AWMP Preparation	Notified of Public Meetings	Sent Copy of Adopted AWMP
Department of Water Resources	X	X	X
City of Modesto	X	X	
City of Riverbank	X	X	
City of Waterford	X	X	
Turlock Irrigation District	X	X	
Stanislaus County	X	X	
Local Newspaper		March 9th & 16th, 2021	
STRGBA GSA	X	X	
LAFCO	X	X	
City/County Library	X	X	
State Library	X	X	X
MID Website	X	Posted February 19th, 2021	X
Tuolumne River Trust	X	X	
California State University, Stanislaus	X	X	

4. AWMP Implementation Schedule

MID continues to implement EWMPs based upon the implementation plan presented in its original AWMP and refined in later AWMP updates.

Following are MID Capital Projects completed from 2015-2020 (since preparation of the District's 2015 AWMP) that are consistent with the goals and EWMPs in this AWMP.

2015 CAPITAL PROJECTS

1. Dr. Moore Headworks Project

The Dr. Moore Headworks Project (Project) is located on the MID Lower Main Canal near the City of Riverbank. The Dr. Moore Lateral is a secondary irrigation lateral that diverts water from the MID Lower Main Canal. The Project replaced an existing Waterman manual metergate with a 36" Rubicon SlipMeter and SCADA controls to allow for remote changes and monitoring of the lateral. The Project benefits Dr. Moore Lateral customers by both efficiently and accurately providing a steady flow delivery to farm turnouts on the lateral.

2. Butler Ditch Headworks Rehabilitation Project

The Butler Ditch Headworks Rehabilitation Project (Project) is located at the bifurcation of MID Lateral 3 and the Butler Ditch Lateral. This project replaced existing control gates with new Rubicon Flume Gates for each primary lateral and integrated the gates into an existing SCADA control system to allow for better measurement and monitoring of diversions down each lateral.

3. Byrd Well #255

MID continued to improve its well field with the installation of a new irrigation production well known as the Byrd Well #255. This 150 HP well is located at the bifurcation of Waterford Lateral 3 and Waterford Lateral 3B and provides nearly 2,600 gal/min of groundwater as a supplemental water source to the downstream users of both laterals.

4. 2015 Lateral Operational Outflows

MID continued to enhance irrecoverable flow measurement sites for laterals located in the western region of the District. The regulated outflows for the MID Lower Main Canal, MID Lateral 5, MID Lateral 7, MID Lateral 8, and Waterford Lower Main Canal were converted from local monitoring equipment to new remote SCADA monitoring equipment. The Lateral 5 regulated outflow was also upgraded to include water quality measurement.

2016 CAPITAL PROJECTS

1. Lateral 8 Headworks Project

The Lateral 8 Headworks Project (Project) is located on the MID Main Canal near the City of Salida. MID Lateral 8 is a primary irrigation lateral that diverts water from the MID Lower Main Canal. The Project replaced an existing Waterman manual metergate with a 42" Rubicon SlipMeter and SCADA controls to allow for remote changes and monitoring of the lateral. The project benefits Lateral 8 customers by providing a steady regulated flow delivery to farm turnouts on the lateral.

2. Tully Lateral Headworks Weir

The Tully Lateral Headworks Long-Crested Weir Project (Project) replaced a Waterman metergate with a long-crested weir structure at the Tully Lateral Headworks. The bifurcation between the Tully Lateral Headworks and Waterford Lateral 10 originally regulated water with two Waterman metergates causing recoverable water to flow down the Tully Lateral and irrecoverable water to flow down Waterford Lateral 10. Upon completion of the Project most Waterford Lateral 10 upstream flows are now diverted to the Tully Lateral where they are recoverable and discharge into the MID Lower Main Canal.

3. Waterford Lateral 10 Weir

The Waterford Lateral 10 long-crested weir was constructed as a diversion structure in Waterford Lateral 10, The long-crested weir holds a steady water elevation making deliveries more efficient and reliable for upstream water users for this lateral section.

4. 2016 Lateral Operational Outflows

MID continued to enhance irrecoverable flow measurement sites for regulated outflows located in the southern region of the District. The regulated outflows for MID Lateral 1 at the Modesto City-County Airport and MID Lateral 2 were converted from local monitoring equipment to new remote SCADA monitoring equipment.

5. MID Lower Main Canal Lining Project

The MID Lower Main Canal Lining Project (Project) was completed as part of the district's long-term concrete lining maintenance program. The concrete lining program is an ongoing project that is designed to ensure canal structural integrity and address seepage that negatively impacts growers throughout the entire MID canal system. The Project relined 133,000 square feet of MID Lower Main Canal with shotcrete upstream of the MID Lateral 3 Headworks diversion structure.

2017 CAPITAL PROJECTS

1. Waterford Lateral 9 Weir

The existing Waterford Lateral 9 was originally constructed with three (3) independent board slot structures to control water level for 2,700 lineal feet of the lateral. The Waterford Lateral 9 long-crested weir was constructed to replace the board slot structures. The long-crested weir holds a steady water elevation for the upstream water users for the entire 2,700 lineal feet of lateral providing a more reliable and efficient solution.

2. Little Shoemake Pipeline Replacement

The MID Little Shoemake Pipeline replacement removed 814 lineal feet of 36" diameter cast-in-place (CIP) pipeline with 36" polyvinyl chloride (PVC) pipeline. The aging section of the Little Shoemake Pipeline was selected due to significant seepage and structural concerns of the existing CIP pipeline. This project is part of the MID long-term goal to improve pipeline infrastructure in the District.

3. Highline Trenchless Rehabilitation

The MID Highline Trenchless Pipeline Rehabilitation Project (Project) was a pilot construction project to better understand trenchless repair technology as a potential for system wide pipeline rehabilitation in locations where open-cut excavation repairs are not feasible. Cured-in-Place Pipe (CIPP) trenchless rehabilitation was the method of choice for the Project. A felt material flexible pipe was installed using winch inversion, compressed air to expand the pipe to conform to the existing pipeline, and steam to cure the pipe in place. The contractor, SAK Construction LLC, installed 721 lineal feet of CIPP for MID's Highline Lateral Pipeline.

4. New Naegele Well # 256

MID continued to improve its well field with the installation of a new irrigation production well known as the New Naegele Well #256. This 200 HP well is located on the MID Lower Main and provides nearly 2,800 gal/min of groundwater as a supplemental water source to the downstream users on the MID Lower, Lateral 6, Lateral 7, and Lateral 8.

5. Miller Lake SCADA Project

The Miller Lake SCADA Project (Project) upgraded both the inflow and outflow weirs of Miller Lake from local monitoring equipment to new remote SCADA monitoring equipment. Miller Lake is supplied by the MID Canal system by means of the MID Main Drain regulated outlet. MID staff has improved the inflow and outflow monitoring of Miller Lake in an effort to better reclaim recoverable MID outflow to land and wildlife surrounding Miller Lake prior to this water becoming irrecoverable into the Stanislaus River.

2018 CAPITAL PROJECTS

1. Waterford Lateral 3 Headworks

The Waterford Lateral 3 Headworks Project (Project) is located near the Waterford Main Canal near the Modesto Reservoir. Waterford Lateral 3 is a primary irrigation lateral that diverts water from the Waterford Lower Main Canal. The Project replaced an existing manually operated Waterman metergate with a 36" Rubicon SlipMeter and SCADA controls to allow for remote changes and monitoring of the lateral. The project benefits Waterford Lateral 3 customers by providing a steady regulated flow delivery to farm turnouts on the lateral.

2. Waterford Lower Main Pump Automation Project

The Waterford Lower Main Pump Automation Project (Project) upgraded the controls and automated a series of three (3) MID deep wells and two (2) lift pumps located northeast of the City of Waterford. The Project utilizes the automated deep wells and lift pumps to supplement agricultural water delivered to agricultural customers along the lower portion of the Waterford Lower Main. Completion of the Project has resulted in increased water delivery flexibility and reduced operational outflows. The Project was integrated into the Irrigation SCADA system to allow Irrigation Operations staff real-time control and data access via a laptop computer located in each ditchtender vehicle.

3. New Bashor Well # 257

MID continued to improve its well field with the installation of a new irrigation production well known as the New Bashor Well #257. This 200 HP well is located on the Waterford Lower Main and provides nearly 2,600 gal/min of groundwater as a supplemental water source to the downstream users of the Waterford Lower Main.

4. Lateral 3 Drop 48 Weir

The Lateral 3 Drop 48 long-crested weir was constructed as a water level control structure in MID Lateral 3. The long-crested weir holds a steady water height resulting in reliable and constant turnout flow rate for upstream water users for this lateral section.

5. Beard Ditch Dry Creek Crossing

The Beard Ditch crossing of Dry Creek replaced a deteriorated steel and concrete crossing with new 18” polyvinyl chloride (PVC) pipeline in an effort to reduce significant irrigation water loss to flood irrigated pasture north of Dry Creek.

2019 CAPITAL PROJECTS

1. Lateral 4 Drop 33

The Lateral 4 Drop 33 long-crested weir was constructed as a water level control structure in MID Lateral 4. The long-crested weir holds a steady water height resulting in reliable and constant turnout flow rate for upstream water users for this lateral section.

2. Rose Avenue Pump Station Project

The Rose Avenue Pump Station is located at the intersection of Rose Ave. and E. Briggsmore Ave. in the City of Modesto. This pump station was originally designed in 1944 to pump agricultural runoff from the MID Cavil Drain into Lateral 3, but due to steady urbanization in this region by the City of Modesto the pump station now delivers both agricultural and urban reclaimed water into Lateral 3. The Project added a fourth variable speed drive (VFD) pump to the original three (3) stage pump station with the purpose of providing a steadier discharge into MID Lateral 3 for reclaimed water use by agricultural customers. In addition, the (3) three original staged pumps were reconditioned to improve overall pump station efficiency and reliability. The Project was integrated into the Irrigation SCADA system to allow Irrigation Operations staff real-time control and data access via a laptop computer located in each ditchtender vehicle,

3. Tidewater Culvert Crossing Rehabilitation

The Tidewater Culvert Crossing is a piped culvert crossing located on the Dr. Moore Lateral in the northern region of the District. The Tidewater Culvert Crossing was the first pilot project completed using sprayed-in-place concrete trenchless technology by use of a new centrifugal pipe lining machine purchased by MID staff. A total of three (3) 30-inch pipe culverts 150 feet in length were lined with a specialized concrete sprayed liner by use of the new trenchless technology under the direction and supervision of factory representatives.

4. Stoddard Well #258

MID continued to improve its well field with the installation of a new irrigation production well known as the Stoddard Well #258. This 150 HP well is located on the MID Lower Main and provides nearly 3,400 gal/min of groundwater as a supplemental water source to the downstream users on the MID Lower Main and MID Lateral 8.

5. Little Shoemake Pipeline Rehabilitation

The Little Shoemake Pipeline is an original 1940 Cast-in-place (CIP) pipeline that has reached its life expectancy and is experiencing significant seepage. MID selected the Little Shoemake Pipeline to be the large pipeline project to be completed using sprayed-in-place concrete trenchless technology by use of the new centrifugal pipe lining machine. This project allowed MID field staff to improve on both installation techniques and development of the specialized concrete sprayed liner. Approximately, 1,600 lineal feet of the Little Shoemake pipeline was rehabilitated with the new concrete trenchless technology.

2020 CAPITAL PROJECTS

1. Main Canal Reservoir

The Main Canal Reservoir (MCR Project) included development of a new, nearly 300 acre-foot (AF) regulating reservoir located at MID's Lower Main Canal and Lateral 3. In addition to the reservoir, project construction was comprised of four water control structures, two flow measurement flumes downstream of the project site, a new Supervisory Control and Data Acquisition (SCADA) system and system integration. The MCR Project was designed to regulate water flows to better match downstream demands for both the Lower Main Canal and Lateral 3.

Through implementation, MID's operational flexibility is increased by allowing short-term changes on either canal to occur without requiring changes in the upper reaches of MID's delivery system. This allows for faster responses to imbalances in the irrigation supplies and customer water demands downstream of the Lateral 3 and the Lower Main Canal bifurcation-which accounts for nearly three-quarters of MID's irrigated acreage. Flow rates and water levels are automatically monitored and controlled, and communication enhancements allow MID to account for flow fluctuations and make corresponding adjustments remotely in real time. The reservoir bottom was not lined with the purpose of allowing groundwater recharge to occur for the surrounding area.

2. Lateral 3 Flume

The Lateral 3 Flume is a replogle flume located on MID Lateral 3 nearly 1,500 feet downstream of the MCR Project. The flume works in conjunction with the MCR Project automatic gate outlet structure to accurately deliver water to downstream reaches of MID's Lateral 3, Lateral 4, and Lateral 5.

3. Pelton Flume and Main Canal Check Structure

The Pelton Flume and Main Canal Check Structure were constructed as part of the MCR Project. The two structures operate together with a new integrated SCADA system to improve reliability and conserve water in a 4.3-mile reach of the MID Lower Main Canal. The Main Canal Check Structure is located at the Main Canal Reservoir and accurately resets the flow to the MID Lower Main Canal with ten (10) calibrated sluice gates while diverting any overage flow into the new Main Canal Reservoir. The Pelton Flume is a second measuring structure located 4.3 miles downstream of the Main Canal Check Structure and several Oakdale Irrigation District (OID) irrecoverable outflows. By use of a complex algorithm, the new integrated SCADA system records flow fluctuations due to known conditions upstream of the Pelton Flume and adjusts the Main Canal Check Structure gates accordingly allowing any excess flow to be diverted into the Main Canal Reservoir in lieu of being lost as unrecoverable flows.

Section II: Description of the Modesto Irrigation District and Service Area

1. Physical Characteristics

The Modesto Irrigation District is a public agency which supplies irrigation and electrical service to agricultural, residential, and municipal customers, and treated municipal water to the City of Modesto. Irrigation water supplies include surface water from the Tuolumne River and groundwater from the Modesto Sub-basin. MID's irrigation service area covers an area of approximately 162 square miles (103,733 acres) in the Tuolumne River watershed (the irrigation service area differs from MID's electric service area). The 1,880 square mile watershed extends to the high Sierra Nevada Mountains and the Tuolumne River flows to its confluence with the San Joaquin River approximately ten miles west of the City of Modesto. Most of the water in the Tuolumne River comes from snowmelt with peak runoff flows occurring from April through July during which time over 60 percent of the annual flow takes place. The Tuolumne River's annual median year runoff is approximately 1,900,000 acre-feet, varying between a low of 382,680 acre-feet in 1977 to a high of 4,862,000 acre-feet in 2017. 2015 was one of the driest years on record, while 2017 was one of the wettest. As for the remaining years, 2016 and 2020 were classified as "Dry", 2018 "Below Normal", and 2019 "Wet" as classified by the San Joaquin Valley Water Year Hydrologic Classification Index[1]. This variability in runoff drives many of MID's irrigation policies and practices. **Figure 2** shows the irrigation service area of the District as well as the cities that are located within the irrigation service area.

Table 2 – Tuolumne River Runoff 2015-2020

Water Year	2015	2016	2017	2018	2019	2020
Full Natural Flow (TAF)[2]	599	1,819	4,862	1,673	2,984	970
Year Type	Critical	Dry	Wet	Below Normal	Wet	Dry

[2]cdec.water.ca.gov

a) Size of the Service Area

MID was formed on July 9, 1887 as the second irrigation district to be established in California under the California Irrigation Districts Act (Wright Act). During its early years, MID acquired numerous water rights including pre-1914 rights and constructed facilities to deliver water to irrigate farmland and to generate electricity. As shown in **Table 3**, a total of 66,452 acres were

[1] The San Joaquin Valley Water Year Hydrologic Classification Index includes the four major rivers In the San Joaquin Valley, the Stanislaus, Tuolumne, Merced and San Joaquin Rivers.

irrigated within MID in 2018, with approximately 62,333 acres of land receiving surface water from MID.

Table 3 – Water Supplier History and Size

Date of Formation	1887
Source of Water	
Local Surface Water (Tuolumne River)	Yes
Local Groundwater	Yes
Gross Acreage – at Time of Formation	108,000
Gross Acreage – Current Irrigation Service Area (2018)	103,733
Current Irrigated Acreage (2018)[1]	66,452

[1]Cropping data taken from TruePoint Crop Summary Report for the selected Water Management Plan year (2018). Includes lands that receive MID water and cropped land within MID that does not currently use MID water.

MID is governed by a five-member, locally elected Board of Directors (Board). Each board member represents a geographical area within MID known as a division. Board members must live within the division they represent and are elected by the registered voters living within that division.

Land use within MID's irrigation service area is primarily agricultural. Prior to the construction of District irrigation conveyance facilities, dry land crops (primarily wheat and pasture) were grown in the irrigation service area.

The City of Modesto, with a population of over 200,000 people, divides the District into essentially two parts – east and west of the City of Modesto. In addition, the City of Waterford, with a population of around 10,000, is located on the District's eastern end. Of the 103,733 acres within the District boundary, over 40,000 acres have been developed into residential, commercial, and industrial centers.

The irrigated acreage within the District has varied over time principally due to minor boundary adjustments, plus a merger with the Waterford Irrigation District in 1978 and changes in land use driven by urbanization. The trend toward greater urbanization within the District's boundaries is expected to continue. City of Modesto's 2019 General Plan to guide development through 2040 has a Planned Urbanizing Area of an additional 19,450 acres. City of Waterford's 2008 General Plan to guide development through 2025 has an Urban Planning Area of an additional 1,608 acres. The anticipated magnitude of this change in land use is shown in **Table 4**.

Table 4 – Expected Changes to Irrigation Service Area

Change to Irrigation Service Area	Estimate of Magnitude	Cause of Change	Effect of Water Supplier
Reduced Irrigation Service Area	None	N/A	N/A
Increased Irrigation Service Area	None	N/A	N/A
Reduction in Irrigated Area	Modesto: 19,450 acres (2019-2040 General Plan) Waterford: 1,608 acres (2008-2025 General Plan)	Urbanization	Change from agricultural to M&I supply

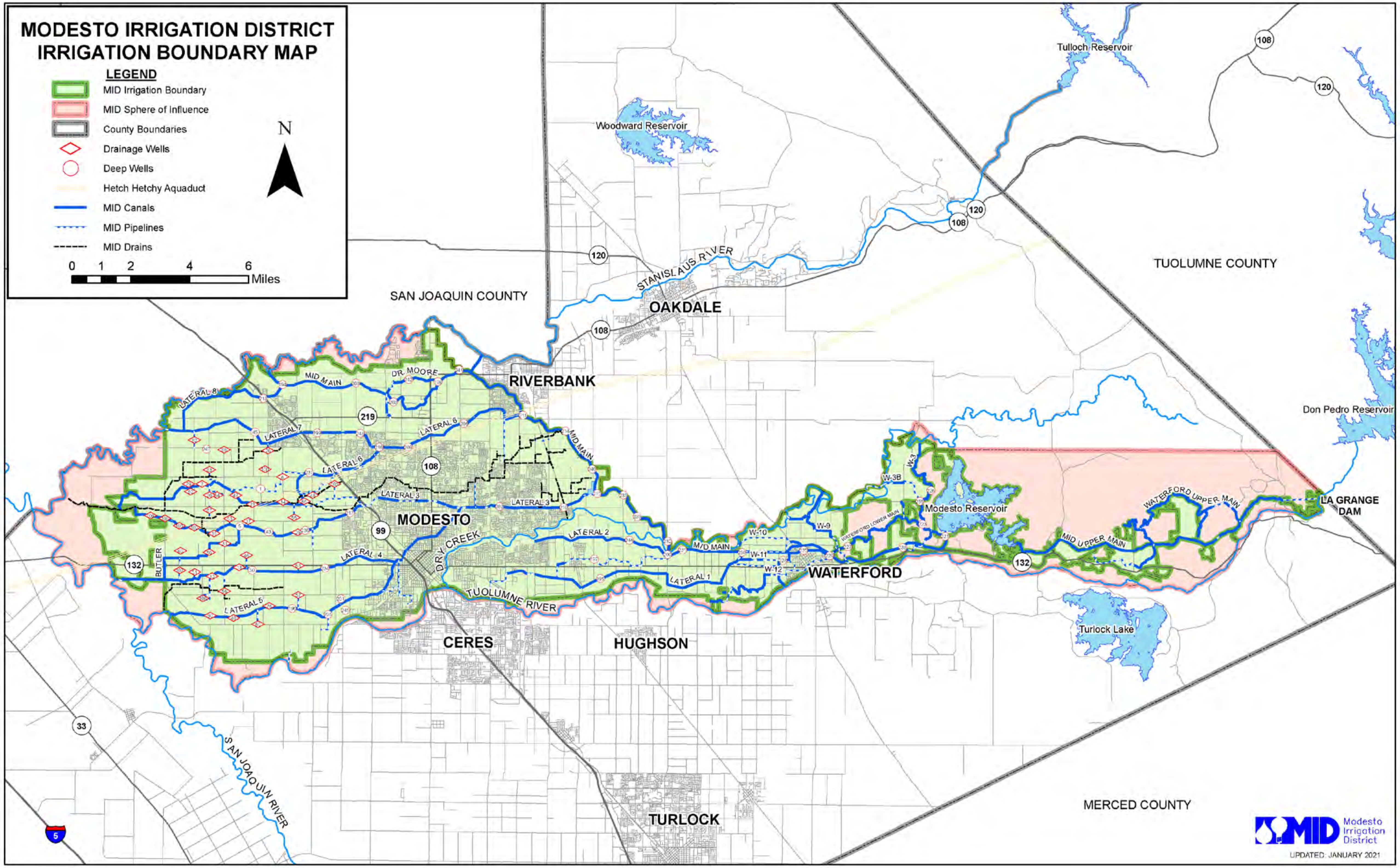


Figure 2 – MID Irrigation Service Area

b) Location of the Service Area and Water Management Facilities

As shown on **Figure 1**, MID is located in northeastern Stanislaus County which lies in the northeastern part of the San Joaquin Valley. MID is bounded on the north by the Stanislaus River, on the south by the Tuolumne River, on the west by the San Joaquin River, and on the east by the Sierra Nevada foothills. Neighboring irrigation districts are Turlock Irrigation District (TID) to the south, Oakdale Irrigation District (OID) and South San Joaquin Irrigation District (SSJID) to the north, and West Stanislaus Irrigation District (WSID) and a few smaller water districts to the west. MID, TID, OID and SSJID all divert irrigation water from the Tuolumne (MID & TID) and Stanislaus (OID & SSJID) Rivers which provide high quality runoff from the Sierra Nevada Mountains.

Within the upper Tuolumne River watershed, the City and County of San Francisco (CCSF) operates three reservoirs with a total storage capacity of 656,000 acre-feet; in the lower part of the watershed, MID and TID (collectively the “Districts”) operate the New Don Pedro Reservoir with a maximum storage capacity of 2,030,000 acre-feet. The Districts are also responsible to maintain regulated fish flows in the Tuolumne River to comply with FERC licensing requirements. MID’s median annual diversion from the Tuolumne River is approximately 295,656 acre-ft of water (hydrologically average period from 2003 to 2019). Of that amount, approximately 30,571 acre-feet (average from 2003 to 2019) is delivered to the MRWTP for treatment and delivery to the City of Modesto.

MID distributes a combination of Tuolumne River water and groundwater via a network of storage facilities, canals, pipelines, pumps, drainage facilities and control structures. The District distribution system is shown in **Figure 2**. MID's first major project was the construction of La Grange Dam completed on December 13, 1893 in conjunction with TID. This masonry dam is still used to divert water from the Tuolumne River into MID's Upper Main Canal, however its size precludes it from re-regulating water. When La Grange Dam was built it was the highest overflow dam in the world. On June 27, 1903 irrigators along the newly completed main canal began receiving water and by September of that year, water was moving through District laterals. **Table 5** provides a summary of existing irrigation facilities in MID.

Table 5 – Water Conveyance and Delivery System

System Used	Number of Miles
Unlined Canals	15
Lined Canals	147
Pipelines	42
Drains	39

Storage and regulation of main canal deliveries began in 1911 with the completion of the 28,000-acre-foot Dallas-Warner Reservoir, now known as Modesto Reservoir. The capacity of this reservoir was too small to allow carryover water from year to year to protect permanent crops from extended droughts. Such storage wasn't available until the completion of the Old Don Pedro Dam and Reservoir. When completed in 1923, at a height of 284 feet, Old Don Pedro Dam was the highest gravity dam in the world. Old Don Pedro Reservoir allowed MID and TID to store a maximum of 290,400 acre-feet of water for irrigation and recreation and to generate electrical power.

In 1970, MID again added to its water storage and power generation facilities with the completion of the 2,030,000-acre-foot New Don Pedro Dam and Reservoir. The New Don Pedro facilities are owned by MID and TID and operated by TID. The Districts also share pre-1914 water rights, water diversion facilities, and water right licenses.

New Don Pedro Reservoir, now referred to as Don Pedro Reservoir, is a multi-purpose water storage facility. In addition to storing water for irrigated agriculture and M&I use, water releases generate electricity and the reservoir is used as a recreation and water sports facility. MID and TID also release water to increase instream flows which enhance the environment downstream of Don Pedro Reservoir.

The City and County of San Francisco (CCSF) has an obligation to release specific flows from the Hetch Hetchy Project into Don Pedro Reservoir depending on the time of year. In order to assist CCSF in managing available water while meeting the Districts' prior water rights, the Districts have agreed to allow CCSF to have a water bank of 570,000 acre-feet in Don Pedro Reservoir. This water bank allows CCSF to pre-release water to the water bank when available, allowing CCSF to optimize their upstream operations while meeting with the District's senior water rights at all times. Whenever there is water in the water bank, CCSF is relieved of its obligation to meet District flow requirements.

There is also a U.S. Army Corps of Engineers (USACE) flood control storage requirement of 340,000 acre-feet of reservoir space that is maintained from October 7 to April 27 of each year. The minimum dead pool storage is 309,000 acre-feet leaving MID and TID with an average working capacity of 1,721,000 acre-feet of which MID's annual share is 31.54 percent or 542,803 acre-feet.

MID has a maximum annual carryover storage capacity of 570,803 acre-feet when storage in the 28,000 acre-foot Modesto Reservoir is included as shown in **Table 6**.

Table 6 – Water Supplier Reservoirs

Reservoir	Capacity (AF)	MID's Storage Rights (AF)
Modesto Reservoir	28,000	28,000
Don Pedro Reservoir	2,030,000	542,803
Total Storage	2,058,000	570,803

The MID water conveyance and distribution system was designed to deliver water by gravity flow from La Grange Dam on the east to the San Joaquin River on the west. This gravity conveyance system is energy efficient, but occasionally creates operational outflows to downstream tributaries. While these operational outflows are of relatively high quality and generate no environmental impacts, they are a lost resource to MID. As part of the CWRMP, MID built the Main Canal Regulating Reservoir and is in the process of evaluating additional facilities to capture and return operational outflows for reuse within the irrigation service area. The District anticipates that it will be able to conserve thousands of acre-feet per year once middle and end of system regulating reservoirs are constructed to capture and re-circulate operational outflows, although there will be a significant cost to construct such facilities.

The need for on-farm surface drainage within the District is minimal, as the majority of the land within the irrigation service area is well drained. Much of the land is irrigated with the use of level basins allowing agricultural water users to retain all irrigation water applied on-farm within the parcels' boundaries. **Table 7** summarizes the existence of tailwater/operational outflow recovery systems. Currently MID has no District-operated recovery system and tailwater returns to the District conveyance system are minimal. Some growers, especially at dairies, re-circulate their water on site.

Table 7 – Tailwater/Operational Outflow Recovery System

System	Yes/No
District Operated Operational Outflow Recovery	No
On-Farm Operated Tailwater/Operational Outflow Recovery	Yes

There have been substantial improvements to MID's main and secondary canals since they were built in the early part of the 20th century. These improvements have increased the effectiveness of water deliveries. In addition to the District facilities, irrigators constructed ditches and pipelines necessary to convey water from the District's canals to the irrigated fields. By the early 1920s, despite improvements to canals and other water service facilities, many private community ditches weren't being maintained. The lack of maintenance to these private ditches and lack of cooperation among the water users resulted in frequent water shortages and inadequate or inefficient water deliveries.

MID couldn't take on the financial burden of improving the private community ditches without raising taxes to all landowners within the District. As an alternative, the District initiated state legislation allowing for the establishment of local ditch and pipeline "Improvement Districts" (ID) within irrigation districts. The legislation to form Improvement Districts was sponsored by a local state senator and became state law in 1927.

Improvement Districts are small locally controlled districts within a larger irrigation district organized for the purpose of more equitably providing improvements to the land and water conveyance facilities serving that specific area’s needs and are, in effect, legal subdivisions of the irrigation district. These Improvement Districts use the technical and financial expertise of the irrigation district, while leaving the basic decision of whether or not to make the improvements in the hands of those using the community facility. In general, the Improvement District landowners make facility improvement decisions that enhance the water delivery efficiency of the local system. Since the Water Code requires that two-thirds of the landowners within an Improvement District agree on the expenditures made to Improvement District facilities, conflicting interests can be a problem. However, Improvement Districts are valuable mechanisms for making improvements where most of the landowners have similar interests. Today, there are approximately 248 active Improvement Districts within MID.

c) Terrain and Soils

The terrain of the District is relatively flat and is composed primarily of alluvial fans sloping from east to west from the foothills to the San Joaquin River. Elevations range from over 200 feet above sea level on the east to less than 40 feet above sea level on the west. On the east, MID is intersected by Dry Creek which drains over 100 square miles of land from the foothills east of the City of Modesto and runs in a westerly direction before merging with the Tuolumne River near the City of Modesto.

Land within MID consists mainly of sediments that have formed the broad alluvial plains of the Stanislaus and Tuolumne Rivers, two perennial streams which flow in a southwesterly direction and discharge into the San Joaquin River. The topography on the eastern one-third of the District's service area consists mostly of hilly to rolling land sloping in a westerly direction. The western two-thirds of the service area are relatively flat with a mild westerly slope.

The predominant irrigation system in MID continues to be gravity-fed level basins. However, pressurized, low-volume drip or micro-sprinkler irrigation systems are now the system of choice for lands converting to permanent orchard and vineyard crops. For this reason, some land planted to permanent crops irrigated using level basins or impact sprinklers is being converted to low-volume irrigation systems. The current rate of conversion to low-volume micro-irrigation systems is estimated to be about 130 acres per year (TruePoint database, 2011-2020 data). In some cases, the flood systems are kept intact to provide occasional flood irrigation events for vermin control or leaching.

The soils of the District consist of a broad range of textures from sand to heavy adobe. The soils are distributed according to their position in six distinct physiographic areas: (1) alluvial flood plains; (2) basin lands; (3) young alluvial fans; (4) low alluvial terraces; (5) high alluvial terraces, partially eroded into rolling hills; and (6) uplands of the Sierra Nevada.

The eastern fringe of arable land occurs in the rolling hills of the upland range where the older granitic alluvium supports irrigated trees, mainly almonds. The western fringe consists of mixed alluvium of low relief with some occurrence of heavy adobe and clay containing alkali. Much of the alkali area has been reclaimed, and the soil supports pasture, row and other field crops and some permanent crops. The largest area of land within the basin rim consists of sand to sandy loam, which also supports a wide range of crops and growing conditions. Hardpan occurs mostly in the eastern and western edges of the District.

A portion of the MID irrigation service area is underlain by the Corcoran Clay, a formation originating from ancient lake deposits of clayey silt. This formation creates a low permeability boundary of 20 to 120 feet in thickness. Irrigation wells drilled in the areas where the Corcoran Clay is present generally penetrate aquifers both above and below the clay. However, some deeper wells are perforated exclusively below the Corcoran Clay as that is where the best quality water is found. Generally, wells screened mostly above the clay exhibit better production characteristics than those screened in zones below the clay. Although numerous silt and clay beds occur above and below the Corcoran Clay, they are not correlated over large areas. Therefore, those beds are only of local importance to the confinement of groundwater.

Table 8 – Landscape Characteristics of Irrigated Land

Topography Characteristics	% of the District	Effect of Water Operations and Drainage
Rolling Land	20% of irrigated land	Land is adaptable to sprinkler and micro-irrigation systems.
Flat Land	80% of irrigated land	Land is adaptable to flood and other types of irrigation systems.

d) Climate

The major features of the climate are hot, dry summers and cool, wet winters. Temperature distribution is uniform throughout the area. Average annual rainfall increases from about 10 inches at the San Joaquin River to about 14 inches at the edge of the foothills with 12 inches in the City of Modesto area. Most of the precipitation occurs from December to March with little to none occurring during the summer months of June through August; the pattern for potential evapotranspiration (ET) and evaporation are just the reverse. Summer temperatures commonly are above 85°F and may exceed 100° F, but rarely exceed 105°F. Winter temperatures commonly fall below 32°F but are rarely lower than 25°F. **Table 9** summarizes climatic conditions for Modesto. **Table 10** presents more detailed information.

Table 9 – Summary Climate Characteristics

Climate Characteristic	Annual Value
Average Precipitation	12.14 inches
Precipitation (2018)	11.40 inches
Minimum Precipitation (1898)	4.28 inches
Maximum Precipitation (1983)	27.71 inches
Minimum Temperature (Avg. Winter)	39.6°F
Maximum Temperature (Avg. Summer)	91.3°F

Note: Data provided by MID 1888-2020

Table 10 – Detailed Climate Characteristics

Month / Time	Average Precipitation (inches)[2]	Average Reference Evapotranspiration (ET_o) (inches)[3]	Average Minimum Temperature (°F)[2]	Average Maximum Temperature (°F)[2]
January	2.38	1.13	38.89	54.73
February	2.05	1.95	41.99	61.45
March	1.91	3.64	44.55	67.09
April	0.96	5.19	47.90	73.37
May	0.49	6.88	52.62	80.75
June	0.10	7.88	57.49	88.13
July	0.02	7.98	60.84	93.67
August	0.03	6.97	59.90	91.86
September	0.20	5.17	57.37	87.64
October	0.62	3.51	51.13	78.02
November	1.33	1.77	43.40	64.70
December	2.10	1.10	39.04	54.97
Wet Season[1]	11.36	18.29	43.84	64.90
Dry Season[1]	0.84	34.82	57.64	88.41

[1]Wet season typically October through April, Dry season typically May through September
[2]Data provided by Modesto Irrigation District per MID Temperature Records since 01/01/1939
[3]ET_o data from Modesto Station #71 (1989-2019)

2. Operational Characteristics

a) Operating Rules and Regulations

The Rules and Regulations Governing the Distribution of Irrigation Water Within the Modesto Irrigation District (2015 revision) (Rules and Regs) is the guideline for the operation and delivery of irrigation water and is presented in **Appendix C**. The Rules and Regs cover the procedures followed to distribute irrigation water in an orderly, efficient, and equitable manner. The Rules and Regulations were updated in early 2015 with significant revisions to allow for improved water resources management. Major revisions were made on the following topics:

- Changes to irrigation scheduling procedures
- Fines for unauthorized water use ($1,500 per infraction)
- Additional details on water measurement
- Irrigators must decide by May 1 if they will be irrigating
- Requirement for backflow prevention from lagoons and agricultural filter discharge stations
- Commitment to annually review the Rules and Regs

The MID on-farm water delivery system was originally designed to deliver irrigation water by gravity with very large flows, 10-20 cubic feet per second (cfs), to each field turnout on a predetermined rotation (typically every 10-20 days) basis. Water delivery on rotation can be an effective method to deliver water to flood irrigated level basins because the soil moisture holding capacity of the crop root zone is utilized to store water for use by the crop until the delivery rotation comes back again. The time between irrigations is dependent on the water holding capacity of the soil and climatic conditions which drive the rate of evapotranspiration (ET), as well as the distribution system itself. However, as irrigators convert their on-farm application practices from flood to pressurized systems, the requests for irrigation water have shifted from rotation to arranged-demand as pressurized micro-irrigation systems need a smaller volume of water but irrigation must occur more frequently, often on a daily basis.

Most of the on-farm gravity water delivery systems were designed and built with cast-in-place pipelines and ditches capable of delivering large flows for flood irrigation on a rotation schedule. These pipelines and ditches typically hold water for only a few days as the rotation moves to other facilities downstream. On-farm arranged-demand delivery requires that water be available most of the time and be delivered at a constant low flow rate, a practice which creates an incompatibility between the delivery requirements of flood and low-volume on-farm systems.

Facing a deteriorating system of ditches and pipelines that wasn't capable of delivering water to the range of on-farm irrigation systems present within the District, the MID Board of Directors has approved funding to upgrade the District's water delivery system and to help landowners modernize their on-farm application systems. These upgrades and replacements help to enhance water delivery flexibility and increase reliability. With District, improvement district, and private upgrades, MID is now capable of delivering irrigation water to a majority of its customers on a demand or an arranged demand schedule as summarized in **Table 11**.

Table 11 – Supplier Delivery System

Type	Check if Used	Percentage of System Supplied
On Demand	X	30
Arranged Demand	X	45
Rotation	X	25

MID operates a decentralized water ordering and delivery system. The ditchtenders take water orders from agricultural water users and coordinate deliveries based on demand and the flow capacity of the distribution system. As MID moves away from rotation to the more flexible arranged demand water delivery system, the ditchtenders' functions have become less routine and more customer-oriented.

Agricultural water users with flood irrigated lands may continue to irrigate on a fairly constant rotation while the water users with pressurized irrigation systems may request irrigation water on an arranged demand basis. Therefore, water order lead times vary depending on the time of year, system capacity, and where water is being routed. For example, an agricultural water user close to Modesto Reservoir with land near a large canal may have a greater probability of receiving water on short notice than an agricultural water user who is more distant from the reservoir and from delivery facilities. The District's goal is to supply water to the agricultural water user when the water is needed and to maintain that delivery for the duration necessary to refill the soil profile or to satisfy the crop water requirement.

Water Allocation Policy

Table 12 illustrates factors used to allocate water at MID on an annual basis. These factors are considered in setting the annual water allocation that is applied uniformly across the District (ag and urban) and which, in a normal year, is approximately 42 inches/year. Since 2016 was a dry year and came on the tail end of successive dry years, the allocation was reduced to 36 inches. 2017, 2018, and 2019 were wetter years and the allocation was 42 inches, uncapped. 2020 however, was a dry year and the allocation was capped at 42 inches.

Table 12 – Water Allocation Policy

	(Check if applicable)			Allocation	
Basis of Water Allocation	**Flow**	**Volume**	**Seasonal Allocations**	**Normal Year**	**Percent of Water Deliveries**
Land within the Irrigation Service Area		X		42 in/year	100%
Reservoir Storage		X		42 in/year	100%
Riparian Rights					
Water Year Type		X		42 in/year	100%
Amount of Land Owned					
Predicted Runoff		X		42 in/year	100%

The annual allocation is based on factors including the volume of water carried over in storage in Don Pedro Reservoir and the projected runoff from the Tuolumne River watershed. The allocation generally isn't finalized on an annual basis until after the rainy season when runoff information has been made available by DWR.

Table 13 describes lead times for water orders and shut-offs now typical of MID operations. The lead time was recently increased from 3 days to 5 days, primarily to account for increased water management opportunities during prolonged droughts. While this is an upper bookend, orders are generally filled as soon as possible.

Table 13 – Lead Times

Operations	Hours
Water Orders	0 – 120
Water Shut-off	0

b) Water Delivery Measurements or Calculations

Following is a brief discussion on current water delivery measurements. The District also performed an extensive delivery point water-measurement pilot-testing program as part of its efforts to comply with SBx7-7 and improve the accuracy of water measurement throughout the District. Refer to Section VIII for more information on delivery point measurement, the Pilot Program and SBx7-7 compliance.

MID uses a variety of devices and methods to measure water within its delivery system. Diversions from the Tuolumne River into the Upper Main Canal are measured continuously by the USGS gage number 11289000 (Modesto Canal near La Grange). MID uses a Supervisory Control and Data Acquisition (SCADA) system to monitor and control diversions from Modesto Reservoir and the various canal branches. Most deliveries to agricultural water users are currently measured using submerged sidegate orifices (commonly referred to as meter gates) that use the gate opening and the pressure differential between the canal and the downstream channel water levels to measure the water flow. When properly calibrated and with favorable field conditions, the submerged orifice can be a reasonably accurate method of measuring the instantaneous flow rate. MID has nine portable Hach meters that are used to verify delivery flow rates when needed.

Table 14 shows typical levels of accuracy for various types of measurement devices currently used within the District.

The main disadvantage of calculating delivered water volumes based on an instantaneous measurement is that the measurement device doesn’t directly record the volume of delivered water. This can be problematic for two reasons. First, an accurate record of the duration of the delivery must be maintained to convert the instantaneous measurement of flow rate into a volume. Secondly, if there are fluctuations in water surface elevations during the course of a delivery, these fluctuations will affect the rate of discharge, and hence, the volume of water delivered. In the case of MID, because the canal water level at nearly every check structure is controlled by a long-crested weir, there is little variation in canal water levels regardless of the flow in the canals. The District is able to maintain a fairly constant canal side, or upstream, water level on the meter gate, but the District has very little control on the landowner, or downstream, water level.

Ditchtenders calculate the volume of a water delivery by measuring the differences in water elevations and the meter gate opening, using calibrated tables to compute the flow rate which corresponds to these parameters, and multiplying that flow rate by the recorded duration of delivery. The calculated water delivery is input into the District's TruePoint water management system which tracks cumulative water delivered to each water user during the irrigation season. This data is then used to bill the agricultural water user on a volumetric basis. The current pricing system is volumetrically based, along with a fixed per acre charge.

Although the District is currently able to bill for water deliveries volumetrically, the District believes that the measurement methodology in some cases may be improved to increase agricultural water use efficiency. Section VIII of the AWMP discusses the proactive steps the District is taking to assess the most viable measurement device(s) and apportionment method and to comply with the water measurement requirements of SBx7-7.

Table 14 – Water Delivery Measurements

<table>
<tr><th>Type of Measurement</th><th>Frequency of Measure</th><th>Frequency of Calibration</th><th>Frequency of Maintenance</th><th>Estimated Level of Accuracy
(+/- % error)</th></tr>
<tr><td>Orifices</td><td rowspan="6">As Required</td><td rowspan="6">Infrequently</td><td rowspan="8">As Needed</td><td>10</td></tr>
<tr><td>Propeller Meters</td><td>5</td></tr>
<tr><td>Flumes</td><td>7</td></tr>
<tr><td>Venturi Meters</td><td>5</td></tr>
<tr><td>Pumps, runtime</td><td>10</td></tr>
<tr><td>Pumps, kwh</td><td>10</td></tr>
<tr><td>Weirs</td><td>Continuously (hourly)</td><td>Occasionally</td><td>10</td></tr>
<tr><td>Hach Meter</td><td>As Required for flow rate verification</td><td>As per manufacturer recommendations</td><td>2-4</td></tr>
</table>

c) Water Rate Schedules and Billing

The MID Board annually establishes a water rate based on budget requirements and board policy. Factors such as cropping doesn't play a role in the Board's determination of water rates. Historically, the District rates included a base water charge (per acre) that entitled the agricultural water user to use up to the allocated amount, and then an increasing block rate (tiered) pricing structure was applied for agricultural water users who exceeded the base amount of allocated water. In 2015, the District implemented a revamped water rate structure inclusive of a volumetric component to comply with one of the mandatory EWMPs of SBx7-7. The water rate structure used since 2015, is to assess a fixed charge (based on acres served) to all agricultural water users, and to volumetrically charge for all water use on an increasing block rate or tiered pricing structure. Raw water sent to the City of Modesto is billed at the same rate as agricultural water users. **Table 15** indicates the basis for the District's water rates.

Table 15 – Water Rate Basis

Type of Billing	Check if Used	Percent of Water Deliveries	Description
Volume of Water Delivered (acre-foot based)	X	100%	Tiered pricing structure for all lands receiving MID water
Fixed Charge – Land Assessment (acres based)	X	100%	Basic fixed charge applied to all lands, regardless of how much water is used
Crop			N/A

As a result, MID has a pricing structure that combines a uniform fixed charge to all lands, along with a block rate structure with increasing price rates applied to lands receiving irrigation water. **Table 16** provides the water rate structure. **Appendix D** provides detailed information on past and current water allocations and rates.

Table 16 – Rate Structure

Type of Billing	Check if Used	Description
Declining Block Rate		N/A
Uniform	X	Based on annual allocation and rate
Increasing Block Rate	X	Based on annually defined block rate structure and associated rates

The MID Board adopted the 2020 irrigation rates using volumetric pricing. The pricing structure consists of a fixed per acre charge and tiered pricing based on volume delivered. The volumetric pricing is structured as follows:

Table 17 – 2020 Volumetric Pricing Structure

Category	Cost
Fixed Charge[1]	$44.00/acre
Volumetric – Tier 1 (up to 24”)	$2.00/AF
Volumetric – Tier 2 (24” to 36”)	$5.00/AF
Volumetric – Tier 3 (36” to 42”)	$11.25/AF
Volumetric – Tier 4 (42” and up)	$40.00/AF

[1]Facilities and Maintenance charge will be ½ of the fixed charge or $22/acre. No minimum charge will be applied.

The Farmer to Farmer and Allocation Return Program described later under Drought Management Plan also have volumetric pricing. Some pricing tiers don’t apply when the annual allocations are below the tier requirements.

The drought from 2012-2015 required the District to increase groundwater pumping and rely on several drought management programs to help meet water demands. As a result, MID implemented a special drought surcharge in 2015 to account for additional drought-related operational expenses. The drought surcharge was calculated using 2014 actual drought expenditures. The 2015 drought surcharge of $16 per irrigated acre was intended to cover the following additional expenditures incurred as part of MID's 2015 drought operations:

1. Additional electrical costs
2. Additional manpower
3. Additional pump maintenance costs
4. Use of an outside security guard for added patrols of the conveyance system.

Currently MID bills its agricultural water users annually at the end of the irrigation season, as shown on **Table 18**. This bill is payable in two equal installments due on or about December 20 of the same year and June 20 of the following year. Water is currently billed, at least in part, on a volumetric basis.

Table 18 – Frequency of Billing

Frequency	Check if Using
Annually	X

d) Water Shortage Allocation Practices

Water supplies on the Tuolumne River vary depending on watershed precipitation, snow melt runoff, and the prior year's carryover storage in Don Pedro Reservoir. As such, water supply planning must take into consideration the amount of water that will be available when the irrigation season starts, the current year water requirements, and the expected carryover for the following season. MID has developed an internal planning tool to determine the annual allocation of water available to its customers (ag and urban). This tool identifies all of the estimated water resources available to MID within a given irrigation season, adjusts for the estimated commitments and accounts for the number of irrigated acres, and forecasts the final allocation and carryover storage of water MID can provide to its customers (ag and urban).

MID also implemented a Drought Management Plan (DMP) in 2014 and 2015, including several special programs to conserve and redistribute water. The DMP is discussed below in Section II.2.e. During consecutive dry years, MID may decrease the water allocation and shorten the irrigation season. MID will also conjunctively use groundwater pumps to supplement surface water diversions during years of short supply and agricultural water users may turn on their private irrigation wells to supplement District-supplied water. These practices are documented in MID Policy 89-77. **Table 19** lists the measures that MID may exercise to respond to water shortages.

Table 19 – Decreased Water Supplies Allocation

Allocation Method	Check if Used
Decrease Allocated Water	X
Shorten Irrigation Season	X
Restrict Water to Certain Crops	

Section 4.2 of the *Rules and Regulations Governing the Distribution of Irrigation Water within the Modesto Irrigation District* specifically addresses consequences to agricultural water users who waste water. Section 4.2.3 states the following:

> *"4.2.3. The District may refuse to deliver District water to any Irrigator who misuses or wastes water either willfully or carelessly, in any way, including but not limited to the following:*
>
> > *4.2.3.1. Flooding of roads, vacant land, or land previously irrigated.*
> >
> > *4.2.3.2. Defective or inadequate non-District Canals or Facilities.*
> >
> > *4.2.3.3. Inadequately prepared land.*
> >
> > *4.2.3.4. Flooding any part of any land to an unreasonable depth or amount, including for the purpose of irrigating other portions of the land.*
> >
> > *4.2.3.5. Flooding across one parcel to irrigate another parcel."*

Table 20 summarizes enforcement methods available to curtail wasteful water uses.

Table 20 – Enforcement Methods of Allocation Policies

Enforcement Method	Check if Used
Shut-off Water	X
Refuse Service	X
Fines / Penalties	X

e) Drought Plan

Irrigation has traditionally been used to dampen the effects of drought in agricultural communities. MID, through strategic long-term planning spanning over a century, has built a strong water resources portfolio. However, drought events can still lead to both economic and social impacts for irrigators and the local community by reducing irrigation water supplies and increasing crop water demand. Further, drought is anticipated to be increasingly problematic in irrigated areas as climate change continues to affect global climates and water resources. The Modesto Sub-Basin contains substantial areas of irrigated agriculture resulting in a strong need to remain diligent and continue to evolve in drought planning efforts.

i) Drought Resilience Planning

(1) Data, indicators, and information needed to determine the water supply availability and levels of drought severity.

MID uses a variety of data, indicators, and information to determine annual water supply availability and levels of drought severity. The District has developed a tool which calculates the annual irrigation allocation based on the following parameters:

- Don Pedro Reservoir storage
- Modesto Reservoir storage
- Projected inflows from upstream reservoirs
- Projected inflows from precipitation
- Estimate of groundwater pumping based on San Joaquin River water year index
- Minimum required flows in the Tuolumne River downstream of La Grange Diversion Dam
- Irrigation system conveyance and evaporation losses
- Projected domestic water demands
- Minimum end of season reservoir storage goal

The tool is updated frequently in the weeks leading up to the irrigation season as the water supply forecasts come into greater focus. MID uses precipitation and runoff forecasts generated by Turlock Irrigation District, the operator of Don Pedro Reservoir. TID has developed computer models that estimate runoff volume into the reservoir based on modeled hydrology for 10, 50 and 90 percent exceedance scenarios using the most current hydrologic conditions. MID uses these forecasted runoff volumes to calculate water availability for that year. As the forecasts get adjusted, the models are rerun, and the water availability determination is modified. MID typically uses the 90 percent hydrologic exceedance scenario for the initial allocation determination.

(2) Analyses and identification of potential vulnerability to drought.

Even though MID has a very robust water supply, the multi-year droughts of the past several decades have shown that the District may be vulnerable to drought depending on its severity. As described in Section III, a significant portion of MID's territory supports high-value permanent crops as well as over half of the drinking water supply to the City of Modesto. MID requires a reliable water supply to meet crop irrigation and municipal demands. This demand requires MID to develop a conjunctive management strategy, which is designed to provide a relatively consistent water supply. Reliability of water supplies is dependent upon the availability of surface water and groundwater supplies. However, the overall availability of surface water supplies relies upon numerous factors including future hydrology, water rights and instream flow requirements. Similarly, while Tuolumne River water diverted by MID adds significantly to the amount of recharge within the Modesto Subbasin, the groundwater is relied upon by various irrigation, domestic, industrial, and municipal water users within the Basin, both within and outside MID boundaries. As a result, the reliability of groundwater resources is dependent upon continued recharge of the groundwater basin, and the ability for the various groundwater users to work cooperatively to manage the water supply. MID as a member of STRGBA GSA works with the other agencies within the Modesto Subbasin to facilitate that effort.

Levels of drought severity are dependent on antecedent year water supply, and reservoir carry-over storage, Tuolumne River Watershed snowpack, precipitation, and groundwater levels. During a solitary dry year, with below normal precipitation, the District's ability to meet full demands for surface water may not be impacted at all. However, consecutive dry years may require MID to cut back on surface water deliveries, which in turn require the customers to supplement their supplies with other supplies, such as groundwater. At the end of the most recent drought period, 2012-2015, MID had to cut back deliveries by over 60 percent. During this time groundwater levels fell, and the degree of recovery has varied based on geographic location within the sub-basin.

(3) A description of the opportunities and constraints for improving drought resilience planning

MID has taken advantage of several opportunities for improving drought resilience planning, including participating in technology advances and improved data collection and analysis. MID is always evaluating new technologies to better forecast the annual water supply. MID has partnered with Turlock Irrigation District, San Francisco Public Utilities Commission and DWR to implement the Airborne Snow Observatory as described in Section III. MID has also partnered with the Center for Western Weather and Water Extremes to advance scientific understanding of atmospheric rivers and their role in extreme events. The Center continues to develop tools and techniques to help forecast extreme precipitation events.

MID has also engaged in several activities over the years to enhance its water supplies particularly during drought conditions. For over 30 years MID along with TID has implemented a cloud seeding program which has successfully provided additional inflow into Don Pedro Reservoir. Past program results have shown an estimated increase in watershed runoff from 2 to 7 percent. A 2 percent increase in runoff will result in approximately 38,000-acre feet increase in Tuolumne River supply.

Another activity is MID's ongoing groundwater recharge operations. According to information contained in DWR's Bulletin 118, the estimated amount of groundwater stored within the Modesto Subbasin, in just 100 feet of saturated thickness, is 5 million-acre feet or 2.5 times greater than the maximum storage capacity of Don Pedro Reservoir. The MID water service boundary is located entirely within the Modesto Subbasin. The primary source of recharge (60%)

in the basin occurs through the deep percolation of agricultural irrigation using surface water supplied by the MID. Other sources of recharge in the basin occur via rainfall and seepage from surface water bodies such as Modesto Reservoir. MID owns and operates approximately 50 production wells that are used to supplement the surface water supply. Most of these deeper wells are located immediately adjacent to the canal system in MID-owned rights-of-way. During drought years, MID increases the amount of groundwater pumping to supplement the surface water supply.

As described in Section III, MID has initiated several programs to improve resilience to drought conditions. These programs include the Farmer to Farmer Delivery Program, Irrigation Pump Rentals Program, Conservation Program and Groundwater Replenishment Program. MID may also cap or reduce annual irrigation allocations in the years leading up to a drought, if it appears that the region may be heading toward a dry cycle.

ii) Drought Response Planning

(1) Policies and a process for declaring a water shortage and for implementing water shortage allocations and related response actions.

The process for declaring a water shortage is fairly straight-forward. At the end of each irrigation season and through the winter months MID begins planning for the next irrigation season. If it becomes apparent that the San Joaquin Valley is caught in a multi-year drought cycle, MID will engage in the following actions:

- Meet with partner agencies such as Turlock Irrigation District and San Francisco Public Utilities Commission, to discuss water supply forecasts, current water supply conditions, and projected water operations and levels of risk.
- Meet with State agencies such as DWR and SWRCB to discuss water supply forecasts, drought emergency declarations, water rights and drought programs.
- Conduct grower meetings to get input on drought programs, reduced allocations, past drought-related actions.
- Present findings from these meetings and make a recommendation for the annual water allocation to the MID Board of Directors for their approval, at a regularly scheduled monthly meeting.

MID will also examine various potential drought response strategies with the intent of informing discussions within MID and between MID and its customers, in addition to providing the framework for future drought response efforts. It is important to note that some of the potential drought response strategies that have been implemented in the past, have the potential to impact agricultural production and under “normal” hydrologic conditions would not be contemplated by MID.

MID has developed temporary Drought Operation Rules to improve water resource and system management, and guide operations planning during the upcoming irrigation season. The Drought Operation Rules include implementing temporary measures, such as decreasing the length of the irrigation season, decreasing irrigation allocations, decreasing domestic water deliveries to the City of Modesto, and decreasing the number of garden head irrigations. The Rules also include several innovative, voluntary programs that provide irrigators flexibility in taking or sharing their District allocations. The decision to implement these programs is based on whether the additional supply will have a beneficial impact on water storage. Water deliveries from these programs are not authorized if they have, or may have, a negative impact on water storage. In making this determination, MID considers the impacts of accepting additional supply by considering, among other factors, real time demand downstream of the input, and MID's obligations to deliver and manage water supply. It should also be noted that any changes to MID's Irrigation Rules and Regulations must be first approved by the MID Board of Directors. However, if the Board of Directors give approval and if the hydrologic conditions warrant a drought related response, MID may undertake the following actions:

- Farmer to Farmer Delivery Program – Irrigation customers may transfer all or a portion of their surface water to another customer within MID's irrigation boundaries. Eligible landowners, for each parcel owned by the landowner, may request MID to change the delivery location of the landowners' water allocation. For each identified parcel, the landowner elects to forego their entire allocation, or a portion thereof, and instead have it delivered to a designated receiving landowner parcel.
- Allocation Return Program - Irrigation customers may sell back their water allocation to MID for monetary compensation and MID would then use that water to create a supplemental pool of water for other customers to draw from. Water sold back however, must be demonstrated to have a beneficial impact on water storage upstream.
- Water Management Alternatives Program – This Program includes three alternatives for eligible landowners:
  - deliver privately pumped groundwater into MID facilities for monetary compensation;
  - deliver privately pumped groundwater for an allocation credit;
  - deliver privately pumped groundwater from one authorized delivery location to another within MID's irrigation service area. MID does not charge a wheeling fee for this service.
- Drought Water Surcharge – Enables MID to recoup additional costs due to drought operations such as additional patrols, enforcement actions and conveyance facilities operations and maintenance.

(2) Methods and procedures for the enforcement or appeal of, or exemption from, triggered shortage response actions.

MID has published rules and regulations governing the distribution of irrigation water and updates the document periodically. The document is provided to all irrigation customers and contains a section on the enforcement of irrigation rules and regulations. During a drought emergency MID will engage in the following activities to ensure the orderly, efficient, and equitable distribution, use and conservation of the water resources of the District. These activities include:

- Increased patrols of irrigation facilities by ditchtenders
- Increase water theft penalties
- Investigate all unauthorized uses of water
- Investigate all unauthorized encroachments
- Send out letters to irrigation customers reminding them of MID's rules and regulations governing the distribution of irrigation water.

(3) Methods and procedures for monitoring and evaluation of the effectiveness of the drought plan.

MID uses various metrics for monitoring and evaluating the effectiveness of a drought plan and its programs. Metrics for monitoring the effectiveness of the programs will include accurate measurement of operational spills, groundwater pumping, Tuolumne River diversions, flow rates, and farmgate deliveries.

However, the best metric for evaluating the effectiveness of the program is the level of grower participation in the various programs. If many growers participate in a specific program, it is usually because there is significant incentive to do so. It also means that the program is well designed, and that implementation is relatively straight forward.

(4) Communication protocols and procedures to inform and coordinate customers, the public, interested parties, and local, regional, and state government.

MID is very proactive in communicating with its growers throughout the year and particularly during emergencies, such as drought emergency. MID's Public Outreach staff uses several different venues to disseminate information to landowners, growers, and the public in general. MID also works closely with the cities of Modesto, Oakdale, Riverbank and Waterford as well as Stanislaus County to provide consistent messaging for the entire area. Some of the typical opportunities for distributing information and gathering public input include:

- Biweekly reports to the Board of Directors
- Annual Grower meetings

- Periodic website updates
- Public outreach campaigns, including mailings, newsletters, workshops, and social media
- Dispatching ditchtenders and MID Irrigation Department staff throughout the district to be a “boots on the ground” point of contact.

(5) A description of the potential impacts on the revenues, financial condition, and planned expenditures of the agricultural water supplier during drought conditions that reduce water allocations, and proposed measures to overcome those impacts, including reserve-level policies.

All of the emergency drought programs offered by MID are self-supporting and none provide additional revenues.

Section III: Description of Quantity of Water Uses

Tuolumne River water is diverted to storage in Don Pedro Reservoir and re-diverted downstream at La Grange Dam into the District's canal system under water right licenses issued by the State Water Resources Control Board (SWRCB). The District also diverts water according to a series of pre-1914 appropriative and storage rights recognized by the State of California. In addition, MID also maintains 93 water wells (including production and drainage wells) that are used to supplement the surface water supply, particularly during consecutive dry years.

Basis for Reporting Water Quantities

Given water year types which have ranged from critical to wet in the recent past, MID chose 2018, a "Below Normal" year type which was preceded by a "Wet" year (2017) and followed by another "Wet" year (2019) and a "Dry" year (2020), as the representative year to serve as the basis for reporting water use and water supply data listed in subsequent tables. MID provided a full allocation to irrigation customers in 2018.

Figure 3 displays a time series of key hydrologic parameters extending from 1972 (the year New Don Pedro Dam was commissioned) through 2019. This figure illustrates the great range of computed natural flow (CNF), Tuolumne River flows below La Grange Dam, and Don Pedro Reservoir maximum storage which characterize the system.

Figure 3 also illustrates that in spite of great fluctuations in CNF, MID diversions have remained relatively stable.

The selection of calendar year 2018 as the representative year is presented in **Table 21**.

Table 21 – Representative Year

	Description
Representative year based upon	2018
First month of representative year	January
Last month of representative year	December

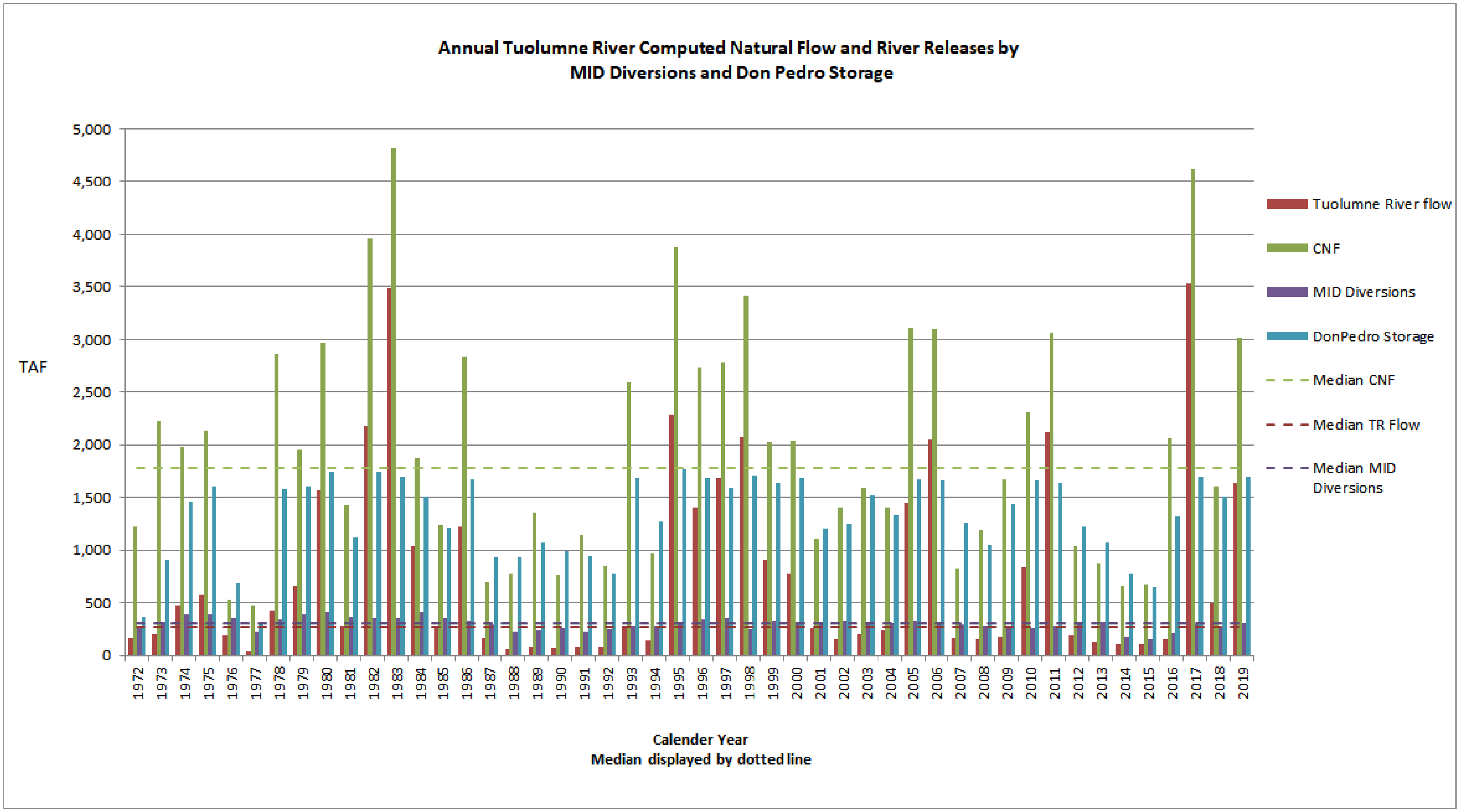


Figure 3 – Annual Tuolumne River Computed Natural Flow and River Releases by MID Diversions and Don Pedro Storage

1. Agricultural Water Use

The primary crops grown within the MID irrigation service area are deciduous trees (mostly almonds), grape vines, grains, row crops, and pasture for livestock. The District serves approximately 3,100 irrigation accounts with an average of 20 acres per account. Improvements in irrigation water delivery systems and changing economic conditions have brought many changes to the crop mix within the District. Nut trees including almonds and walnuts have been the crops with the most rapidly expanding acreages. During the last several years, thousands of acres of pasture and annual crop land have been converted to orchards and other high value permanent crops.

As the cropping pattern changes, low-volume irrigation systems such as drip and micro-sprinkler are replacing flood irrigation resulting in improvements in on-farm irrigation water use efficiency. Despite these changes the total water requirement for the MID irrigation service area has remained constant over the years as the total annual crop water requirement doesn’t appreciably change with a corresponding change in irrigation system. **Table 22** summarizes the agricultural water use within the District in 2018.

Table 22 – Agricultural and Municipal Water Use for 2018

Source	2018 (AF)
Agricultural Water Supplies	
Surface and Groundwater[1]	258,660
Other (City of Modesto M&I use)[2]	30,570
Other Water Supplies	
Surface Water	N/A
Groundwater (Private Pumping)	N/A
Other	N/A

[1]Includes total surface water diversions (-) M&I deliveries (+) MID production wells (+) MID drainage wells
[2]Includes MID surface water deliveries to the City of Modesto. Does not include City of Modesto groundwater pumping

Table 23 describes water needs for specific crops grown within MID’s irrigation service area.

Table 23 – Agricultural Crop and Water Demand Data for 2018

Crop Category	Total ET Demand[1 2] (in/yr)	Acres[3]	Total ET Demand (AF/yr)
Alfalfa, Hay and Clover	47.33	2,532	9,987
Almonds	41.58	27,905	96,691
Apple, Pear, Cherry, Plum and Prune	41.81	589	2,052
Corn and Grain Sorghum	31.00	8,421	21,754
Flowers, Nursery and Christmas Tree	40.22	461	1,545
Grain and Grain Hay	20.46	1,191	2,031
Grape Vines w/ 80% canopy	29.75	1,020	2,529
Idle	0.00	4,119	0
Melons, Squash and Cucumbers	19.75	3	5
Misc. Subtropical	40.22	0	0
Misc. Deciduous	40.22	781	2,618
Misc. Field Crops	27.33	166	378
Pasture and Misc. Grasses	48.09	6,600	26,450
Peach, Nectarine and Apricots	41.27	1,596	5,489
Rice	41.88	263	918
Small Vegetables	21.23	1,129	1,997
Strawberries	27.33	35	80
Walnuts	45.00	9,641	36,154
	Total	66,452	210,676
	Double Cropping (assumed)		5,000
	Total		215,676

[1]ET Demand takes into account contribution from effective precipitation.
[2]Calculations performed using regional ET rates for a Typical Year published by the Irrigation Training & Research Center (ITRC)
[3]TruePoint

The District's gross irrigation service area encompasses approximately 103,733 acres. As shown on **Table 24** in 2018 approximately 62,333 acres (66,452 acres less 4,119 idle acres) were irrigated with surface water, MID groundwater and private groundwater. Total evapotranspiration demand of applied water (after effective precipitation) was 215,676 AF.

The majority of the non-irrigated land in the irrigation service area is within the City of Modesto's sphere of influence.

Since submission of MID's 2012 AWMP, MID has also started using remote sensing data to determine evapotranspiration (ET) within its irrigation service area. Mapping of EvapoTranspiration with Internal Calibration (METRIC) computes ET using LandSAT Thematic Mapper (LandSAT) data. A comparison of ET from 2010 (calculated using METRIC) showed that the ET was within approximately 5% of the calculated ET using standard ET rates for water balances as published by ITRC. METRIC data has been used for specific projects within the District. However, CIMIS stations are more routinely used as the ET source in the District's Water Balance.

Table 24 – Irrigated Acres for 2018

Irrigation Service Area	103,733 acres
Surface and Groundwater Irrigated Area	62,333 acres

For the purposes of this AWMP, cropped acres are essentially the same as irrigated acres. The amount of irrigated land that isn't cropped at any time during the year is shown on **Table 23** as Idle. Over 50 percent of the cropped acres are planted with permanent crops with almonds being the predominant permanent crop with 27,905 acres. Permanent crops cover about 39,731 acres, and pasture and grain crops used primarily for dairy cattle feed cover about 18,744 acres. All other crops cover less than 4,000 acres. Land planted to grain crops is typically double cropped during the winter and spring months with winter forage also used primarily for dairy cattle. As shown in **Table 25,** inter-cropping isn't a common practice within the MID irrigation service area.

Table 25 – Multiple Crop Information for 2018

Cropped	62,333 acres
Inter-cropping	Negligible
Double Cropping	Not Available

Based on cropping records, it is estimated that about 64% of cropped land is irrigated with flood/furrow irrigation, 35% is irrigated with high efficiency drip or sprinkler irrigation, and about 1% of the area has no data.

2. Environmental Water Use

MID and TID own Don Pedro Dam and Reservoir and operate these facilities under a license from the Federal Energy Regulatory Commission (FERC). The Districts are currently in the process of renewing the FERC license. The FERC license currently requires minimum releases of between 94,000 and 301,000 acre-feet per year downstream of the dam to protect fisheries, specifically salmon. As a result of an agreement signed in 1995, the minimum flows below La Grange Dam are based on a 10-step water year classification as used by DWR. During wet years the mandated minimum flows are as high as 300 cfs and in consecutive dry years as low as 50 cfs. In addition to the minimum flows, MID and TID release pulse flows in the spring to encourage juvenile salmon to migrate downstream through the Delta and into the open ocean. They also release fall attraction flows to entice and encourage salmon to return to the river for spawning. The actual pre-release flood flows can be several thousand cfs during wet winters. The required minimum flows may be revised in the future as a result of the FERC license renewal.

Required minimum flows have an impact on the amount of water available for beneficial uses. Storage limitations imposed by the State Water Resources Control Board, the minimum in-stream flow requirements imposed by FERC, and flood control rules issued by the USACE, are all factors that govern storage and releases from Don Pedro Reservoir. The volume of in-stream flow releases shown in **Table 26** is based on the 2018 FERC minimum flow requirement; MID's share in 2018 was 70,753 AF.

Table 26 – Environmental Water Uses for 2018

Environmental Resources	Volume (AF)
In-stream flow releases	70,753[1]
Streams	0
Lakes or reservoirs	0
Riparian vegetation	0
Total	70,753

[1]The boundary for the MID water balance presented in the AWMP begins at La Grange Dam, the point where MID diverts water from the Tuolumne River. Since in-stream flow releases from Don Pedro Reservoir aren't diverted at La Grange Dam, these releases are an element of MID operations but aren't included in the accounting of water diverted into the irrigation system that is presented in the AWMP water budget.

3. Recreational Water Use

Don Pedro Reservoir, also known as Don Pedro Lake, has a maximum storage capacity of 2,030,000 acre-feet. Recreational activities at Don Pedro Lake include swimming, camping, fishing, and boating. MID, TID, and CCSF are partners in the operation of the Don Pedro Recreation Agency (DPRA) which administers the recreational activities at Don Pedro Lake.

Modesto Reservoir is also a popular recreational facility offering activities similar to those available at Don Pedro Lake. MID is the sole owner of Modesto Reservoir. Through an agreement, MID leases the recreational facilities at Modesto Reservoir to Stanislaus County.

Table 27 summarizes the facilities' non-consumptive recreational water uses. As seepage and evaporation from Don Pedro Reservoir occur outside of the boundary of the AWMP water balance, and as seepage and evaporation from Modesto Reservoir are accounted for as losses which would occur with or without recreational activity, there are no consumptive uses attributable to recreation that apply to the AWMP water balance.

Table 27 – Recreational Water Uses for 2018

Recreational Facility	Volume (AF)
Don Pedro Reservoir[1]	1,909,000
Modesto Reservoir[2]	22,900
Total	1,931,900

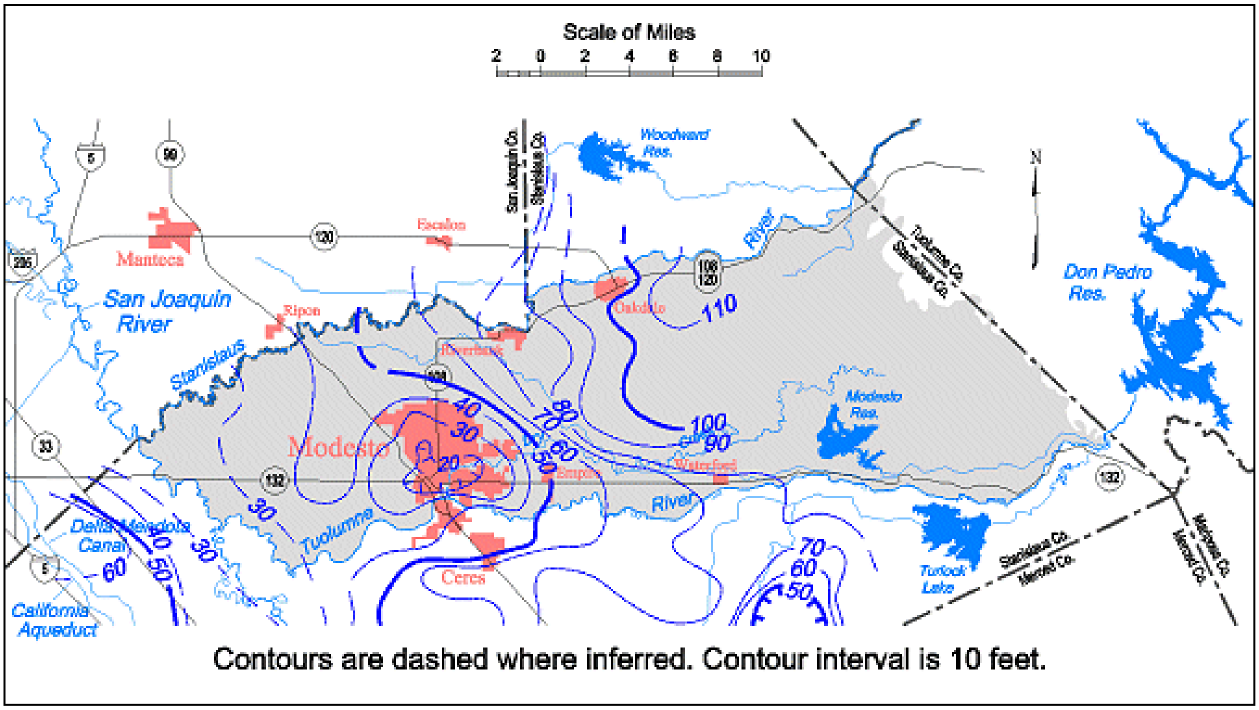
[1]Maximum Storage, USGS Water Data Report for 2018
[2]MID water data

4. Municipal and Industrial Use

Prior to 1995 all M&I water use in the MID irrigation service area was from groundwater pumping. The City of Modesto, other local communities, rural residences, and businesses all pumped groundwater from the Modesto Groundwater Sub-basin for domestic and commercial uses. Beginning in the 1940's, drought conditions and the communities' growth demands contributed to a reduction in groundwater levels and created a cone of depression under the City of Modesto. This cone of depression, combined with increasingly stringent federal and state water quality requirements, prompted a 1983 study of the groundwater supply that recommended a conjunctive water use program that would supplement the M&I groundwater supply with water from the Tuolumne River. Following the recommendations of the 1983 study, MID and the City of Modesto signed an agreement in 1986 to allow MID to pursue the construction of a surface water treatment plant to supply treated water from the Tuolumne River to the City of Modesto. In 1994, MID completed Phase I of the Modesto Regional Water Treatment Plant (MRWTP), a 30-million gallon per day (33,600 acre- foot/year) domestic water project. Since its completion, the plant has been operated by MID and provided approximately 762,589 AF of treated Tuolumne River water to the City of Modesto through 2019. Absent this cooperative local agreement, that volume of water would have come from the Modesto Sub-basin. The City still pumps groundwater to meet their remaining needs, but as intended, the delivery of Tuolumne River water to supply the area's urban needs has contributed to the significant rebound of groundwater levels within the Modesto Sub-basin. Since 1994 groundwater levels beneath the City of Modesto have rebounded by approximately 20 feet, as shown in **Figure 4** and **Figure 5.** With completion of Phase II MRWTP in 2017 MID now has the capacity to deliver up to 67,204 AF of treated surface water to the City of Modesto.

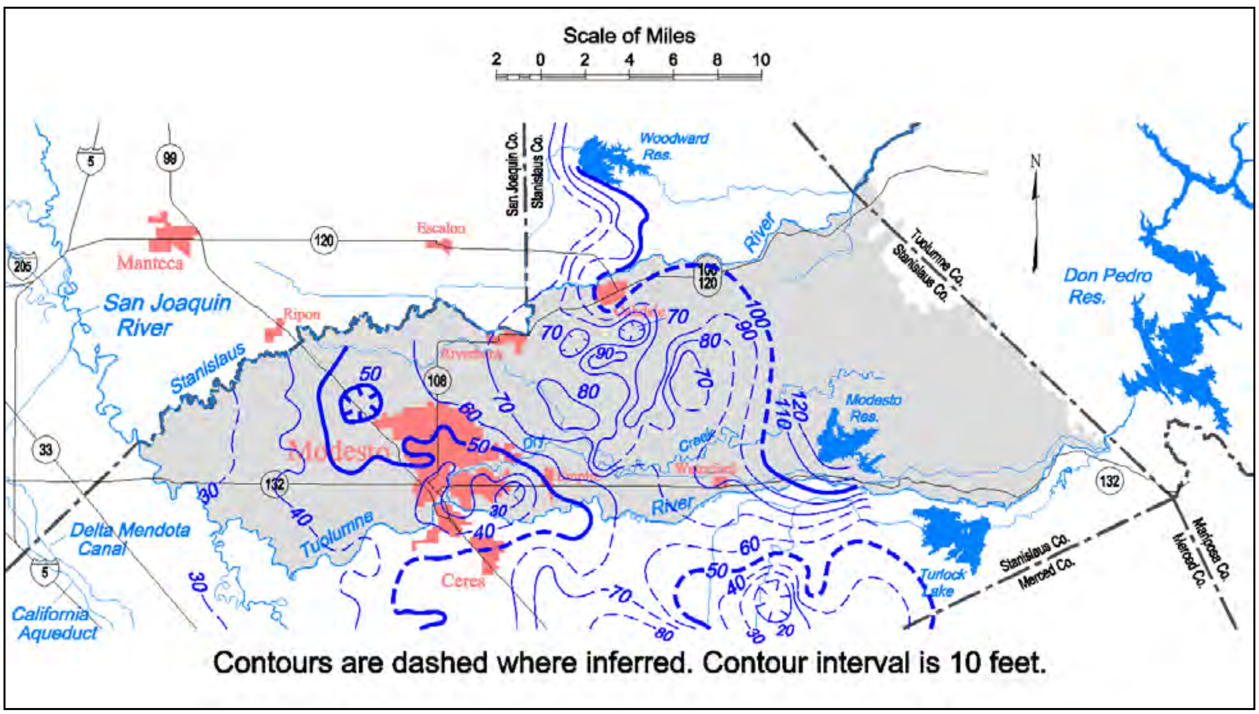
Table 28 – Municipal and Industrial Water Uses for 2018

	Volume (AF)
Municipal Entity	
City of Modesto – Surface Water from MID	30,570
City of Modesto – Groundwater from City wells	17,512
Industrial Entity	
N/A	
Total	48,082



Source: California Department of Water Resources

Figure 4 – Modesto Groundwater Basin, Spring 1994 Groundwater Elevations, Unconfined Aquifer



Source: California Department of Water Resources

Figure 5 – Modesto Groundwater Basin, Spring 2010 Groundwater Elevations, Unconfined Aquifer

5. Groundwater Recharge Use

Most of the groundwater recharge in the Modesto Groundwater Sub-basin is the result of deep percolation of applied surface water to agricultural lands, seepage from canals and reservoirs, and deep percolation of precipitation and urban storm runoff. Seepage from Modesto Reservoir is estimated to be approximately 24,500 acre-feet per year. Approximately 91 percent of MID canals are concrete lined; thus, the amount of canal seepage is relatively small.

Groundwater recharge also occurs in the City of Modesto through deep percolation of landscape irrigation water. Wastewater from the City of Modesto is treated within the City but then exported outside of MID's irrigation service area and doesn't contribute to local crop water demands or groundwater recharge. Deep percolation of City stormwater is included in a water balance parameter Deep Percolation from Precipitation, which is assumed to be 20% of all precipitation falling over the District's irrigation service area.

The overall efficiency of on-farm irrigation application in MID is assumed to be approximately 73 percent when the efficiencies of both level-basin and low volume application systems are combined (USGS, 2004). Because on-farm runoff from MID fields is negligible, the remaining 37 percent of the applied water is assumed to be destined to groundwater recharge with a portion of this recharge satisfying leaching requirements. Total groundwater recharge is estimated to be 125,200 acre-feet in 2018, as shown in **Table 29**. The deep percolation from irrigation exceeds the requirements for crop leaching and, therefore, satisfies the leaching requirement. The importation of surface water contributes substantially to the local groundwater recharge, and far exceeds estimates of groundwater inflow to the District.

It is anticipated that as irrigation methods evolve from surface irrigation to more efficient low-volume micro-irrigation systems, there may be a negative impact on the effective amount of groundwater recharge since the majority of groundwater recharge is obtained currently through on-farm irrigation. Increasing the efficiency of an on-farm irrigation system in a conjunctive use district may reduce the total amount of applied water but won't have a net positive effect on the groundwater because less deep percolation will occur.

The University of California Davis is currently researching the feasibility of flooding permanent crop fields during dormancy as a means of recharging groundwater. This could be a viable opportunity for MID and other local agencies to replenish groundwater within the Modesto Sub-basin. The Modesto Sub-basin Groundwater Sustainability Plan is likely to identify artificial recharge projects within the Modesto Sub-basin to achieve continued sustainability and compliance with SGMA.

Groundwater Replenishment Program (GRP)

Following a very wet water year in 2017, the Modesto Irrigation District Board of Directors directed staff to look at how surplus surface water could be made available to help with sustainable groundwater management within the Modesto Sub-basin. To accomplish this, the

Groundwater Replenishment Plan was created and implemented. This voluntary plan is designed to deliver surface water to eligible landowners outside of MID's irrigation boundaries who are solely dependent on groundwater, but within MID's sphere of influence for the purpose of groundwater replenishment through in-lieu recharge. The surface water MID provides through the program is for agricultural use only and participants must demonstrate that surface water received is put to beneficial use. In 2018 the GRP provided over 2,000 AF of surface water in lieu of groundwater pumping. MID also received first place in the large utilities water programs category for the GRP from the California Municipal Utilities Association's (CMUA) 2020 Resource Efficiency and Community Service Awards.

Table 29 – Groundwater Recharge Water Uses for 2018

Location	Method of Recharge	Volume (AF)
MID Service Area	On-farm Irrigation[1]	79,700
MID Service Area	Canal Seepage	11,900
Modesto Reservoir	Reservoir Seepage	24,500
Modesto Urban Area	M&I Deep Percolation	9,100
	Total	125,200

[1]Calculated assuming all ET demands are met and a 73% irrigation efficiency

6. Transfer and Exchange Use

The District hasn't transferred any water outside its irrigation service area since 2010. **Table 30** summarizes MID activity in external water transfers in 2018.

For the 2014 and 2015 irrigation season, the MID Board approved three special voluntary drought programs. The Farmer to Farmer Delivery Program allowed eligible landowners to transfer all or a portion of their surface water allocation to other landowners in MID's irrigation service area. This allowed for redistribution of water supplies (on a voluntary basis) and helped local agricultural water users to better meet their water demands. This program was authorized again by the MID Board on April 14, 2020 for the 2020 irrigation season. MID is only responsible for processing agreements and is not involved in any financial transactions for this program. Participation in this internal transfer program is not reflected in **Table 30**.

Table 30 – Transfers and Exchanges Water Use for 2018

From What Agency	To What Agency	Type of Transfer or Exchange (Ag to M&I, M&I to Ag, Ag to Ag)	Volume (AF)
Modesto Irrigation District	-	-	0

7. Other Water Use

All water uses of any significance have been described previously in this section. Negligible volumes of water are used within the District for livestock watering, mixing with agricultural chemicals before spraying, and dust abatement. **Table 31** notes that the cumulative water use for these purposes is insignificant.

Table 31 – Other Water Uses for 2018

Water Use	Volume (AF)
No other uses of significance	N/A

8. Projected Water Use

As the developed areas of the City of Modesto and other communities within the MID irrigation service area expand, irrigated land is being replaced by urban land uses. As noted earlier, in 2018 MID delivered 30,571 acre-feet to the MRWTP for the City of Modesto.

Future changes in agricultural water use will be driven by changes in cropping, irrigation practices, climate change, and fluctuations in the hydrology of the Tuolumne River watershed. Although the irrigated service area within MID is expected to remain relatively stable, even considering the impacts of urban expansion, changes in the availability of surface water will continue to influence the annual allocation of water.

Given the unknown nature of the impacts of climate change, as well as possible regulatory impacts on water supply from the FERC relicensing process and the Bay-Delta restoration process, it appears likely that surface water supplies will become less dependable which will lead to an increasing reliance on groundwater and on the conjunctive management practices needed to sustain groundwater elevations. Among the consequences of any future increases in groundwater pumping needed as a substitute for surface water delivered by gravity will be an increase in the energy required for groundwater pumping, as well as the air quality impacts of increased energy use.

Section IV: Description of Quantity and Quality of the Water Resources of the Modesto Irrigation District

1. Water Supply Quantity

a) Surface Water Supply

Water that flows from Don Pedro Reservoir and is re-diverted at La Grange Dam flows through the MID Upper Main Canal and into the Modesto Reservoir. Some water is supplied to water users directly from the Upper Main Canal before it arrives at Modesto Reservoir. From Modesto Reservoir water is diverted into the lower lying downstream irrigation canals for delivery to agricultural lands. Water is also diverted directly from the Modesto Reservoir to the MRWTP. **Table 32** shows MID's water diversions from the Tuolumne River for the years 2015-2019 in acre-feet per year. **Table 33** lists restrictions or imposed limitations on sources of MID water supply.

Table 32 – Surface Water Supplies – Agricultural and Municipal for 2015-2019

Source	Diversion Restriction	2015	2016	2017	2018	2019
MID Water Diverted from the Tuolumne River at La Grange	Water year type, conveyance capacity and licenses	149,442 AF	215,476 AF	295,656 AF	269,479 AF	307,327 AF

Table 33 – Restrictions on Water Sources

Source	Restrictions or Imposed Limitations	Name of Agency Imposing Restrictions	Operational Constraints
Tuolumne River	Pre-1914 Water Rights Pre-1914 Storage Rights	Prior appropriation and use	Limited to unimpaired flow
Tuolumne River	Storage Rights	SWRCB	SWRCB license limits
Tuolumne River	Minimum In-stream Flow Requirements	FERC	In-stream water volume and rate of change in river flow, water year type, FERC license requirements
Tuolumne River	Flood Control	USACE	USACE flood control rule curve

b) Groundwater Supply

Groundwater is pumped in the MID irrigation service area to supplement the surface water supply and to help control high water tables on the west side of the District. The combined pumping capacity of the approximately 94 groundwater wells owned by the District (including production wells and drainage wells), as shown on **Figure 2,** is approximately 250 cfs. However, based on MID's experience during prolonged droughts, pumping at this rate by MID, combined with pumping by other users within the Modesto Groundwater Sub-basin, wouldn't be sustainable over extended periods of time.

The depth to groundwater in the District ranges from approximately ten feet on the west side of the District near the San Joaquin River to over 100 feet east of the City of Modesto. The hydraulic gradient of the unconfined groundwater is generally southwesterly from the mountains toward the valley parallel to the slope of the river channels. In areas influenced by the rivers, by urban pumping centers or by agricultural pumping, the direction of the local groundwater flow gradient is altered significantly.

Long term water-level data in selected wells representing the unconfined to semiconfined aquifer east of Modesto, adjacent to Modesto, and west of Modesto suggest that water levels generally decreased in the eastern and central Modesto area until the early 1990s. A series of wet years, as well as the completion of the MRWTP in 1994, resulted in recent recovery of water levels under the City of Modesto. By contrast, water levels in the unconfined aquifer in the northwestern part of the study area have remained relatively constant during this same period.

Deep percolation of applied surface water to agricultural areas comprises the major source of groundwater recharge for the groundwater basins. Other significant sources of recharge include stream-aquifer interactions and precipitation. **Table 34** summarizes information on the size and capacity of the Modesto Groundwater Sub-basin.

Table 34 – Groundwater Basins

Basin Name	Size (sq. mi.)	Estimated Capacity (AF)[1]	Safe Yield (AFY)
Modesto Sub-basin (DWR Basin 5-22.02)	385	6,500,000	Unknown

[1]DWR Bulletin 118 also states that 14 million AF were stored to a depth of 1,000 feet in 1961. A more recent estimate was not provided.
DWR San Joaquin District Modesto Groundwater Basin Information:
https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Groundwater-Management/Bulletin-118/Files/2003-Basin-Descriptions/5_022_02_ModestoSubbasin.pdf

Sustainable Groundwater Management Act

MID has been actively engaged in sustainable groundwater management within their irrigation service area for more than 25 years. MID will continue to represent the best interests of its growers through a multitude of local groundwater organizations, and the District is optimistic that through State law and the continued cooperation of local water purveyors that MID will bring careful, deliberate and coordinated action to continued groundwater sustainability moving forward.

MID participates in local groundwater management through strategic operation of district-owned production and drainage wells. Groundwater management at the sub-basin level is achieved through cooperation with the Stanislaus and Tuolumne Rivers Groundwater Basin Association (STRGBA). The STRGBA was created in 1994 to provide a forum in which the participating agencies could work cooperatively to provide coordinated planning to make the best use of available water resources of the subbasin to meet the needs of the agencies, and to accomplish the Association’s stated purposes. The current members of the STRGBA include: City of

Modesto, MID, City of Oakdale, Oakdale Irrigation District, City of Riverbank, Stanislaus County, and City of Waterford.

In September 2014, Governor Jerry Brown signed The Sustainable Groundwater Management Act of 2014 (SGMA). The SGMA is a comprehensive three bill package that includes Assembly Bill (AB) 1739 (Dickinson), Senate Bill (SB) 1168 (Pavely) and SB 1319 (Pavely). From MID's perspective, SGMA sets the framework for statewide sustainable groundwater management by local agencies. SGMA requires, among other items, the formation of Groundwater Sustainability Agencies (GSA) and the preparation of Groundwater Sustainability Plans (GSP) with a focus on long-term sustainability in the sub-basin.

In 2017, the STRGBA became the local GSA for the Modesto Sub-basin to comply with SGMA. MID is complying with SGMA through a regional effort involving the seven current members of STRGBA, now the STRGBA GSA. While the region must satisfy numerous requirements for SGMA, the DWR has presently determined that the Modesto Sub-basin is a high-priority basin due to the regional dependence on groundwater, but is not in a condition of critical overdraft (see **Figure 6** below). STRGBA GSA is currently developing their GSP and developing guidelines to comply with SGMA. The GSP will provide further analysis of groundwater conditions within the Modesto Subbasin. The final GSP must be submitted to DWR by January 31, 2022.

Irrigation Wells

Because of the availability of high quality surface water, groundwater pumping by the District as a source of supply has generally been used only to supplement reduced availability of water from the Tuolumne River during consecutive dry years, and to serve areas where it is more difficult to deliver adequate amounts of surface water.

Groundwater pumping becomes crucial in areas adjacent to downstream laterals where flow fluctuations in canals occur most frequently. In gravity water delivery systems, flow fluctuations towards the ends of canals are common due to various factors including farm delivery mismatches, evaporation losses, water being turned on and off, and flow restrictions. In some cases, to avoid the need to divert additional surface water to minimize delivery shortages, groundwater pumping is used to balance differences between water orders and water deliveries. By using the pumps to minimize these fluctuations, the overall system efficiency is improved. One of the functions of the District's Decision Support System (DSS) is to determine which wells to use in order to efficiently minimize mismatches between demands and the availability of water for delivery.

Beginning in the late 1940's, irrigator reliance on District surface water began to change as some field crop land was converted to permanent crops such as orchards and vineyards. Since the mid-1970's, this conversion has accelerated as additional irrigators converted from flood irrigation to low-volume irrigation technologies for convenience and to maximize crop yields. Because low-volume irrigation requires more frequent irrigations and water free from debris, some agricultural water users began converting to groundwater to supply their pressurized irrigation systems when desired rather than continuing to receive surface water on a rotation basis and having to install filtration required for operation of low-volume systems. In an effort to combat this shift and encourage agricultural water users to remain on canal water, and to support conjunctive management, the District provides incentives and develops and implements management strategies which include, but are not limited to:

- Rehabilitation of headworks;
- Deep well optimization to decrease response time;
- Allowing agricultural water users to install new delivery points to provide for more responsive water delivery;
- Construction of the Main Canal Reservoir to improve customer service and irrigation flexibility;
- Recommending the construction of private regulating reservoirs;
- Recommending coordinated planning and construction of multi-landowner pressurized irrigation systems;
- Using full canal capacity to maximize instream storage opportunities;
- Enhancing and encouraging groundwater recharge during wet years;
- Implementing a conservation program, including providing funding for water delivery system improvements, and
- When possible, making water available on demand or arranged demand rather than rotation.

Many of these proposed improvements are documented in the MID CWRMP that is expected to be released for public review in early 2021.

The ability to use groundwater to augment surface water supplies to more efficiently deliver water through the conveyance system is one important benefit of the conjunctive water management approach implemented by the District. If groundwater levels decline to the extent that the operational flexibility afforded by conjunctive management is compromised, additional groundwater management measures will need to be exercised by the District to protect the sustainability of groundwater. Without these measures, increases in private pumping could have far-reaching effects on the area's water supply reliability.

The volume of groundwater pumped by MID and the City of Modesto in 2018 is shown in **Table 35**. Although privately-owned wells are also pumped within the District irrigation service area, the District doesn’t have a reliable estimate of the volume of private pumping. As MID progresses with implementation of SGMA to better understand groundwater conditions, they will seek methods to estimate private groundwater pumping. One potential opportunity could be provided in the coming years as SmartMeters come online which will enable MID to track energy usage by privately-owned wells since MID is the energy supplier, and to possibly apply this usage as a factor in estimating pumping based on pump test results.

Table 35 – Groundwater Supplies for 2018

Groundwater Users	Volume (AF)
MID Direct Pumping[1]	19,800
City of Modesto Pumping[2]	17,500
City of Waterford	1,100
Total	38,400

[1]MID pumping includes deep well irrigation pumping as well as drainage pumping on the western part of the District
[2]City of Modesto M&I pumping based on city records

c) Other Water Supplies

During the 2018 irrigation season, approximately 7,824 acre-feet of non-recoverable outflow from OID entered MID canals. The OID non-recoverable outflows entering the MID system aren't scheduled; therefore, MID can't always fully utilize this inflow. However, MID constructed the new Main Canal Reservoir Project in 2019 and it became operational for the 2020 irrigation season. Under this project MID constructed the Pelton Flume downstream of the regulating reservoir which has the capability of accounting for a portion of OID discharges into the MID system. The MID Lower Main Canal directs corresponding flow into the regulating reservoir in order to make use of the unanticipated inflows. More time will be needed in order to analyze the amount of water saved. MID plans to construct a regulating reservoir downstream of the Pelton Flume to capture all OID non-recoverable outflows in the future.

d) Drainage from the Water Supplier's Surface Area

Drainage wells have been employed by the District to control shallow groundwater in the western part of the District since 1918. Drainage wells are relatively shallow (usually less than 100 feet deep) and are perforated throughout their depth. They are generally pumped during the irrigation season to maintain groundwater levels below the crop root zone, which helps control root zone salinity and allows for healthy root development and growth.

Where sufficient downstream demand exists, drainage wells are used as irrigation water supply wells to supplement surface water. In these areas, the groundwater levels are below the root zone and are not damaging to the crops. Although drainage well water is generally of poorer quality than surface water, it is suitable for agriculture. As **Table 36** summarizes, there are no flows to saline sinks and flows to a perched water table are minimal.

Table 36 – Drainage Discharge for 2018

Surface/Subsurface Drainage Path	Volume (AF)
Flows to saline sink	N/A
Flows to perched water table	Minimal

e) Water Supply Reliability

The average calculated median annual unimpaired runoff from the Tuolumne River basin at La Grange is approximately 1,752,765 acre-feet (1901 – 2019 records). However, the annual runoff is highly variable with no predictable year-to-year correlation. Historic annual runoff values have ranged from 468,270 acre-feet in 1977 to 4,814,000 acre-feet in 1983. Therefore, water storage facilities and conjunctive management practices that carry over water from years of abundance to dry years are critical for the well-being of the communities who depend on the river. The importance of water storage and conjunctive management became particularly apparent during the prolonged droughts of 1987-1992 and 2012-2015.

Excluding consecutive dry years, sufficient natural precipitation and watershed runoff occurs to satisfy the local agricultural and domestic needs. During consecutive dry years, the District relies on carryover storage and irrigation wells to supplement river water diversions. However, in recent years increased demands on MID's water supplies, such as additional fish flows, domestic water needs, and SGMA are creating greater uncertainty. As a result, MID is continuously developing new technologies and adopting conservation techniques to manage its water supply. For example, MID has expanded its Supervisory Control and Data Acquisition (SCADA) system to better monitor and manage the water flows in the water distribution system and has implemented a Well Field Optimization Decision Support System (DSS) to increase the efficiency of groundwater use. MID also built its first regulating reservoir in 2019 under the Main Canal Reservoir Project, which went into operation in 2020. MID regularly works with agricultural water users to improve on-farm water application to both increase crop productivity and to improve on-farm water use efficiency.

The MID Comprehensive Water Resources Management Plan (CWRMP) will be an important guidance document in helping to improve water supply reliability by reviewing previous planning efforts and performing additional analysis through a comprehensive water management approach. More information on the CWRMP can be found in Section I.1.

f) Future Water Supply

MID derives all of its surface water from diversions from the Tuolumne River; therefore, future changes in the MID water supply will be driven by changes in hydrology and particularly by the volume, nature, and timing of precipitation in the Tuolumne River watershed. Although the extent of which is currently unknown, potential impacts on the District’s water supply include the on-going FERC relicensing process and the Bay-Delta restoration process. The discussion presented in Section VI of this AWMP describes how climate change may affect the hydrology of the Tuolumne River watershed.

Future surface water supplies are also threatened by loss of Tuolumne River diversions to enhance river fisheries and Delta water quality. On December 12, 2018, the State Water Resources Control Board (SWRCB) adopted Phase 1 of its Bay-Delta Water Quality Control Plan which, if implemented, will require 40 percent of unimpaired flow, for February–June for the Stanislaus, Tuolumne, and Merced Rivers through to the San Joaquin River near Vernalis. This would substantially alter water use in the area resulting in severe water shortage for municipal and agricultural water users in addition to potentially significant impacts to continued groundwater sustainability within the Modesto Sub-basin. MID is actively engaged in this process to try to minimize impacts on the District's water users. MID continues to innovate and explore ways of making our water supplies go further with increased efficiencies and conservation efforts. MID remains aware of the many possible outcomes from future SWRCB decisions and will continue to participate in future discussions about our water supply.

The secondary source of water supply for the District is groundwater. Although not immediately affected by changes in surface water hydrology, local groundwater is a derivative of surface water hydrology in that groundwater recharge is driven by percolation of applied irrigation water, municipal water, and precipitation. Conversion of irrigation methods from surface irrigation to more efficient low-volume micro-irrigation systems will have a negative impact on the effective amount of groundwater recharge since the majority of groundwater recharge is obtained currently through on-farm irrigation. While MID has no way to control the volume of water flowing into Don Pedro Reservoir, the District's conjunctive management program provides mechanisms for generating deep percolation needed to maintain sustainable groundwater levels within MID's irrigation service area. Therefore, while changes in watershed hydrology may reduce the reliability of surface water from the Tuolumne River watershed in ways the District can't control, the District is committed to adapting its water management practices, particularly its exercise of conjunctive management, to respond to these changes as best it can so long as adequate surface water supplies exist.

Critically Overdrafted Groundwater Basins – January 2016 — North Central and South Central Regions

Source: DWR

Figure 6 – Critically Overdrafted Groundwater Basins

2. Water Supply Quality

MID's groundwater and surface water quality is generally good to excellent. Surface water diverted from the Tuolumne River originates from snowmelt in the high Sierras. The water is of excellent quality with a total dissolved solids (TDS) content of less than 20 ppm as shown in **Table 37**. Groundwater used for irrigation is also of relatively high quality with a TDS generally less than 500 ppm.

MID performs water quality monitoring consistent with the CVRWQCB Irrigated Land Regulatory Program (ILRP) through participation in the East San Joaquin Water Quality Coalition. MID conducts real-time water quality analyses on several operational outflows. Water quality sensors collect data for temperature, conductivity and pH which can be monitored through SCADA.

a) Surface Water Supply Quality

The Tuolumne River watershed covers approximately 1,880 square miles of the western slopes of the central Sierra Nevada Mountains including portions of the Yosemite National Park. Snowmelt from the central Sierra Nevada is of excellent quality. For example, surface water diverted from the Tuolumne River at La Grange has a TDS of approximately 19.6 milligrams per liter (mg/l). Other water quality constituents that impact agricultural and domestic water use are also very low or negligible. The quality of the river water is fairly consistent from year to year. As runoff from agricultural and developed land is introduced into the lower part of the river, the overall water quality degrades some, but remains good.

Table 37 – Modesto Reservoir Average Water Supply Quality for 2018

Parameter	Units	Value
Al	mg/l	0.058
As	µg/l	ND
Ba	mg/l	ND
Ca	mg/l	2.7
Cu	µg/l	6.7
Fe	mg/l	0.067
Mg	mg/l	1.0
Se	µg/l	ND
Na	mg/l	1.4
TDS	mg/l	19.6

b) Groundwater Supply Quality

Groundwater quality in the District ranges from mostly good in the unconfined aquifer to poor in some areas of the confined aquifer. Total TDS in groundwater in the eastern two-thirds of the District is generally less than 500 mg/L with a range from 63 mg/L to 500 mg/L. High TDS (2,000 mg/L) groundwater is present beneath the District at a depth from about 400 feet in the west to about 800 feet in the east. This degraded water originates in marine sediments underlying the San Joaquin Valley and is not used for irrigation. The shallowest high TDS groundwater (TDS greater than 1,000 mg/L) occurs around 120 feet below land surface within a 5 to 6-mile-wide zone parallel to the San Joaquin River.

c) Other Water Supplies

Other water supplies include operational outflows from Oakdale Irrigation District (OID) into Modesto Irrigation District. In the past these have been estimated to average 17,000 AF/year. In recent years operations within OID have improved and the spills were estimated to be 7,824 AF in 2018.

d) Drainage from the Water Supplier's Surface Area

Subsurface drainage for lands served by MID is controlled with drainage wells. Subsurface drainage control is required in the western portions of the District where high water tables are typical. Therefore, there is currently no need for on-farm subsurface drainage systems, because the shallow groundwater is generally of good quality (less than 500 ppm of dissolved solids) and is suitable for most irrigation purposes. During the irrigation season, some drainage well water is used to supplement the District's irrigation water supply. The use of drainage wells to supplement surface water serves as a source of supply during consecutive dry years and improves the overall efficiency of the water delivery system by making water available where and when it is needed.

On-farm tailwater drainage within the District's service area is minimal due to the prevalence of low-volume and level-basin irrigation systems. In cases where on-farm tailwater is generated, the water users typically contain it within their property, especially at dairies. In some instances, surface drainage water is recycled by downstream water users. As presented in **Table 39**, the quality of water which enters the MID system from Modesto Reservoir is high. As a result, water quality throughout the system remains very good and doesn't limit the reuse of drainage water as shown in **Table 38**.

Table 38 – Drainage Reuse Effects

Analyte	Drainage Reuse Limitations				
	Increased Leaching	Blending Supplies	Restricted Area of Use	Restricted Crops	Other
TDS	No Limitation	No Limitation	No Limitation	No Limitation	N/A

3. Water Quality Monitoring Practices

a) Source Water

MID monitors the quality of water diverted from the Modesto Reservoir and pumped from groundwater in compliance with several water quality monitoring programs. **Table 39** provides general information on monitoring of source water quality in the District.

Table 39 – Water Quality Monitoring Practices

Water Source	Monitoring Location	Monitoring Practice	Frequency of Analysis
Surface Water	Various canal locations	Agricultural Suitability, state-wide aquatic herbicide general permit	Periodically and in compliance with permit requirements
Surface Water	Real-time monitoring locations on Lateral 3, Lateral 4, and Lateral 6	Agricultural Suitability	Continuous
Surface Water	Modesto Reservoir	Domestic Water Quality Standards	Daily
Groundwater	Irrigation water wells	Agricultural Suitability	Annually

b) Drainage Water

As noted on **Table 40**, MID conducts periodic monitoring and analyses of surface drainage and groundwater.

Table 40 – Water Quality Monitoring Programs for Surface and Sub-Surface Drainage

Monitoring Program	Analyses Performed	Frequency of Analysis
Surface Water	Ag-Suitability Lab	Periodically
Groundwater	Ag-Suitability Lab	Annually
Surface Water	EC, Temp, pH	Continuously
Aquatic Herbicide General Permit	Permit Requirements	Permit Requirements

Section V: Water Budget

1. Quantifying the Modesto Irrigation District's Water Supplies

a) Modesto Irrigation District's Water Quantities

Tuolumne River water diversions at La Grange Dam vary from year to year depending on the weather, the amount of runoff, and operational considerations. For purposes of the AWMP, 2018 is the reference year. Water year 2018 was classified as a "Below Normal" year on the Tuolumne River watershed and was a typical water delivery year for MID in terms of surface water diversions from the Tuolumne River. The irrigation season started on February 25, 2018 (March 15 is the typical start) and ended on November 2, 2018 (typical end being October 31). **Table 42** summarizes monthly diversions from the Tuolumne River to the MID water delivery system in 2018.

In addition to water diverted from the Tuolumne River, MID, the City of Modesto, and other local communities and agricultural water users pump groundwater. MID reporting of groundwater pumping includes drainage water pumped to lower the shallow water table in the western part of the District. Most of the water pumped by MID was used to supplement surface water when the local demand was greater than the available surface water supply, a practice that eliminates ordering make-up water from a reservoir several miles away.

Table 41 summarizes the quantity of groundwater pumped by MID and the City of Modesto in 2018. The quantity of water pumped from privately-owned wells within the District boundaries isn't included in this AWMP's accounting of groundwater pumping because there are now no reliable estimates of the extent of private pumping.

Table 41 – Groundwater Supplies Summary for 2018

Month	MID Total[1] (AF)	City of Modesto Total[2] (AF)	Total (AF)
January	12	898	910
February	557	918	1,475
March	125	904	1,029
April	497	1,039	1,536
May	2,138	1,715	3,853
June	2,212	1,963	4,175
July	3,122	2,197	5,319
August	4,096	2,208	6,304
September	3,777	2,179	5,956
October	3,131	1,631	4,762
November	87	994	1,081
December	1	866	867
Total	19,755	17,512	45,682
		City of Waterford[3] (AF)	1,131
		Total	**38,398**

[1]MID pumping includes deep well irrigation pumping and drainage pumping in the western part of the District
[2]City of Modesto M&I pumping based on city records
[3]Waterford monthly data not available

Table 42 – Surface and Other Water Supplies for 2018

Source	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Tuolumne River	3,978	6,615	9,334	18,170	39,340	40,940	49,580	39,900	32,990	20,970	7,239	423	269,479
Transfers & Exchanges	0	0	0	0	0	0	0	0	0	0	0	0	0
Recycled Water	0	0	0	0	0	0	0	0	0	0	0	0	0
OID Operational Outflow[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	7,824
													277,303

[1]OID operational outflow was estimated to be 7,824 AF. There are no measurements of the monthly distribution of this flow.
All totals are in acre-feet

b) Other Water Sources Quantities

Surface water diverted from the Tuolumne River and groundwater are the two sources of water actively managed by MID. Another and more variable source of water available to District lands is effective precipitation. Effective precipitation was estimated using a method developed by DWR specifically for the San Joaquin Valley and documented in a 1989 DWR publication entitled Effective Precipitation (MacGillivray and Jones). **Table 43** includes estimated values of effective precipitation for 2018. Lastly, operational inflows from Oakdale Irrigation District are another supply. They were estimated to be 7,824 AF in 2018.

Table 43 – Effective Precipitation Summary for 2018

Month	Volume (AF)
January	8,800
February	0
March	3,200
April	0
May	0
June	0
July	0
August	0
September	0
October	0
November	8,000
December	6,400
Total	26,400

2. Quantification of Water Uses

Table 44 shows the volume of surface water delivered to MID irrigation customers in 2018. The volume of water delivered is based on measurements to customers used as the basis for computing water charges.

Table 44 – Applied Water for 2018

	Volume (AF)
Delivered surface water charged to landowners	126,130

During 2018, there were estimated to be 62,333 acres irrigated by either groundwater or surface water within the District and crop evapotranspiration of applied water during that year was estimated to be 215,676 acre-feet (after effective precipitation).

Seepage losses from the canal system are based on canal loss calculations performed by the Kings River Water Conservation District on canals of similar characteristics as those at MID and preliminary canal seepage tests conducted by MID. Modesto Reservoir seepage losses are based on preliminary water seepage calculations performed at the end of each irrigation season. The 30,571 acre-feet for M&I surface water usage were based on the actual 2018 water deliveries to the City of Modesto in accordance with the treatment and delivery agreement. **Table 45** summarizes the amount of on-farm surface and subsurface drainage water leaving the service area. As discussed earlier, the amount of on-farm drainage water leaving the service area is minimal.

Table 45 – Quantity of Water Leaving the District for 2018

Drain Water	Volume (AF)
Surface water	Minimal
Subsurface water	Minimal
Subtotal	Minimal

There are no flows to saline sinks or perched water tables within the District as indicated in **Table 46**.

Table 46 – Irrecoverable Water Losses for 2018

Drain Water	Volume (AF)
Flows to saline sink	N/A
Flows to perched water table	N/A
Subtotal	N/A

3. Annual Water Budget

Surface water is the volume of water diverted from the Tuolumne River to the MID water system as shown on **Table 42**. The groundwater volume includes MID pumping from deep wells and drainage pumping on the western part of the District, City of Modesto pumping, City of Waterford pumping, and an estimate of private groundwater pumping. The total rainfall in Modesto for the period of January 2018 to December 2018 was 11.40 inches. Annual effective rainfall precipitation was determined using empirical equations developed for the San Joaquin Valley. The effective precipitation based on annual rainfall over 62,333 acres of irrigated land was 26,400 AF or 0.42 feet per acre. This parameter is also called Evapotranspiration of Precipitation.

An overall water balance for MID is presented in **Table 47**. The water balance shows all of the water supplies, demands, modes of groundwater recharge, and non-recoverable losses. The inflows and outflows to the groundwater basin are compared to the estimated change in groundwater storage from changes in groundwater levels. The two values agree relatively well, and the annual water balance is considered acceptable.

The water balance shows that MID water contributes significantly to the local groundwater recharge through deep percolation of irrigation water, canal seepage and reservoir seepage.

Table 47 – Overall Water Balance for 2018

Description	Symbol	Volume	Source
	Irrigation Eff.	73%	
Description	**Symbol**	**Volume**	**Source**
Supply			
1. Surface Water – Irrigation	Qirr	238,900	Measured
2. Surface Water – M&I	Qmi	30,600	Measured
3. Groundwater Pumping – Irrigation (Agency Wells)	Gwirra	19,800	Measured
4. Groundwater Pumping – Irrigation (Private Wells)	Gwirrp	104,400	Residual
5. Groundwater Pumping – M&I (Agency Wells)	Gwmia	18,600	Measured
6. Groundwater Pumping – M&I (Private Wells)	Gwmip	0	Calculated
7. Precipitation	P	97,900	Measured
8. Spill Inflows: Oakdale Irrigation District	Si	7,824	Calculated
9. Other Supply	Os	0	Calculated
Total Supply		**518,024**	
Demand			
Consumptive Use			
10. Evapotranspiration – Applied Water	ETc	215,700	Calculated
11. Evapotranspiration – Effective Precipitation	ETp	26,400	Calculated
12. Evapotranspiration – M&I	ETmi	21,300	Calculated
13. Other Consumptive Use:	Od	0	
Consumptive Subtotal		**263,400**	
Groundwater Recharge			
14. Groundwater – Inflow	GWi	7,600	Calculated
15. Deep Percolation – Irrigation	PRCirr	79,700	Calculated
16. Deep Percolation – Precipitation	PRCp	19,600	Calculated
17. Deep Percolation – M&I	PRCmi	9,100	Calculated
18. Seepage – Channels (& Pipeline Leakage)	Sch	11,900	Calculated
19. Seepage – Reservoirs	Sr	24,500	Calculated
20. Urban Stormwater – Recharge	Rus	0	Calculated
21. Local Streams/Rivers – Recharge	Rst	-10,000	Calculated
22. Groundwater – Intentional Recharge	Rint	0	Measured
23. Other Recharge:	Or	0	
GW Recharge Subtotal		**142,400**	
Nonrecoverable Losses			
24. Groundwater – Outflow	GWo	1,900	Calculated
25. Evaporation – Channels	Ech	2,400	Calculated
26. Evaporation – Reservoirs & Recharge Basins	Er	9,200	Calculated
27. Precipitation – Evaporation and Runoff	Ep	51,900	Residual
28. Operational Spills	S	37,400	Measured
29. Groundwater – Export	GE	0	Measured
30. Other Losses:	Ol	0	
Nonrecoverable Subtotal		**102,800**	
Method 1			
Estimated Annual Change in Groundwater Storage		**(2,300)**	
GW Recharge - #14 thru #23	142,400		Calculated
GW Pumping - #3 thru #6	(142,800)		
GW Outflow - #24 and #29	(1,900)		

Some of the parameters in the water balance aren't discussed in this AWMP but were calculated as part of the District's water balance model. **Table 48** shows each parameter in the water balance shown in **Table 47** where it is found in this AWMP, or the basis for its calculation if it isn't presented herein.

Table 48 – Water Balance Parameters and Information Sources

No.	Parameter	Source
1	Surface Water – Irrigation	Table 32
2	Surface Water – M&I	Table 22 & Table 32
3	Groundwater Pumping – Irrigation (Agency Wells)	Table 35 & Table 41
4	Groundwater Pumping – Irrigation (Private Wells)	No data available. Back calculated from other parameters.
5	Groundwater Pumping – M&I (Agency Wells)	Table 35 & Table 41
6	Groundwater Pumping – M&I (Private Wells	Assumed to be negligible (USGS Report 2015-5045)
7	Precipitation	Table 9 (annual precipitation x District area)
8	Spill Inflows – Oakdale ID	Data provided by Oakdale ID
9	Other Supply	Not Used
10	Evapotranspiration – Applied Water	Table 23
11	Evapotranspiration – Effective Precipitation	Table 43
12	Evapotranspiration – M&I	Assumed 65% of M&I water used outdoors with 70% landscape irrigation efficiency
13	Other Consumptive Use	Not Used
14	Groundwater – Inflow	Calculated using data in USGS Reports 2004-5232 and 2015-5045. USGS acknowledged this parameter is very difficult to estimate and can be a source of error.
15	Deep Percolation – Irrigation	Table 29
16	Deep Percolation – Precipitation	Assumed to be 20% of total precipitation based on data in USGS Professional Paper 1766
17	Deep Percolation – M&I	Table 29
18	Seepage – Channels (& Pipeline Leakage)	Table 29 plus 2,500 AF City of Modesto pipeline leakage (USGS Report 2004-5232)
19	Seepage – Reservoirs	Table 29
20	Urban Stormwater – Recharge	See #16 Source
21	Local Streams/Rivers – Recharge	Estimated from data in USGS Report 2015-5045 (Fig. 35)
22	Groundwater – Intentional Recharge	None in the area
23	Other Recharge	Not Used
24	Groundwater – Outflow	Calculated using data in USGS Reports 2004-5232 and 2015-5045. USGS acknowledged this parameter is very difficult to estimate and can be a source of error.
25	Evaporation – Channels	Previously estimated by MID
26	Evaporation – Reservoirs & Recharge Basins	Previously estimated by MID
27	Precipitation – Evaporation & Runoff	Calculated as Precip. – Effective Precip. – Deep Percolation of Precip.
28	Operational Spills	Measured annually by MID
29	Groundwater – Export	Table 30
30	Other Losses	Not Used
	Irrigation Efficiency	CH2M Water Balance Tool Development Report, 2018
	Change in Groundwater Storage	Estimated with change in average groundwater level in MID

4. Identify Water Management Objectives

Established in 1894 as the second irrigation district in California, MID has been committed to its stated mission of providing electric, irrigation and domestic water services for its customers, delivering the highest value at the lowest cost possible through teamwork, technology, innovation, and commitment. MID strives to uphold this mission and commitment to its customers while carefully managing precious, local water resources. The following water management efforts and practices have been implemented with these goals in mind, with continuous evaluation and efforts to improve water management.

a) Volumetric Pricing Structure. Section II-2.c,

The MID Board annually establishes a water rate based on budget requirements and board policy. In 2015, the District implemented a revamped water rate structure inclusive of a volumetric component to comply with one of the mandatory EWMPs of SBx7-7. The water rate structure used since 2015, is to assess a fixed charge (based on acres served) to all agricultural water users, and to volumetrically charge for all water use on an increasing block rate or tiered pricing structure. The pricing strategy aligns with MID's conjunctive management practices and is set to encourage surface water use in lieu of groundwater. Efforts to improve water delivery measurement for volumetric pricing are on-going.

b) Water Shortage Allocation Policies. Section II-2.d,

With varying surface water supplies that are reliant on watershed precipitation, snow melt runoff and carryover storage in Don Pedro Reservoir, the MID Board of Directors adopts a water allocation each year with the goal of meeting customer expectations while balancing near-term and long-term water supplies. In wet years, the allocation is set to leverage available supplies and maximize carryover for the following season. Dry years rely heavily on storage maintained in Don Pedro Reservoir and groundwater resources. MID's internal planning tool has been designed to provide staff with the ability to calculate an allocation given the estimated water resources available to MID within a given irrigation season, runoff forecasts, commitments, and the desired carryover storage.

c) Conjunctive Management. Section VII-1,

The District remains committed to maintaining a balance between surface water and groundwater as sources of supply and has pursued pricing policies and operational practices that support conjunctive management. The effort required to sustain groundwater levels and retain the ability to tap this resource during periods of prolonged drought has served the District and its landowners well and may serve as an effective mechanism for meeting requirements of the Sustainable Groundwater Management Act (SGMA) and responding to the effects of climate change. In addition, surface water deliveries to the City of Modesto for domestic use in lieu of groundwater pumping adds to the District's conjunctive use portfolio. The district's Groundwater Replenishment Program is a voluntary plan that is designed to deliver available surface water to eligible landowners outside of MID's irrigation boundaries who are solely dependent on groundwater, but within MID's sphere of influence for the purpose of groundwater replenishment through in-lieu recharge.

d) System Efficiency Improvements.

MID has a long history of innovation and proactive efforts in improving system performance. A central consideration in the District's determination of how best to implement a program of EWMPs for improving water management is the District's goal of providing flexible, reliable service to its agricultural water users. The requirements of customer service are changing within MID as many landowners are transitioning from producing field crops to producing permanent crops and shifting from flood irrigation toward pressurized, low-volume drip and micro-sprinkler systems. To meet these changing needs, MID employs a number of programs including robust remote monitoring and control, on-farm conservation incentives, infrastructure modernization, and both short- and long-term planning.

- Remote monitoring and control has been implemented at all MID headworks sites, operational spills, and strategic locations throughout the District. The automation of water distribution and operational outflow facilities gives the District greater flexibility to manage the water distribution system and increases the reliability of on-farm water deliveries.
- MID encourages its landowners to improve their on-farm irrigation systems and has made matching funds available to it growers through the conservation program for over 30 years, investing millions of dollars over that period to improve on-farm irrigation efficiency.
- System improvement and modernization is an ongoing effort guided by MID's Comprehensive Water Resources Management Plan. The most recent efforts included construction of the Main Canal Reservoir, which has enhanced MID's ability to efficiently meet system demands, improve response time, and decrease operational outflows. Additional reservoir sites and potential system interconnections are being evaluated to further improve operational efficiency.
- Water Operations staff uses the AWMP as a short term (5 year) planning document complimenting its long-term Comprehensive Water Resources Management Plan (CWRMP). The District's CWRMP is a multi-phase effort intended to incorporate elements of prior planning efforts, new information, and creative ideas into a comprehensive plan to guide future water management decisions.

5. Quantify the Efficiency of Agricultural Water Use

To help quantify the agricultural water use efficiency within the MID service area, the Water Management Fraction (WMF) quantification methodology developed by DWR was selected. The WMF method best accounts for the water supplies available in the MID service area and may inform the District if and where improvements can be made. The WMF was calculated by comparing the Evapotranspiration of Applied Water (ETAW) and the Recoverable Flows (RF) to the Total Water Supplies Available (AW) throughout the MID service area. For this analysis the WMF was calculated as shown below, where AW equals the total surface water supplies available for irrigation minus losses such as system seepage and evaporation and operational spills (SW) plus total groundwater pumping from MID wells and private wells (GW). See **Table 47** for description of variables in italics.

- Water Management Fraction (WMF) = (ETAW + RF) / AW
    - ETAW = *ETc*
    - RF = *PRCirr*
    - AW = SW + GW
        - SW = *Qirr + Si – Sch – Sr – Rst – Ech – Er – S*
        - GW = *Gwirra + Gwirrp*

Table 49 – Water Management Fraction

Evapotranspiration of Applied Water (ETAW)	Recoverable Flows (RF)[1]	Total Water Supply Available (AW)	Water Management Fraction (WMF)
Acre-Feet per Year	**Acre-Feet per Year**	**Acre-Feet per Year**	
215,700	79,700	295,524	0.999

[1]RF= Deep Percolation of Irrigation Water (see Table 47)

As can be seen from the high water management fraction, almost all of the District's water supplies are used to meet irrigation demands or are recovered to beneficially recharge the groundwater table.

Section VI: Climate Change

1. Effects of Climate Change on Water Supply

The future availability of the MID water supply will be driven by changes in hydrology and particularly by the volume, nature, and timing of precipitation in the Tuolumne River watershed. In addition to direct impacts on surface water supplies, climate change may indirectly affect groundwater resources. This section describes analyses of how climate change may affect the hydrology of the Tuolumne River watershed.

The most recent study of the possible effects of climate change on the Tuolumne River watershed was conducted by the Turlock Irrigation District along with San Francisco Public Utility Commission (SFPUC) in January 2012 (Hydrocomp et al. 2012). The purpose of this study was to determine streamflow sensitivities to possible increases in temperature and change in precipitation due to climate change, rather than attempting to address potential water supply impacts. The study evaluated changes in streamflow and watershed hydrologic response to potential temperature and precipitation changes for the years 2040, 2070, and 2100, as compared to the base year of 2010. Hydrologic processes were simulated using a physically based conceptual model. The following excerpt is from the Executive Summary of the Hydrocomp study which does an excellent job at presenting the results:

"Climate Change Scenarios: Climate change scenarios for this study were selected to represent a range of possible future climate conditions based on the range of predictions by global climate models. **Table 50** lists the potential future climate condition in terms of a change in temperature and precipitation from the 2010 conditions for the years 2040, 2070 and 2100 for each climate change scenario. A 34-year stationary meteorological database was developed and the increments shown in **Table 50** were used to create adjusted temperature and precipitation timeseries that represent potential future conditions for each climate change scenario. This technique allowed the analysis of a 34-year period with consistent climate conditions at three future dates, each of which had six combinations of temperature and precipitation changes.

Hydrologic Simulation Model: The Hydrocomp Forecast and Analysis Model (HFAM) a hydrologic model of the Tuolumne River Watershed, developed by Hydrocomp over a twelve year period for the Turlock Irrigation District (TID), was used in this study to simulate the watershed's hydrologic response to precipitation, temperature, evaporation, solar radiation and wind. The model calculates the hydrologic response of more than 900 land segments in the watershed above Don Pedro and routes runoff downstream to reservoirs through 75 channel reaches. Each land segment represents the elevation, soil and rock outcrop, vegetation and aspect associated with a portion of the watershed. The model performs detailed mass and energy budget calculations to simulate the hydrologic cycle on each land segment. By combining and routing the flow from each segment, the model provides detailed information on the effects of basin wide temperature and precipitation changes on runoff, snow, evapotranspiration, and soil moistures.

Table 50 – Constructed climate change scenarios with temperature increases and precipitation changes

Scenario	Description	Mean Annual Temperature (°F(°C))[1]			Mean Annual Precipitation (in)[1]		
Current Conditions	2010 Conditions	55.1 (12.8)			36.9		
Future Climate Change Scenarios		Change from Base (°F(°C))[2]			Change from Base (%)[3]		
		2040	2070	2100	2040	2070	2100
1A	Low temperature increase no precipitation change	+1.1 (0.6)	+2.3 (1.3)	+3.6 (2)	0	0	0
2A	Moderate temperature increase no precipitation change	+1.8 (1)	+4.0 (2.2)	+6.1 (3.4)	0	0	0
2B	Moderate temperature increase precipitation decrease	+1.8 (1)	+4.0 (2.2)	+6.1 (3.4)	-5	-10	-15
2C	Moderate temperature increase precipitation increase	+1.8 (1)	+4.0 (2.2)	+6.1 (3.4)	+2	+4	+6
3A	High temperature increase no precipitation change	+3.0 (1.65)	+6.3 (3.5)	+9.7 (5.4)	0	0	0
3B	High temperature increase precipitation decrease	+3.0 (1.65)	+6.3 (3.5)	+9.7 (5.4)	-5	-10	-15

[1]Mean annual temperature and precipitation at HTH (Hetch Hetchy) station.
[2]Temperature increases are given in degrees F (degrees C) added to the current conditions static meteorological database.
[3]Precipitation changes are given in percent change to the 2010 current conditions static meteorological database.

Simulated Reservoir Inflows: Climate change in the Tuolumne River affects snow accumulation and melt, soil moisture and forests, reservoir inflows, and the water supplies available for all purposes. **Table 51** summarizes the modeling results in terms of the change in simulated median annual runoff at O'Shaughnessy and Don Pedro dams for the different future climate conditions (climate change scenario at future climate date).

Simulated changes in median annual runoff do not fully describe how water supplies would be affected. When firm yield from reservoirs is evaluated, low runoff years are critical. Climate change effects are exacerbated in low runoff years. **Table 52** summarizes the modeling results in terms of the change in simulated 5 (extremely wet), 50, and 95 (critically dry) percent exceedance annual runoff for two climate change scenarios, 2A moderate temperature increases with no precipitation change, and 3B high temperature increases with precipitation decreases.

Table 51 – Change in median runoff volume for future climate conditions

Climate Change Scenario		O'Shaughnessy Runoff (% change from 2010)			Don Pedro Runoff (% change from 2010)		
		2040	2070	2100	2040	2070	2100
1A	Low temperature increase no precipitation change	-0.7%	-1.5%	-2.6%	-1.1%	-2.4%	-3.6%
2A	Moderate temperature increase no precipitation change	-1.2%	-2.9%	-5.4%	-1.8%	-4.0%	-6.4%
2B	Moderate temperature increase precipitation decrease	-7.6%	-15.8%	-24.7%	-9.5%	-19.1%	-28.7%
2C	Moderate temperature increase precipitation increase	1.4%	2.2%	2.4%	1.1%	2.0%	2.8%
3A	High temperature increase no precipitation change	-2.1%	-5.6%	-10.2%	-3.0%	-6.5%	-10.1%
3B	High temperature increase precipitation decrease	-8.6%	-18.6%	-29.4%	-10.7%	-21.6%	-32.3%

Table 52 – Change in runoff volume for future climate conditions for extremely wet, median, and critically dry years (based on results from 1975-2008)

Climate Change Scenario		Example Years	O'Shaughnessy Runoff (% change from 2010)			Don Pedro Runoff (% change from 2010)		
			2040	2070	2100	2040	2070	2100
2A	Moderate temperature increase no precipitation change	Extremely Wet	-0.6%	-1.4%	-2.4%	-1.1%	-2.6%	-3.7%
2A	Moderate temperature increase no precipitation change	Median	-1.2%	-2.9%	-5.4%	-1.8%	-4.0%	-6.4%
2A	Moderate temperature increase no precipitation change	Critically Dry	-3.4%	-8.8%	-15.1%	-4.2%	-9.8%	-16.1%
3B	High temperature increase precipitation decrease	Extremely Wet	-7.1%	-14.3%	-21.8%	-8.7%	-16.7%	-24.3%
3B	High temperature increase precipitation decrease	Median	-8.6%	-18.6%	-29.4%	-10.7%	-21.6%	-32.3%
3B	High temperature increase precipitation decrease	Critically Dry	-14.7%	-30.9%	-46.5%	-16.6%	-33.3%	-48.1%

Runoff timing within the water year changes under the future climate conditions. **Table 50** shows the average monthly median runoff volume at O'Shaughnessy for the current climate and for the 2040, 2070 and 2100 future climate condition for two climate change scenarios (2A moderate temperature increases with no precipitation change and 2B moderate temperature increases with precipitation decreases). Reservoir operations may need to be revised to manage increased runoff in November through April, and decreased runoff in May for most scenarios, and in June and July for all scenarios.

The study concluded that the simulated changes in 2040, 2070 and 2100 hydrologic conditions based on the climate change scenarios results in a progressively altered snow and runoff regime in the watershed. Snow accumulation is reduced and snow melts earlier in the spring. Fall and early winter runoff increases while late spring and summer runoff decreases, and these changes become more significant at the later time periods. Total runoff is projected to decrease under the climate change scenarios evaluated, in some cases marginally and others significantly." (Hydrocomp et al. 2012)

The findings of the study for the Tuolumne Watershed provide a useful indication of the nature and extent of the potential impacts of climate change on inflow to Don Pedro Reservoir. Trends in April through July runoff predicted in the Hydrocomp report are supported by observations presented in the DWR study, Progress on Incorporating Climate Change into Management of California's Water Resources (DWR July 2006). Based on analysis of historical flows of four rivers in the San Joaquin River watershed (Stanislaus, Tuolumne, Merced, and San Joaquin), the DWR report notes April through July runoff has declined by approximately 7 percent relative to total water year runoff over the past 100 years (1905-2005). However, the DWR study also shows that the average annual unimpaired runoff in the Tuolumne River at Don Pedro Reservoir has increased by 4 percent. Therefore, while total runoff in these watersheds has increased slightly, April through July runoff has decreased at a greater rate. The DWR paper then states that, "It is reasonable to conclude that this trend is the likely result of climate change and warming and an attendant decline in Sierra snowpack. A portion of the trend may also be attributable to progressively earlier melting of Sierra snowpack due to warming."

2. Effects of Climate Change on Agriculture's Water Demand

Climate change is expected to increase temperatures in the Central Valley resulting in changes to growing season and higher daytime and nighttime temperatures. The general increase in temperatures coupled with greater variability in precipitation in the valley is expected to lead to increases in evapotranspiration resulting from warmer seasons; thereby creating a general increase in agricultural water demand for irrigation water and an increase in the year-to-year variability of demand. A study conducted in 2014 by the Wheeler Institute for Water Law & Policy, University of California, Berkeley, analyzed the potential impacts of climate warming on water supply reliability in the Tuolumne River basin. The study projected impacts of climate change on hydrology and water supply to two major irrigation districts in the area (Modesto and Merced), using uniform temperature increases of 2°C, 4°C, and 6°C. The study concluded that for Modesto ID, the surface water supply reliability decreases by 82%, 79%, and 75% with each 2-degree incremental increase in temperature. The results show that the warming scenarios decrease streamflow magnitude by 4 to 12 percent and streamflow timing by 5 to 21 days earlier, while increasing demands by 1.4 to 5.8 percent. The study goes on to say that "the net effect of these changes is that modeled surface water supply reliability decreases in each district, but less than might be expected were the reliability response a simple summation of supply and demand changes. The substantial reservoirs providing storage intended to buffer the effects of climate variability serve to reduce, but not eliminate, the hydrologic impacts of climate change in the same way as they offset short-term hydrologic droughts."

The effects of increased temperatures are also expected to be particularly pronounced on fruit and nut crops such as almonds, apples, cherries, and pears, due, in part, to the reduction of winter chill hours likely to result from warmer temperatures. The DWR report states, "Plant physiological responses to increasing temperature will be mixed, therefore there are likely to be varying agronomic responses to climate change. For example, fewer frost days would allow citrus production to extend to higher latitudes and elevations, including in the Central Valley. However, fewer frost days would be detrimental for tree crops having a chill requirement." By the end of the 21st century, the safe winter chill needed for these orchard crops is predicted to disappear, while the number of hours of winter chill in the San Joaquin Valley has decreased from about 1,500 a few decades ago, to approximately 1,000 to 1,200 hours. From 1995 to 2020 however, the number of hours of winter chill in the Modesto area has stayed steady at about 1,100 hours, while the number of Degree-days has increased from 3,500 to 4,200 hours.

Studies are now underway to breed varieties of fruit trees which can withstand the decreased winter chill hours. However, replanting orchards with varieties of these crops better suited to warming temperatures may not be feasible for many irrigators.

3. MID Response to Effects of Climate Change

While changes in watershed hydrology and in temperature-driven crop water demand may result from climate change, there is little consensus about the rate at which climate change will occur or the magnitude of the impacts. Given the general agreement that climate change is taking place and the general uncertainty regarding the rate of change, MID is committed to monitoring key indicators of climate change that affect the hydrology of the Tuolumne River watershed and growing conditions in the District's irrigation service area and to adapting its water management practices to respond to changes as they become evident.

In addition to adaptive management, implementation of the water conservation initiatives now underway at MID is intended to help the District and its agricultural water users prepare for the potential impacts of climate change by improving operational control within the District. Improving operational control will enable the District to exercise adaptive management measures should they become necessary.

Section VII: Water Use Efficiency Information

1. EWMP Implementation and Reporting

a) Water Use Efficiency Improvements

Table 53 summarizes the status of implementation of EWMPs at MID. As the table indicates, each of the EWMPs required by SBx7-7 and listed in the DWR publication A Guidebook to Assist Agricultural Water Suppliers to Prepare a 2020 Agricultural Water Management Plan is now being implemented.

The District has chosen to implement some EWMPs that, when viewed in isolation, aren't locally cost-effective water conservation measures. These measures are being implemented because MID's goal is to provide the flexibility and reliability of water service necessary to maintain the District's system as the water source of choice by all irrigators within the District's irrigation service area. Maintaining irrigators' preference to receive water from gravity deliveries is fundamental to MID's ability to manage water conjunctively, to conserve energy, and to maintain the District's financial viability. Therefore, when viewed as an overall strategy for serving its agricultural water users, the benefits of implementing the full program of EWMPs are clear.

MID's integrated program for implementation of EWMPs is apparent in the District's Comprehensive Water Resources Management Plan. This plan includes a comprehensive program of new and rehabilitated facilities and improved control systems to improve the efficiency and effectiveness of water management throughout the District.

From 2015 to 2020 MID has completed several projects that enhance water measurement, automation of facilities, reduce operational spills, and line canals. These projects contribute to the EWMPs and are discussed in Section I.4 – AWMP Implementation.

Table 53 – Report of EWMPs

EWMP No.	EWMP Category	Current Status	Notes
Critical EWMPs – Water Code §10608.48.b			
1	Measure the volume of water delivered to customers with sufficient accuracy to comply with subdivision (a) of Section 531.10 and to implement paragraph (2) of the legislation.	Proceeding with implementation	MID currently measures, monitors, and controls flows throughout its water delivery system. The District also measures deliveries in order to bill agricultural water users accurately under the District's tiered water pricing structure. As agricultural water users convert their on-farm systems from flood to low volume irrigation systems, cumulative water measuring devices such as meters are being installed. MID is financially supporting the upgrade of water users' water delivery facilities devices by contributing up to 50% of the installation cost of water measuring devices including water meters. MID has compiled an inventory, survey and classification of its turnouts and is concurrently pilot testing various flow measurement devices at representative sites within the District. These efforts will allow it to establish a comprehensive, planned, and economical corrective action plan to bring non-compliant turnouts into compliance. The District is committed to comply with the requirements of SBx7-7 by verifying the accuracy of seasonal measurement of irrigation water deliveries using the methodology described in Section VIII of this AWMP.
2	Adopt a pricing structure for water customers based at least in part on quantity delivered	Adopted in 2015	MID has adopted a pricing structure based at least in part on volume used. The District staff pays careful attention to the implications of volumetric pricing on water use efficiency, irrigation service, conjunctive management, and other aspects of the District's mission to ensure that water pricing strategies serve their intended purpose.
Conditional EWMPs – Water Code §10608.48.c			
1	Facilitate alternative land use for lands with exceptionally high-water duties or whose irrigation contributes to significant problems, including drainage	Currently Implemented	MID facilitates and considers requests for alternative land uses, including assistance with drainage problems. On-farm tailwater drainage within the District's service area is minimal due to the prevalence of low-volume and level-basin irrigation systems, however it is common on dairies. In cases where on-farm tailwater is generated, the water users typically contain it within their property. In some instances, surface drainage water is recycled by downstream water users.
2	Facilitate use of available recycled water that otherwise would not be used beneficially, meets all health and safety criteria, and does not harm crops or soils	Currently Implemented	MID facilitates and considers requests for use of recycled water. MID pump station facilities from the Cavil Drain into MID Lateral 3 to recycle urban storm runoff during the irrigation season. Currently, one MID water user has a contract with the community of Salida to use reclaimed water on their property. MID is currently working on a project with a local food processor whereby operational releases of distillate from the powdered milk production process will discharge from the Facility into the District Lateral 4.
3	Facilitate financing of capital improvements for on-farm irrigation systems	Currently Implemented	For over 30 years, MID has financially assisted its water users and has contributed up to 50% of the cost of projects to replace private ditches and pipelines. The District has also provided low interest loans for the other 50% of the projects' costs. When state grants are available, MID has contributed up to 67% of the projects' cost. MID has developed and updates a detailed formal application process for funding future on-farm improvements. The program provides up to 50% funding for physical improvements and management practices. Appendix F includes details on applicant eligibility, eligible projects, available funding, the application process, payment procedures, project ranking, contractual obligations, and suggested design requirements.
4	Implement an incentive pricing structure that promotes one or more of the following goals: (A) more efficient water use at the farm level; (B) conjunctive use of groundwater: (C) appropriate increase of groundwater recharge, (D) reduction in problem drainage; (E) improve management of environmental resources; (F) effective management of all water sources throughout the year by adjusting seasonal pricing structures based on current conditions.	Currently Implemented	MID has adopted a pricing structure based at least in part on volume used. Therefore, growers have incentives to conserve water. In addition, over the last few years, the water pricing structure has increased the cost of water at a rate of about 10% per year but increased 40% in 2015. Furthermore, special Drought Surcharges are added to the water pricing structure to cover drought related operations, such as increased groundwater pumping and enforcement of Rules and Regulations.

EWMP No.	EWMP Category	Current Status	Notes
5	Expand line or pipe distribution system and construct regulatory reservoirs to increase distribution system flexibility and capacity, decrease maintenance and address seepage when negative impacts exist.	Currently Implemented and ongoing	MID has concrete lined approximately 91% of its canals. The remaining 9% lie in soils with low permeability and in areas where groundwater recharge is beneficial. The B/C ratio for this EWMP is low due to the small amount of water that can be conserved by lining 20 miles of canal when compared with the estimated cost. The District accepted this EWMP because, in addition to water conservation, there could be reasons such as improving water supply reliability by reducing the threat of canal bank failures that could decrease the potential for liability. The District completed in 2020 the Main Canal Reservoir (MCR Project) a nearly 300-acre foot (AF) regulating reservoir to increase distribution system flexibility and capacity. The District is also investigating several potential recapture reservoirs at the end of the irrigation system to help reduce operational spills. MID completed a cured-in-place trenchless technology using a flexible-felt-tube on the MID Highline Pipeline in 2017. MID continued to invest in the trenchless pilot program in 2019 by completing the Tidewater Culvert Crossing and Little Shoemake Pipeline Rehabilitation Project with spray-in-place concrete trenchless technology by use of a new centrifugal pipe lining machine. MID anticipates the spray-in-place concrete trenchless technology will be used in future trenchless technology pipe rehabilitations and will describe the program in further detail in the 2025 AWMP.
6	Increase flexibility in water ordering by, and delivery to, water customers within operational limits.	Currently Implemented	MID strives to add flexibility to water ordering and delivery. Most water orders and deliveries are based on an arranged demand system where the frequency and duration are flexible. The rate of flow is flexible to the extent that capacity of the delivery system allows. As water users convert from flood to low volume irrigation systems, the District's ability to provide greater water delivery flexibility increases. In addition, MID policy allows water transfers between water users within the boundaries of the District. The policy allows water users to transfer water to parcels owned or rented by the water user. Implementation of the EWMP has been supported by District programs that have replaced some of its own pipelines and contributed to funding for the replacement of private pipelines. These projects were financed by the District to improve service and are timely elements of the District program to improve flexibility and reliability of deliveries as the District replaces its old cast-in-place pipelines. The District is attempting to minimize the number of water users who leave surface water in favor of groundwater for 100% of their irrigation water needs. To increase flexibility the District has also allowed some agricultural water users to construct their own turnout to better serve new pressurized irrigation systems. MID has completed the Main Canal Reservoir Project and is studying numerous smaller reservoirs at the lower end of the system to help improve operational flexibility.
7	Construct and operate supplier operational outflows and tailwater recovery systems	Currently Implemented (grower tailwater recovery)	MID completed rehabilitation work in 2019 on the Rose Avenue Pump station which recovers urban storm water and agricultural runoff from the MID Cavil Drain. Some agricultural water users, especially at dairies, re-circulate their water on site. An operational outflow recovery system may assist in recovering district spills that flow to local rivers and streams and are irrecoverable for use within MID's irrigation service area.
8	Increase planned conjunctive use of surface water and groundwater within the supplier service area	Currently Implemented	Conjunctive use of water has been practiced by the District for many years. The District uses groundwater supplies to supplement its water supply during dry years and as needed to minimize operational outflows by using wells to supply nearby water user needs rather than diverting water from several miles away. In addition to its own wells, the District's water treatment and supply agreement with the City of Modesto specifies that when requested by the City, the city may exchange some of its groundwater supply for a like amount of additional treated surface water. In addition to District wells, a large number of surface water users have also installed private groundwater pumps which they can use for irrigation during dry years. MID is also working jointly with the Stanislaus and Tuolumne Rivers Groundwater Basin Association to comply with the Sustainable Groundwater Management Act, which requires that groundwater be managed sustainably with no net long-term overdraft. MID will accomplish this through a combination of continued improvements to water management, spill reduction, municipal water deliveries, potential future development of groundwater recharge basins and continued conjunctive use.

EWMP No.	EWMP Category	Current Status	Notes
9	Automate canal control structures	Currently Implemented	MID has automated approximately 60 monitoring and flow control stations at Modesto Reservoir and water diversion points and installed monitoring stations along some reaches of its canals. The District has identified another 15 locations that could be automated for greater water management flexibility. The District has added, and will continue to add, canal automation to its in-house SCADA system in order to enhance water delivery flexibility to water users. The District has also installed controls to automate some irrigation water wells. With this automation, the wells can be turned on and off remotely based on demand within the canal. As with other district initiatives, MID has proceeded with implementation of this EWMP as a vehicle to improve customer service by increasing the flexibility of deliveries to support the increasing number of conversions from annual to permanent crops and from flood to low volume irrigation systems.
10	Facilitate or promote customer pump testing and evaluation	Currently Implemented	Upon request by the customer, MID tests private water supply pumps. MID has installed water flow meters on approximately 70% of its pumps and has developed a well field Decision Support System to efficiently operate the pumps.
11	Designate a water conservation coordinator who will develop and implement the water management plan and prepare progress reports	Currently Implemented	Through a Board Resolution, the MID Board of Directors has appointed John B. Davids, the current Assistant General Manager, Water Operations, as the Water Conservation Coordinator for Modesto Irrigation District.
12	Provide for the availability of water management services to water users.	Currently Implemented	MID financially supports the following: 1) CIMIS website water use information; 2) water flow and measurement information; 3) publishes a periodic newsletter; 4) dissemination of co-op extension and other data; 5) water well pump testing; 6) supports local agricultural education programs at both the college and high school level; 7) contributes to the East Stanislaus Resource Conservation District mobile irrigation lab.
13	Evaluate the policies of agencies that provide the supplier with water to identify the potential for institutional changes to allow more flexible water deliveries and storage.	Currently Implemented	MID owns pre- and post-1914 water rights on the Tuolumne River. The MID Board of Directors has the legal authority to directly set and implement policies that affect the distribution of water. Given MID’s total reliance on water to which the District holds the rights (including local groundwater), there is no need to identify policies of agencies or other institutional changes with agencies that will result in increased water supply flexibility for MID.
14	Evaluate and improve the efficiencies of the supplier’s pumps	Currently Implemented	The District’s well operation Decision Support System was instituted specifically to improve the efficiency and effectiveness of the District groundwater pumping program. In addition, MID has implemented a well field optimization program for regular inspection and maintenance of pumps and wells to keep them in good working order. As part of this program, MID personnel are formally trained and educated in well/pump maintenance and operation. MID also follows the recommendations and improvements set forth in a well field optimization study.

b) Evaluation of Water Use Efficiency Improvements

The EWMPs presented in **Table 53** can help to improve water use efficiency. Quantifying the improvements in water use efficiency is difficult, or in some cases impossible, due to the complexity of the MID conveyance system, varying water supply on an annual basis, limited implementation periods, and lack of certain data needed for evaluations. However, a qualitative assessment using existing data in consideration of completed and proposed projects and/or policies is a more feasible approach in quantifying the magnitude of efficiency improvements. **Table 54** discusses the qualitative improvements in water use efficiency for each EWMP. **Table 54** also shows improvements in water use efficiency that have occurred since MID's 2015 AWMP, and those that are anticipated to occur in the next 5-year reporting period. The improvements are qualitatively denoted as potentially Negligible, Minor, Moderate or Significant. Potential projects and improvements below are all contingent on available funding.

Table 54 – Report of EWMPs Efficiency Improvements

EWMP No.	EWMP Category	Estimate of Water Use Efficiency Improvements Since Last Report (2015-2020)	Estimated Water Use Improvements 5 to 10 Years in the Future
Critical EWMPs – Water Code §10608.48.b			
1	Measure the volume of water delivered to customers with sufficient accuracy to comply with subdivision (a) of Section 531.10 and to implement paragraph (2) of the legislation.	**Moderate** Flowmeters are installed when an agricultural water user converts their on-farm system from flood to low-volume micro irrigation systems. Maintenance activities continue on existing meter gate turnouts. MID also uses Hach meters to verify flow rates in many areas. The current measurement system has proven adequate for volumetric billing. Refer to Section VIII for information on recent work related to SBX7-7 compliance and a successful meter pilot-testing program. New SCADA projects have improved flow measurements on main canals and laterals and provide ditchtenders real-time access to flow data at multiple SCADA sites. MID also measures boundary outflow at many sites, which provides for real time system management.	**Significant** Substantial improvements may be made over the next 5-10 years to comply with the water measurement provisions of SBx7-7, including but not limited to the installation of calibrated flowmeters or provisions for measurement farm delivery point to allow for improved volumetric measurement. MID has compiled an inventory, survey and classification of its delivery points and is concurrently pilot testing various flow measurement devices at representative sites within the District.
2	Adopt a pricing structure for water customers based at least in part on quantity delivered	**Minor** The Board of Directors establishes the tier prices in MID volumetric billing structure on an annual basis. The Board's goal is to maintain a price that encourages surface water use over groundwater pumping while encouraging efficient water use. The most recent price increases by the Board were in 2014, 2015, and 2016. MID also implemented a special Drought Surcharge to cover increased costs for groundwater pumping and drought management programs as previously discussed. These were both adopted in 2015.	**Significant** The District established a water pricing rate structure in 2015 that includes a fixed charge along with a volumetric component for the quantity of all water delivered. The volumetric charge is tiered and increases the more water per acre is delivered. The rate structure, including volumetric pricing will continue into the future, with the Board of Directors annually establishing the water rates. The District may continue to implement a special Drought Surcharge, as needed.
Critical EWMPs – Water Code §10608.48.c			
1	Facilitate alternative land use for lands with exceptionally high-water duties or whose irrigation contributes to significant problems, including drainage	**None** The need to facilitate alternative land use in MID is minimal.	**None**
2	Facilitate use of available recycled water that otherwise would not be used beneficially, meets all health and safety criteria, and does not harm crops or soils	**Minor** MID has upgraded the Rose Ave Pump Station that recovers urban and agricultural runoff from the Cavil Drain into MID Lateral 3.	**Moderate** In late 2020 MID completed the Main Canal Check Structure and Pelton Flume to measure flow on the MID Lower Main Canal. By use of a complex algorithm, the integrated SCADA system records flow fluctuations caused by Oakdale Irrigation District operational outlets and adjusts the Main Canal Check Structure gates accordingly allowing any excess flow to be diverted into the Main Canal Reservoir. It is anticipated the new recovery system will recover a portion of the OID operational outlets that were irrecoverable flows prior to 2020.
3	Facilitate financing of capital improvements for on-farm irrigation systems	**Moderate** The District has provided cost share to fund several on-farm improvement projects. From 2015 to 2020, the financing has ranged from approximately $150,000 to $250,000/year.	**Moderate** The District continues to update the Conservation Funding Program to provide financial incentives to agricultural water users for capital improvements. See detailed guidelines in Appendix F. With formal guidelines, advertisement and more focus on lands that have a high-water use per acre, it is expected that agricultural water users will be more interested in the program and the potential impact on efficiency will be greater.

4	Implement an incentive pricing structure the promotes one or more of the following goals: (A) more efficient water use at the farm level; (B) conjunctive use of groundwater: (C) appropriate increase of groundwater recharge, (D) reduction in problem drainage; (E) improve management of environmental resources; (F) effective management of all water sources throughout the year by adjusting seasonal pricing structures based on current conditions.	**Minor** MID continues to implement a tiered pricing structure and annual rate increases to encourage efficient water management consistent with MID's Rules and Regulations Governing the Distribution of Irrigation Water Within the Modesto Irrigation District. The tiered pricing structure was adopted in 2015.	**Minor** The rate structure established by the Board of Directors in 2015 includes a volumetric pricing component that is evaluated each year. It's expected to continue to promote efficient water use at the farm level, although there may be a negative impact on groundwater recharge. By establishing the price of water each year, the Board of Directors must be cognizant of establishing a price for surface water that encourages agricultural water users to use surface water rather than groundwater.
5	Expand line or pipe distribution system and construct regulatory reservoirs to increase distribution system flexibility and capacity, decrease maintenance and reduce seepage.	**Moderate** The Main Canal Reservoir (MCR Project) included development of a new, nearly 300 acre-foot (AF) regulating reservoir located at MID's Lower Main Canal and Lateral 3. In addition to the reservoir, project construction was comprised of four water control structures, two flow measurement flumes downstream of the project site, a new Supervisory Control and Data Acquisition (SCADA) system and system integration. The MCR Project was designed to regulate water flows to better match downstream demands for both the Lower Main Canal and Lateral 3. The District's non-evasive pipeline project provided insight into both Cured-In-Place and spray-In-Place trenchless technology for a system wide pipeline replacement program. The Highline Trenchless Rehabilitation Project used the Cure-In-Place method with a felt material flexible pipe installed by an outside contractor. The Little Shoemake Pipe Rehabilitation and Tidewater Culvert Crossing used the Spray-In-Place method installed by MID construction crews. MID has purchased the MID selected the Little Shoemake Pipeline to be the large pipeline project to be completed using sprayed-in-place concrete trenchless technology by use of the new centrifugal pipe lining machine.	**Significant** Through implementation of the Main Canal Reservoir Project, MID's operational flexibility is increased by allowing short-term changes on either canal to occur without requiring changes in the upper reaches of MID's delivery system. This allows for faster responses to imbalances in the irrigation supplies and customer water demands downstream of the Lateral 3 and the Lower Main Canal bifurcation- which accounts for nearly three-quarters of MID's irrigated acreage. Flow rates and water levels are automatically monitored and controlled, and communication enhancements allow MID to account for flow fluctuations and make corresponding adjustments remotely in real time. The Main Canal Reservoir Project will be instrumental to MID in evaluating numerous smaller re-regulating reservoirs within the lower reaches of the canal system through the Comprehensive Water Resource Management Plan. MID's extensive Cast-in-Place (CIP) pipeline distribution system continues to reach its pipeline life expectancy and is continuing to show signs of old age resulting in significant amounts of seepage. MID has selected the Spray-In-Place concrete trenchless technology as the system wide method to rehabilitate much of the CIP pipeline system. MID has purchased the centrifugal pipe lining machine with the goal of using this technology for system wide improvements. MID field staff will continue to improve on both installation techniques and development of the specialized concrete spray liner.
6	Increase flexibility in water ordering by, and delivery to, water customers within operational limits.	**Minor** Flexibility continues to increase as the District modernizes its conveyance system to serve growers who convert to low volume irrigation systems.	**Moderate** Continued conveyance facility improvements and reservoir construction will allow more flexible water delivery for conversion to more efficient on-farm irrigation systems. Implementation of several projects in the MID Comprehensive Water Resources Management Plan will further the goal of increasing operational flexibility. Through implementation of the Main Canal Reservoir Project, MID's operational flexibility is increased by allowing short-term changes on either canal to occur without requiring changes in the upper reaches of MID's delivery system. This allows for faster responses to imbalances in the irrigation supplies and customer water demands downstream of the Lateral 3 and the Lower Main Canal bifurcation- which accounts for nearly three-quarters of MID's irrigated acreage. Increased flexibility in water ordering and delivery will be discussed in more detail in the 2025 AWMP.

7	Construct and operate supplier operational outflows and tailwater recovery systems	**Minor** Several SCADA and automation projects constructed from 2012-2014 will help to reduce operational outflows.	**Significant** MID has installed boundary outflow measurement using SCADA at numerous locations and will continue to add outflow monitoring stations. These provide for real-time monitoring and control and can allow for better water management and spill reduction.
8	Increase planned conjunctive use of surface water and groundwater within the supplier service area	**Significant** The District has effectively practiced conjunctive use for many years through the use of both surface water and groundwater to serve irrigation customers. In addition, surface water deliveries to the City of Modesto for domestic use in lieu of groundwater pumping adds to the District's conjunctive use portfolio. Prior to 1995, the City of Modesto relied solely on groundwater to meet its municipal and industrial needs. MID has the capacity to deliver up to 67,000 acre-feet of treated Tuolumne River water per year to the City of Modesto for M&I uses with completion of Phase II of the Modesto Water Treatment Plant in 2017.	**Significant** The District will continue to effectively practice conjunctive use for many years through the use of both surface water and groundwater to serve irrigation customers. In addition, surface water deliveries to the City of Modesto for domestic use in lieu of groundwater pumping will continue to add to the District's conjunctive use portfolio. It is anticipated that the City of Modesto's population will continue to increase creating more demand for the 67,000-acre feet of Phase II water that is currently available.
9	Automate canal control structures	**Significant** The District completed several projects that help to automate controls (see Section I.D.) including: Dr. Moore Headworks Project (2015) Butler Ditch Headworks Rehabilitation (2015) Lateral 8 Headworks Project (2016) Waterford Lateral 3 Headworks (2018) Waterford Lower Main Pump Automation Project (2018) Rose Ave Pumps Station Project (2019)	**Moderate** The District has identified 15 additional locations that could be automated for greater water management flexibility and will pursue these projects using funding approved through 2025.
10	Facilitate or promote customer pump testing and evaluation	**None** MID has continued to provide pump testing of private wells on request, which can lead to more efficient pumping and less energy use.	**None**
11	Designate a water conservation coordinator who will develop and implement the water management plan and prepare progress reports	**Moderate** A new Water Conservation Coordinator was recently appointed. Several water conservation measures were enacted; In particular, programs to address the current drought (see Section II.B.4) and changes to the MID Rules and Regulations (see Section II.B.1).	**Moderate** Water conservation is a key component of MID water management and will be continually pursued through a variety of programs and projects directed by the Water Conservation Coordinator.
12	Provide for the availability of water management services to water users.	**Minor** The Conservation Funding Program implemented by the District (see detailed guidelines in Appendix F) provides financial incentives for water management practices such as scientifically based irrigation scheduling and soil moisture monitoring.	**Minor** The Conservation Funding Program implemented by the District (see detailed guidelines in Appendix F) provides financial incentives for water management practices such as scientifically based irrigation scheduling and soil moisture monitoring.
13	Evaluate the policies of agencies that provide the supplier with water to identify the potential for institutional changes to allow more flexible water deliveries and storage.	**None** The MID Board of Directors has the legal authority to directly set and implement policies that affect the distribution of water.	**None**
14	Evaluate and improve the efficiencies of the supplier's pumps	**Minor** MID has continued to use a well field operation decision support system and optimization program. Continuous improvements in pump efficiency are realized through these efforts. MID has added three (3) new agricultural production wells to its current well field.	**Minor** MID will continue to use a well field operation decision support system and optimization program. Continuous improvements in pump efficiency are realized through these efforts. MID will continue to add and replace agricultural production wells to its current well field.

Table 55 presents the schedule for implementing EWMPs.

Table 55 – Schedule to Implement EWMPs

EWMP	Implementation Schedule	Finance Plan	Budget Allotment for 2021[1,2]	AWMC MOU Demand Measures
Critical				
1 – Water Measurement	Implemented / Ongoing	Annual Irrigation Operations Budget	$226,500	C-1
2 – Volume-Based Pricing	Implemented / Ongoing	Annual Irrigation Operations Budget	$31,100	
Conditional				
1 – Alternate Land Use	Implemented / Ongoing	Annual Irrigation Operations Budget	$164,600	B-1
2 – Recycled Water Use	Implemented / Ongoing	Annual Irrigation Operations Budget	$471,200	B-2
3 – On-Farm Irrigation Capital Improvements	Implemented / Ongoing	Annual Irrigation Operations Budget	$251,600	B-3
4 – Incentive Pricing Structure	Implemented / Ongoing	Annual Irrigation Operations Budget	$37,300	C-2
5 – Infrastructure Improvements	Implemented / Ongoing	Annual Irrigation Operations Budget	$2,138,300	B-5
6 – Order/Delivery Flexibility	Implemented / Ongoing	Annual Irrigation Operations Budget	$269,700	B-6
7 – Supplier Operational Outflow and Tailwater Systems	Implemented / Ongoing	Annual Irrigation Operations Budget	$428,300	B-7
8 – Conjunctive Use	Implemented / Ongoing	Annual Irrigation Operations Budget	$434,200	B-8
9 – Automated Canal Controls	Implemented / Ongoing	Annual Irrigation Operations Budget	$443,100	B-9
10 – Customer Pump Test/ Evaluation	Implemented / Ongoing	Annual Irrigation Operations Budget	$5,000	
11 – Water Conservation Coordinator	Implemented / Ongoing	Annual Irrigation Operations Budget	$155,500	A-2
12 – Water Management Services to Customers	Implemented / Ongoing	Annual Irrigation Operations Budget	$269,100	A-3
13 – Identify Institutional Changes	Implemented / Ongoing	Annual Irrigation Operations Budget	$297,700	A-5
14 – Supplier Pump Improved Efficiency	Implemented / Ongoing	Annual Irrigation Operations Budget	$613,700	A-6
		Total of All EWMPs	**See Note 1**	

[1]Budget allotments are not necessarily applicable to a specific EWMP and may spread across multiple EWMPs. Consequently, they aren't additive.
[2]Amounts shown are rounded to nearest $100 and are specific to the 2021 Budget Year.

2. Documentation for Non-Implemented EWMPs

MID has chosen to implement each of the recommended EWMPs. Although certain measures aren't locally cost-effective as individual water conservation measures, the District views them as elements of a broad program that enables MID to provide a high level of service to its agricultural customers and to responsibly manage surface water and groundwater resources in the District's irrigation service area. This position is summarized below in **Table 56**.

Table 56 – Non-Implemented EWMP Documentation

EWMP No.	Description	Technically Infeasible	Not Locally Cost-Effective	Justification / Documentation
N/A	-	-	-	All EWMPs are being implemented as they support MID's long-term water management objectives

Section VIII: Supporting Documentation

1. Agricultural Water Measurement Regulation Documentation

a) Introduction

MID recognizes the need for uniform standards and procedures for measuring and recording farm water deliveries in order to: (1) improve water management by equitably distributing water to each agricultural water user; (2) provide cost-effective service to all agricultural water users; (3) improve operational records for analysis and planning purposes, and (4) comply with recent regulatory requirements. MID currently measures all farm water deliveries, but the current measurement methods may not comply with regulated accuracy requirements in all circumstances. Regulations requiring a specified level of delivery point measurement accuracy were incorporated into California Code of Regulations Title 23 Division 2 Chapter 5.1 Article 2 Section 597 (23 CCR §597) in July 2012 as an outgrowth of Senate Bill X7-7 (SBx7-7), the Water Conservation Act of 2009. MID's existing farm delivery point measurement devices, referred to as meter gates, and current measurement methods have been adequate to allow MID to measure water at the farm delivery point level for many years with sufficient accuracy to bill for water use. However, recent analysis and field investigations have indicated that a more accurate measurement method could be employed at some delivery point locations to help satisfy the accuracy requirements of SBx7-7.

Briefly summarized, SBx7-7 (23 CCR §597) requires that agricultural water suppliers providing water to 25,000 irrigated acres or more measure the volume of water delivered to customers with sufficient accuracy to comply with AB 1404 and bill water customers based at least in part on the quantity of water delivered (volumetric pricing). AB 1404 (2007) amended the California Water Code to add §531.10 regarding water measurement and water delivery reporting as follows:

- Any agricultural water supplier, either public or privately owned, supplying 2,000 AF or more of surface water annually for agricultural purposes, or serving 2,000 or more acres of agricultural land, must comply with reporting requirements.
- An agricultural water supplier shall submit an annual report to DWR that summarizes aggregated farm-gate delivery data, on a monthly or bi-monthly basis, using best professional practices.
- §531.10(a) states that a water supplier is to use best professional practices in reporting annual aggregated farm-gate delivery data, while §531.10(b) states that "*nothing in this article shall be construed to require the implementation of water measurement programs or practices that are not locally cost effective*".

The final SBx7-7 Agricultural Water Measurement regulation (Regulation) that was prepared by DWR and adopted in July 2012 requires that the volume of water delivered by an agricultural water supplier be measured at the delivery point where the agricultural water supplier transfers control of delivered water to a customer or group of customers, and be of sufficient accuracy to meet the requirements of AB 1404. In most cases, the transfer of control occurs at the farm-gate, but the regulation does allow for measurement upstream in a lateral under certain conditions. Regardless of where the measurement is made, the following numeric accuracy standards apply to the volume of delivered water:

- Existing measurement devices shall be certified to be accurate within ±12% by volume.
- New or replacement measurement devices shall be certified to be accurate within ±5% by volume in the laboratory if using a laboratory certified device (such as an ultrasonic meter) or ±10% by volume in the field if using a device that is non-laboratory certified (such as meter gates).

If a device measures a value other than volume, for example, flow rate, velocity or water elevation, the accuracy certification must incorporate the measurements or calculations required to convert the measured value to volume, such as flow rate and elapsed time. If existing measurement devices don't meet the accuracy requirements, water suppliers must include in the AWMP a plan to take corrective action to comply with the SBx7-7 requirements.

The Regulation requires measurement at the location where the agricultural water supplier transfers control of delivered water to a customer or group of customers. In most cases, the transfer of control occurs at the individual delivery point or farm-gate, but the regulation does allow for measurement upstream in a lateral under certain conditions. If a water supplier elects to measure upstream on a lateral, the water supplier shall document in their water management plan the criteria used to apportion the volume of water delivered to individual downstream customers, and document that the method is sufficient to establish a pricing structure based at least in part on the volume delivered.

This document describes MID's proactive efforts over the course of the last reporting period to establish a comprehensive, planned and locally cost effective corrective action plan to bring non-compliant turnouts into compliance with the water measurement provisions of SBx7-7, including a schedule, budget and financing plan. Implementation will be a dynamic process that may potentially be impacted by emerging technologies, drought, and various other local drivers. As a result, MID will continually assess progress and adapt the plan as necessary to ensure that compliance is achieved through practical engineering, cost analysis and efficient program management.

b) Existing Facilities and Measurement Practices

MID distributes a combination of Tuolumne River water and groundwater via a network of storage facilities, canals, pipelines, pumps, drainage facilities and control structures. MID's canal system begins at La Grange Dam where Tuolumne River water released from Don Pedro Reservoir for irrigation purposes is diverted into the MID Main Canal for conveyance to Modesto Reservoir. MID operates Modesto Reservoir as a regulation reservoir to store and release irrigation water supplies, to balance irrigation deliveries with irrigation demands, to minimize flow rate fluctuations in the District's irrigation canals and laterals, and as a buffer for hydroelectric power generation. From Modesto Reservoir, water is released into the Lower Main Canal and Waterford Lower Main for distribution through a gravity flow system to downstream agricultural water users for irrigation purposes. MID's distribution system is comprised of approximately 147 miles of concrete lined canals, 15 miles of unlined canals, 42 miles of pipelines and 39 miles of drains. The conveyance canals generally run in an easterly to westerly direction. Private ditches and pipelines used to convey water from the MID distribution facilities to a group of landowner fields are owned by "Improvement Districts", a subdivision of MID. These Improvement Districts use the technical and financial expertise of MID, while leaving the basic decision of whether or not to make any improvements in the hands of those using the community facility. There is a total of 248 Improvement Districts within MID.

MID has a total of approximately 760 existing delivery points, or turnouts, where MID transfers control of delivered water to a customer or group of customers. Most of these delivery points have existing measurement devices that are known as meter gates (also known as rated gate or calibrated gate) which operate as a submerged variable area orifice. This device can provide a good estimate of the instantaneous flow rate under the correct conditions, and the volume delivered can be determined by employing a time factor to convert the flow rate to volume of water delivered. Some of the initial testing of this type of device was conducted in the late 1920's and was later updated by USBR in the early 1950's and more recently by the Irrigation Training and Research Center (ITRC) at Cal Poly San Luis Obispo. This type of measurement device is based on measuring the head differential between the upstream water surface and the downstream water surface as water flows through the gate. A stilling well is placed a certain distance (usually 12") behind a turnout gate that measures the water level in the pipeline downstream of the gate. Information on meter gates and recent testing conducted by ITRC is contained in **Appendix G**. The instantaneous flow rate is determined by cross referencing the known gate opening with the head differential on a standard rating table. Recent testing by ITRC indicates that the best accuracy is obtained when the gate is between 20% and 75% open. This type of measurement device requires full pipe flow downstream of the turnout and a constant head differential for the duration of the delivery in order to provide a constant flow rate. Meter gates can provide accurate flow rate measurements as long as the device is installed properly and can provide accurate volumetric quantities with proper water level measurement, flow rate consistency, and time factor conversion.

The source canal water level (upstream water surface) is maintained relatively stable by the numerous long-crested weirs MID has installed throughout its distribution system, however, MID has no control over the downstream water level. Many of the MID delivery points are very large for the flow rate currently being delivered and the gate opening may not fall within the desired range for device accuracy. Additionally, the time factor may not always be well documented since the District doesn't open and close every delivery point. Therefore, the current measurement method doesn't always comply with the accuracy requirements of SBx7-7.

MID is in the process of completing an extensive and time-consuming physical inventory of every delivery point in the District, comprised of both canal and pipeline turnouts. The District is using this physical inventory and other District records to associate each irrigated parcel to a delivery point and has divided the turnouts into acreage ranges that will be used to identify the type of measurement device or method that may be used to comply with SBx7-7 as explained in Section G below. The physical review and inventory will also be used to determine the modifications that must be made to those delivery points where a measurement device will be installed. The turnout inventory is currently being reviewed and verified, but the preliminary turnout inventory indicating the number of turnouts for each acreage group is presented below:

Table 57 – Preliminary Turnout Inventory

Acreage Range	Delivery Points		Acreage Billed		Avg. Acres / Turnout
	Number	%	Acres	%	
< 5 ac	22	3	65	0	3.0
5 – 10 ac	73	10	514	1	7.0
10 – 50 ac	368	48	9,817	17	26.7
50 – 100 ac	126	17	8,673	15	68.8
> 100 ac	171	23	38,784	67	226.8
Total	**760**		**57,853**		**76.1**

As shown above, approximately 67% of the acreage is served by only 23% of the delivery points. In addition, approximately 13% of the delivery points serve less than 10 acres and only account for approximately 1% of the acreage. The amount of acreage served by each delivery point generally corresponds to the amount of water delivered, so it is reasonable that the most "bang for the buck" regarding compliance can be obtained by focusing efforts on those delivery points that serve more than 10 acres. As the delivery point inventory is finalized, it is expected that there will be some revisions to fine tune the above acreage breakdown, but it is anticipated that the general trend will remain consistent.

c) Legal Certification and Apportionment Required for Water Measurement

The District has legal access to measure water at every Delivery Point, defined by MID as the location where the District transfers control of delivered water to the irrigator or a group of irrigators. Rule 5.5.2 of the District Rules and Regulations as shown in **Appendix C** states that "*The District has the authority to install or require the installation and maintenance of irrigation flow measurement devices or structures at all District Delivery Points in compliance with the prevailing state law and regulations promulgated by the California Department of Water Resources or other regulatory agency as may be applicable*".

Most of the MID irrigators receive water through Improvement District (ID) facilities, which are privately owned community facilities, usually pipelines. Most often, only one irrigator at a time draws water from the ID pipeline when typically using the flood irrigation method because the ID systems were originally designed to deliver "one-head" of water for one user at a time on a rotation basis. Since only one irrigator is typically irrigating at a time, measurement at the head of an ID facility or "one-headed" lateral is equivalent to measurement at individual delivery points on the lateral. Hence, measurement of the individual delivery points on ID facilities or one-headed laterals can't be economically justified as allowed under California Water Code §531.10(b). MID currently measures the water flowing into the head of the pipeline (the delivery point), which is upstream of the actual turnout to the irrigator's place of use. The flow rate into the pipeline is currently based upon a rated meter gate.

A standard head (or delivery) of water within MID is fifteen (15) cfs, as noted by Rule 2.6.1 of the Rules and Regulations, shown in **Appendix C** which states: *"All new Private or Improvement District Facilities used for flood irrigation purposes shall provide for a minimum gravity flow of fifteen (15) cubic feet per second. A variance from this minimum flow shall be evaluated by the District on a case-by-case basis based on the impact on the operation of the District's water delivery system"*.

As cropping patterns change within the District, more agricultural water users are converting their irrigation systems to pressured delivery systems, which use much smaller delivery rates than the standard head for flood irrigation. As such, the District is seeing more instances where two agricultural water users might be irrigating at the same time from an ID facility, where one agricultural water user is flood irrigating and another user is irrigating with an on-farm pressurized delivery system such as solid set sprinkler or micro-irrigation system (drip/micro-spray). If multiple agricultural water users are taking water from the ID pipeline at the same time, then the water use is apportioned to each agricultural water user by the ditchtender who takes into account that amount of water that is being delivered to the pressure system and subtracts the pressure delivery amount from the total flow, with the balance being the amount of water delivered to the flood irrigated delivery point. When an irrigator takes water from the ID pipeline into an on-farm pressurized delivery system, the volume of water delivered can be determined several ways: 1) by reading a flowmeter that was installed by the landowner on the system, or 2) by measuring the system flow rate with a portable meter operated by the District (such as a Fuji strap-on meter) and multiplying the flow rate by the time interval, or 3) by estimating the flow rate based on the design of the pumping system, and multiplying the flow rate by the time interval.

This method of apportionment has been verified by use over many years and has been found to be sufficient for allocating water use among agricultural water users and establishing the basis for how each agricultural water user is charged for the amount of water delivered during each irrigation event and the total amount over the irrigation season. The District is currently conducting a survey of the pressure system locations and preferred measurement method to assist in apportioning the water use.

A 2012 report published by ITRC regarding SBx7 Compliance, shown in **Appendix G** – *SBx7 Flow Rate Measurement Compliance for Agricultural Irrigation Districts*, contained the following as one of its conclusions:

> *The wording of SBx7 appears to clearly indicate that the proper, most downstream flow measurement location would be at the head of any "community ditches". "Community ditches (sometimes called "improvement districts") are defined as privately owned distribution systems that receive water from the irrigation district. The distribution, partitioning, and scheduling of water deliveries within the "community ditch" is not done by irrigation district personnel.*

d) Engineer Certification and Apportionment Required for Water Measurement – Technically Infeasible

Not applicable – there are no turnout locations within the District that are technically infeasible to measure, although conditions at some locations make measurement challenging.

e) Description of Water Measurement Best Professional Practices

<u>Description of District Operations</u>

MID operates a decentralized water ordering and delivery system. The ditchtenders take water orders from agricultural water users and coordinate deliveries based on demand and the flow capacity of the distribution system. As MID moves away from rotation to the more flexible arranged demand water delivery system, the ditchtenders' functions have become less routine and more customer-oriented.

Agricultural water users with flood irrigated lands may continue to irrigate on a fairly constant rotation while the water users with pressurized irrigation systems may request irrigation water on a more frequent arranged demand basis. Therefore, water order lead times vary depending on the time of year, system capacity, and where water is being routed, and can vary from very short notice to up to 120 hours' notice. For example, a water user close to Modesto Reservoir with land near a large canal may have a greater probability of receiving water on short notice than a user who is more distant from the reservoir and from main MID delivery facilities. The District's goal is to supply water to the irrigator when the water is needed and to maintain that delivery for the duration necessary to refill the soil profile or to satisfy the crop water requirement.

Rule 5.4.2 of the District Rules and Regulations, as shown in **Appendix C,** states that "*Where possible, irrigation water will be provided to the Irrigator based on an arranged demand delivery, under which the delivery rate is fixed, but the frequency and duration of use are requested by the Irrigator. Where the capacity of the system is limited, rotation delivery may be used by the Ditchtender. The Ditchtender may, at the Ditchtender's discretion, alter the rotation or cause water to be delivered upon request. Advance notice for rotation deliveries will be made with an appropriate amount of warning time to take into consideration the preparation needed to commence irrigation."*

Collection of Water Measurement Data

MID uses the "TruePoint" water accounting system, a database which is an established program for scheduling, tracking, monitoring, and billing of agricultural water use. The database allows input of various measurement methods including meters, meter gates and other rated measurement devices. The ditchtender enters the pertinent delivery information into a laptop computer in the field. This information is downloaded at least once a week. The delivery measurements are reviewed by a highly trained irrigation supervisor, well experienced in water measurement methods and historical usage patterns.

The water delivery data are currently made available to the agricultural water user by the District by posting the water usage reports online weekly. MID implemented a grower's portal, called TrueCIP, for the 2017 irrigation season that allows agricultural water users to log on and access their account to view past usage, remaining water allocation, etc., allowing each agricultural water user to monitor their water usage. Approximately 87 growers have signed up for TrueCIP. The billing system uses the volumetric pricing structure adopted by the MID Board of Directors each year to determine the appropriate pricing tiers and subsequent bill amount. Starting in 2015, each bill sent to an agricultural water user takes into account the amount of water measured and delivered to the agricultural water user on a volumetric basis.

Frequency of Measurements

The District measures the water levels at operating meter gates and measures the gate opening at least once a day, sometimes more often. A measurement is made each time a scheduled flow rate change is made. District staff will measure the head differential and gate opening generally within 1 hour of the scheduled change in flow rate.

Recent meter gate testing conducted by ITRC, as shown in **Appendix G –** *Improving Flow Measurement Accuracy at Farm Delivery Gates in California*, concluded that an error in the delivery duration estimate of 4% (1 hour in 24 hours) coupled with conservative expected errors of upstream and downstream water level measurements would still allow meter gates to measure the volume of water within the required ±12% accuracy as long as the instantaneous flow measurement uncertainty was within ±10.7%.

Method for Determining Irrigated Acres

The amount of irrigated acres is annually determined in compliance with Rule 5.3.1 of the Rules and Regulations, as shown in **Appendix C**, which states that "*No later than May 1 of each year, each Landowner or designee shall provide to the District a signed statement, on the District's form, of the kinds of crops and number of acres of each crop that will be irrigated on each parcel of land, and such other relevant information as the District may reasonably require on the same statement. After May 1 of each year, no changes to the amount of irrigated acreage or non-irrigated acreage will be allowed, but the kind of crop that is going to be planted may be changed at any time.*"

The irrigated acreage is determined based upon a crop forecast report that is prepared by the agricultural water user each winter for the upcoming season. These crop reports include information provided by the agricultural water user and identify the following:

- Previous year crop type and projected crop for the upcoming year
- Irrigated and non-irrigated acreage for each crop from the previous year
- Projected irrigated and non-irrigated acreage for each crop for the upcoming year
- Irrigation methods

The agricultural water user indicates if only a portion of a parcel will be irrigated that year and accounts for non-irrigable acres such as home sites, storage yards, roads, etc. The irrigated acreage values are reviewed and verified by the District. The annual fixed charges are based on the assessed acreage, with different charges for the portion of a parcel on irrigation status versus that on facilities and maintenance status.

Quality Control and Quality Assurance Procedures

MID staff monitors deliveries for quality assurance throughout the irrigation season by use of various control systems. These systems are both technological and based on personal experience. As noted previously, the standard delivery rate for flood irrigation is 15 cfs. Private systems installed for pressurized delivery will deliver a known flow rate that is provided to the District. The District currently utilizes nine portable Hach meters to spot check and verify flow rates at delivery points throughout the District.

On meter gates a mark is painted on the gate stem to indicate the closed position, then a certain distance referred to as the "dead stem" (generally 1-inch) will be subtracted to obtain the "zero" point on the gate when water starts to trickle past the gate. This "dead stem" difference is to account for the gate movement required within the mechanism to get to the "zero" point and can vary slightly as the gate wears and more "slop" is encountered. The District will periodically have a senior ditchtender check the "slop" in a gate and make adjustments to the amount subtracted for the dead stem as necessary, so an accurate gate opening is obtained, further improving the District's QC/QA.

Water measurement data is now available using the TrueCIP irrigation services portal, allowing the District agricultural water users to track their water use. Information is available by customer ID on the website, as well as information from last year so growers can compare their water deliveries. This is one of the ultimate means of QC/QA, as the irrigators generally know how much water they are delivering and will raise any questions they have. This has especially been true during the recent drought, as agricultural water users try to stretch their water allocation as far as possible.

f) Documentation of Water Measurement Conversion to Volume

SBx7-7 requires an annual volumetric accuracy of within 12 percent on existing devices. The main disadvantage of calculating delivered water volumes based on an instantaneous measurement is that the measurement device doesn't directly record the volume of delivered water. This can be problematic for two reasons. First, an accurate record of the duration of the delivery elapsed time must be maintained to convert the instantaneous measurement of flow rate into a volume. Secondly, if there are fluctuations in either the upstream or downstream water surface elevation during the course of a delivery, or if the gate opening changes, these fluctuations will affect the rate of discharge, and hence, the volume of water delivered. In the case of MID, because the water level at nearly every check structure is controlled by a long-crested weir, there is little variation in canal water levels regardless of the flow in the canals, leading to very accurate upstream water level measurements. The District is able to maintain a fairly constant canal side, or upstream, water level on the meter gate, but the District has no control on the landowner side, or downstream, water level. Nonetheless, it is expected that fluctuations over the irrigation season will typically balance themselves out.

Ditchtenders calculate the volume of a delivery by measuring the differences in water elevations and the sidegate opening, using calibrated tables to compute the flow rate which corresponds to these parameters, and multiplying that flow rate by the recorded duration of delivery. The time component is manually recorded by the ditchtenders, which is an honor system and historically meant that recorded times may not always be precise. Recordation of delivery duration has improved considerably in recent years as the drought has caused the District and agricultural water users to focus on efficient water use to stretch limited supplies.

The calculated water delivery is entered into the District's TruePoint water management system, which tracks cumulative water delivered to each agricultural water user during the irrigation season. This data is used to bill the agricultural water user on a volumetric basis in accordance with the tiered pricing structure established annually by the Board of Directors.

g) Device Corrective Action Plan Required for Water Measurement

i) Device Pilot Program

Although the District is currently able to bill for water deliveries volumetrically, the District believes that the current measurement methodology may be improved to ensure compliance with the provisions of SBx7-7 in all cases. To that end, the District continues conducting the Pilot Program initiated in 2015 to test several different types of measurement devices to see which types work best for MID agricultural water users and irrigation staff. During development of the Pilot Program, MID screened dozens of available flow measurement devices and chose devices from three different manufacturers that staff felt had the greatest likelihood of meeting the unique circumstances in the District. Factors considered in the screening criteria included:

- Ease of installation and use

- Device accuracy
- Ability to accumulate volumetric delivery information
- Expected life
- Automation (SCADA) potential
- Capital cost
- Expected O&M cost

The measurement devices tested in the Pilot Program included:

- Rubicon FlumeMeter – A transit-time metering device that is attached to the canal turnout on the upstream, or canal side of the turnout. Transit-time meters send and receive sound waves and determine the difference in time, which correlates to a velocity and ultimately a flow rate. The FlumeMeter has 32 sensors across 8 planes providing 3D reconstruction of the velocity profile. The FlumeMeter is attached to the canal turnout with a frame that allows the existing canal gate to remain in place and operational. The FlumeMeter is for water measurement only, and comes complete with a pedestal mounted data logger, solar panel, and battery backup. The FlumeMeter and pedestal can be moved from one location to another as long as the alternate location has a frame to receive the FlumeMeter and a pedestal mount to hold the pedestal. The device measures instantaneous flow rate and accumulates the volume of water delivered in the data logger. The FlumeMeter is primarily used on canal turnouts and is difficult and costly to install on pipeline turnouts.
- Rubicon FarmMeter – A transit-time ultrasonic metering device that is attached to the canal turnout on the upstream, or canal side of the turnout. Transit-time meters send and receive sound waves and determine the difference in time, which correlates to a velocity and ultimately a flow rate. The FarmMeter has 32 sensors across 8 planes providing 3D reconstruction of the velocity profile. The FarmMeter is attached to the canal turnout with a frame that allows the existing canal gate to remain in place and operational. The FarmMeter is for water measurement only and has a self-contained data logger on board. No pedestal required.
- SonTek IQ Pipe – An acoustic doppler meter that sends and receives acoustic pulses at a fixed frequency that collide with water particles, allowing for a determination of velocity. The SonTek IQ Pipe is designed for pipe flow and contains both depth and velocity sensors, meaning it can measure partial-pipe flow. The meter is strapped to the inside of a pipe or bolted down to the bottom of the pipe. Since the meter reads velocity and depth, the area for which it is placed must be known through the use of a rated section or known pipe size. Since the sensor is inside the pipe there are no right-of-way issues and the

instrumentation and cabling can be near the canal. The device measures instantaneous flow rate and accumulates the volume of water delivered in the data logger.

- Mace AgriFlo – An acoustic doppler meter similar to the SonTek IQ Pipe. The meter normally only measures velocity so it must be used in a full pipe, but a depth sensor can be added if partial pipe flow will be encountered.
- Teledyne ISCO Signature Flow Meter – An acoustic doppler meter similar to the SonTek IQ Pipe. The device measures instantaneous flow rate and stage and accumulates the volume of water delivered in the data logger.
- Hach portable flowmeter – A portable, handheld electromagnetic flowmeter that the District has used for spot measurements for many years. The device measures instantaneous flow rate only. Sensor is mounted on a calibrated rod to allow the District to take three measurements at different locations to develop a velocity profile of the pipe flow. Requires accurate knowledge of pipe size and an access vent in the pipe where the pipe is flowing full.
- Metergate – Predominant measurement device currently in use in the District. As previously described, water level is measured upstream and downstream of a turnout gate through the use of stilling well downstream of gate. Knowing the head differential across the gate and the gate opening area, an instantaneous flow rate can be determined using a rating table. Volume of water delivered can be estimated if flow rate remains fairly constant and time interval is recorded.

Prior to the start of the 2015 irrigation season, a number of delivery point sites were reviewed to identify some representative sites for testing the selected measurement devices. During the first year a total of 8 sites were selected to test 3 devices with a total of 10 meters so there was some replication in testing the same device under different conditions during the first year. Since then the District has moved the devices to different locations to continue to test these devices under various circumstances. In total 16 sites have been determined to be test sites and an additional 2 devices were tested; these were the Teledyne ISCO Meter and the Rubicon FarmMeter. At all sites it was desirable to have an existing operational meter gate. Also, at each site access would be provided for a Hach portable meter reading. The characteristics of each site that was selected to be included in the Pilot Program is shown in **Table 58**. The site locations were selected to represent different conditions within the District but were purposely chosen to be in relatively close proximity to each other to aid in collecting test data. The location of the test sites is shown in **Figure 7** below.

Table 58 – Pilot Program Site Characteristics

Gate Number	Site Name	Acres Served	Pipeline Diameter	Metergate Site	Air vent available?
L6-008	Coffee Davis	337	36”	No	Yes
MLM-084	Potts Ditch	292	30”	Yes	Yes
MLM-074	Litt Ditch	457	36”	Yes	No
MLM-068	Private	306	30”	Yes	Yes
MLM-066	Neagle ID	447	36”	Yes	Yes
L2-030	Cupp ID	24	30”	Yes	Yes
L2-028	Huff ID	66	36”	Yes	Yes
MLM-110	Hardie ID	391	30”	Yes	No
MLM-140	McHenry ID	163	30”	Yes	Yes
MLM-195	Haughton ID	326	36”	Yes	Yes
MLM-200	Dale ID	445	36”	Yes	Yes
L6-068	Miller ID	337	36”	Yes	No
L6-082	Curtis ID	972	36”	Yes	Yes
L7-086	Epperson ID	676	36”	Yes	Yes
L3-108	Brashear ID	564	30”	Yes	Yes
L5-070	Baker Shiloh	1,902	30”	Yes	Yes

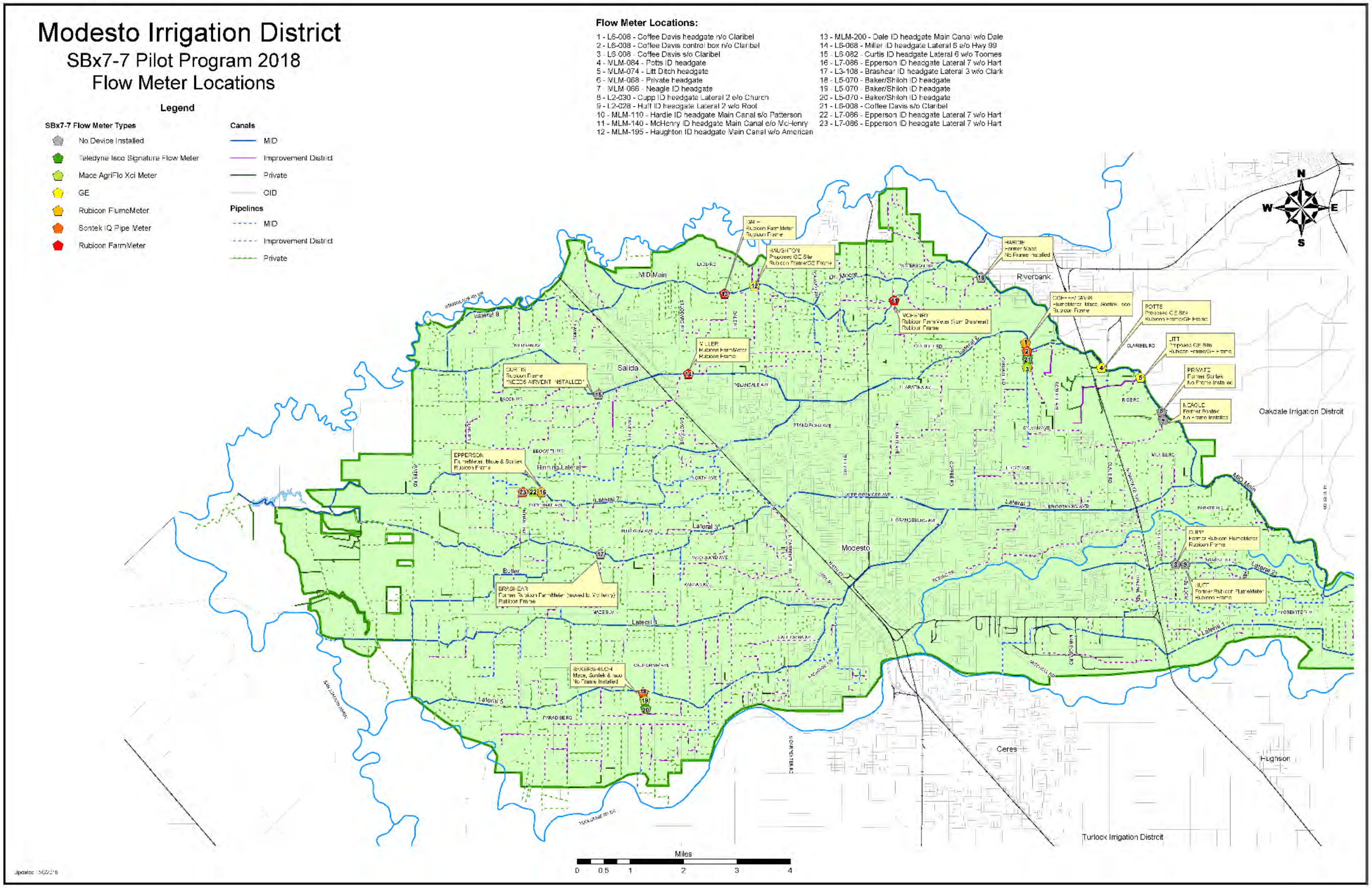


Figure 7 – Pilot Program Site Locations

Detailed cost information was maintained by the District for capital costs to purchase the meters that were tested and install the device with all associated appurtenances at each test site. Costs incurred with the Pilot Program are shown below, but it should be noted that this was a small-scale pilot project and it is expected that costs would be less with wide scale implementation.

Table 59 – Pilot Program Costs Per Site

Estimated Measurement Device Costs[1] per turnout site				
	Device Capital ($)	Installation Materials ($)	Installation Labor ($)	Est. Installed Cost ($)
Rubicon FlumeMeter[2]	16,200	2,000	4,000	22,200
Rubicon FarmMeter[2]	9,800	2,000	4,000	15,800
SonTek IQ Pipe Meter	12,000	300	1,000	13,300
Mace AgriFlo Xci (full pipe)	5,600	200	3,000	8,800
Mace AgriFlo Xci (partial pipe)	8,900	200	3,800	12,900
Teledyne ISCO Signature Flow Meter[3]	-	-	-	-
Hach Portable Meter[4]	50	300	200	550
Meter Gate[5]	-	-	-	-

[1] Costs shown are what was incurred for Pilot Study, purchasing only 3 or 4 devices. It is expected that the capital cost would be reduced if a larger volume of devices are purchased, and labor costs would also likely be reduced as experience is gained in installation.
[2] If Rubicon devices are rotated to calibrate meter gates – assume each device stays at a site for at least the entire irrigation event (typically 21 days), then is moved to another site. Assuming one week to move to another site and set up, and assuming typical irrigation season of 7 months, each device could cover 7 sites once modifications have been made at each site to accept the devices. Capital costs per site would then be $1/7^{th}$ that shown.
[3] Teledyne ISCO meters were utilized and installed at no cost to The District as a prototype. The District did not expand implementation of the device and the equipment was returned.
[4] Capital cost assumes 4 more Hach meters are purchased and utilized at 500 sites, and each site requires a new access vent.
[5] Assumes no capital modifications are required to existing meter gates.

Most measurement devices were operational in late April or early May, near the beginning of the 2015 irrigation season. FarmMeters were added during the 2016 irrigation season. During the irrigation season, District staff would periodically visit each site to collect data. Since SBx7-7 requires accuracy based on volume, two readings were always taken each irrigation event, one generally at the beginning and one at the end. While the time duration was not ideal (usually only a few hours between readings), it was desired to obtain readings while conditions were consistent. At each site the measurements were made sequentially for each device in the same order, so the time duration was constant for all devices on a given day.

- For the Rubicon, SonTek, ISCO and Mace devices, the flow rate in cfs and volumetric reading in acre-feet from the device were obtained each time the site was visited. The measured volume delivered was the difference between the two readings. As a cross-check, the volume delivered by each device was also calculated based on the average of the flow rates over the time duration.

- For the meter gates, the gate opening, and the head differential was recorded and the existing rating table for that gate was used to determine the instantaneous flow rate. The volume delivered was calculated based on the average of the flow rates over the time duration.
- For the Hach portable meter, the instantaneous flow rate was measured and recorded. The volume delivered was calculated based on the average of the flow rates over the time duration.

Due to the drought conditions and limited water supplies during the first year of the Pilot Program, some sites didn't operate very long and limited data was obtained. The District has significant variety in site characteristics of each of the delivery locations throughout the District. It was determined that the best devices for the District would be those that can be adapted to fit several different types of delivery locations so these devices were moved often to continue to evaluate the adaptability of each device at different locations that were representative of the District. Each year prior to the start of the irrigation season, the pilot program sites were evaluated, and the devices were moved to another site to evaluate the challenges and how the devices were able to adapt.

Table 60 illustrates how many days were measured at each site and the duration between the first reading and the last reading.

Table 60 – Measurement Devices Tested

Gate Number	Site Name	Acres Served	Measurement Device							Days Measured	Start Date	End Date
			Rubicon Flume Meter	Rubicon Farm Meter	SonTek IQ Meter	Mace AgriFlo Meter	ISCO Meter	Meter gate	Hach			
L6-008	Coffee Davis	337	X		X	X	X		X	31	05/18/2015	05/30/2018
MLM-084	Potts Ditch	292	X					X	X	27	05/06/2015	09/17/2015
MLM-074	Litt Ditch	457	X					X	X	56	05/06/2015	09/13/2016
MLM-068	Private	306			X			X	X	39	04/22/2015	08/30/2017
MLM-006	Neagle ID	447			X			X	X	28	04/22/2015	08/30/2017
L2-030	Cupp ID	24				X		X	X	2	05/04/2015	07/09/2015
L2-028	Huff ID	66			X			X	X	7	06/02/2015	09/28/2015
MLM-110	Hardie ID	391				X		X	X	18	05/21/2015	07/21/2017
MLM-140	McHenry ID	163		X				X	X	11	06/06/2017	07/10/2018
MLM-195	Haughton ID	326		X				X	X	5	06/22/2017	07/27/2017
MLM-200	Dale ID	445		X				X	X	18	07/01/2016	07/10/2018
L6-068	Miller ID	337		X				X	X	10	08/19/2016	07/10/2018
L6-082	Curtis ID			X				X	X			
L7-086	Epperson ID	676	X		X	X		X	X	23	08/09/2016	09/21/2018
L3-108	Brashear	564		X				X	X	6	07/25/2016	09/07/2016
L5-070	Baker Shiloh	1,902			X	X	X	X	X	31	07/27/2016	09/19/2018

The Pilot Program data was collected during the irrigation season and analyzed in a summary report each year. The Hach portable meter was the only measurement device that was used at all sites, so the Hach portable meter was used to provide a comparison of the relative accuracy of the other devices. The District has confidence in the accuracy of the Hach portable meter, but inaccuracies could be introduced by comparing to a meter that is not calibrated for each site. Since SBx7-7 specifies an accuracy based on volumetric measurement, all comparisons were made to the volume of water estimated using measurements obtained with the Hach portable meter. However, since the volume of water delivered as measured by the Hach meter at each site was calculated based on the average of the instantaneous flow rates over the time duration, if the two instantaneous flow rate readings measured by the Hach on a given day were more than 10% different, the reading that day was not utilized in the analysis since it was unknown when the flow rate changed. The comparison of each device to the Hach meter on a volumetric basis for all sites is shown below. Site specific analysis of the data was conducted to determine if there is variability across the sites. From the preliminary analysis after the first year, it was apparent that additional testing was required, ideally under normal operating conditions. MID continued to actively collect and test each of the devices until 2018. Since that time MID has moved into a monitoring phase to determine the durability, reliability, and maintenance needs of the devices as well as keeping aware of emerging technologies. The District will most likely utilize a host of devices in order to best fit the various locations. The District is also in the process of creating an inventory of the private pressurized systems throughout the District for additional water supply tracking.

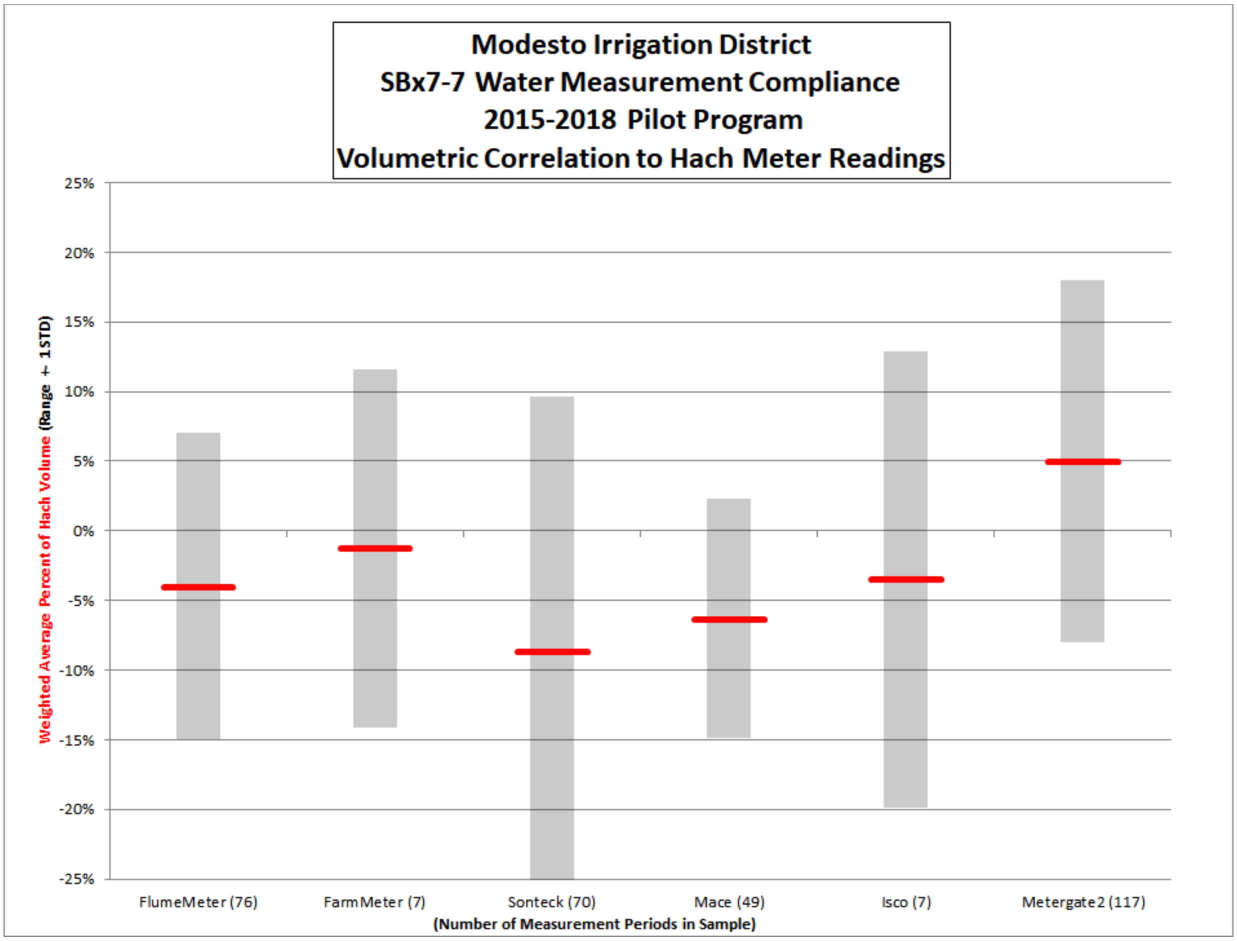


Figure 8 – Preliminary Pilot Program Test Results

Based on the findings, it appeared that the Rubicon devices performed the best out of the four manufacturers that were tested. It should also be noted that the existing meter gates performed well compared to the Hach meter measurements. Additional testing and maintenance information is required before the District can select a device or method for wide scale implementation, but the District is utilizing these preliminary results from the Pilot Program to begin structuring a potential program to improve delivery point water measurement within the District.

The District is developing a program that it believes is implementable, locally cost effective, and compared to other alternatives has the most likely chance of being approved by landowners. Prior to plan implementation it will be necessary for the District to conduct a successful Proposition 218 election to fund the program costs. The District has developed the following goals for a water measurement program:

- The Program must be locally cost-effective and achieve the most “bang-for-the-buck” during implementation.
- The Program will employ water measurement using a combination of individual customer turnout measurement devices and lateral level (upstream) turnout measurements to multiple customers on private laterals (Improvement Districts).

- Measurement devices and methods will be standardized as much as possible, so that standardized operations can be used at delivery points throughout the District. Devices or methods used for canal and pipeline measurement will likely be different.
- For permanent installations on the largest delivery points, it may be desirable for the measurement device to indicate the instantaneous flow rate and the accumulated volume delivered and be readable in the field by both District staff and the agricultural water user, with the provision that data could be conveyed to the SCADA system in the future if desired.
- The measurement device must be a proven technology that the District and the agricultural water user can easily understand.
- The ability to secure the measurement device is important to prevent, or at least hinder, theft and vandalism.

Based on the results obtained to date with the Pilot Program, the District has preliminarily selected a measurement method or device to be used at each delivery point in each acreage range group. Continued testing will occur of the various devices that may refine the recommended measurement devices or methods. For existing meter gates, a system for improved control of the time component, documenting the on and off times, is currently being developed to improve volumetric calculation accuracy. For purposes of developing a schedule and budget for implementation of measurement methods or devices at each delivery point, the District has preliminarily selected the following:

Table 61 – Flow Measurement Implementation Plan

Acreage Served by Turnout	Preliminary[1] Measurement Method / Device
< 5 ac	No change. The volume of water delivered to Gardenhead[2] parcels is significantly less than 1% of the total volume delivered annually, so the existing turnout meter gate will continue to be used.
5 – 10 ac	No change. The acreage billed, and hence the amount of water delivered, through turnouts delivering water to parcels less than 10 acres is only approximately 1% of the total volume delivered annually, so the existing turnout meter gate will continue to be used for measurement.
10 – 50 ac	Serving approximately 17% of the irrigated acreage. Meter gate to be used for measurement. Hach or other portable meter will be used to verify meter gate flow readings. Measurement through meter gate at every turnout will be verified within approximately three years. Any meter gates that are found to have the measured flow rate outside ±12% accuracy will be re-calibrated with the Hach or other portable meter or replaced if meter gate can't be properly calibrated.

Acreage Served by Turnout	Preliminary[1] Measurement Method / Device
50 – 100 ac	Serving approximately 15% of the irrigated acreage. <u>Canal turnouts</u> Installation of frame for Rubicon FarmMeter at each site. Rotate a FarmMeter between approximately 7 sites during a typical year to verify or re-calibrate each individual meter gate. Each FarmMeter to remain at a site for duration of at least one entire irrigation event. Once all meter gates have been verified with respect to accuracy or re-calibrated, rotation of FarmMeters will continue and each meter gate will be verified/re-calibrated at least every five (5) years. Any meter gates that can't be verified or re-calibrated to within ±12% accuracy will be replaced. <u>Pipeline turnouts</u> Meter gate to be used for measurement. Hach or other portable meter will be used to verify or re-calibrate each individual meter gate. Once all meter gates have been verified or re-calibrated, Hach or other portable meter will continue to be used periodically to verify flow rates at each meter gate at least every five (5) years. Any meter gates that are found to have the measured flow rate outside ±12% accuracy will be replaced if meter gate can't be properly calibrated.
> 100 ac	Serving approximately 67% of the irrigated acreage. First priority for measurement improvements. <u>Canal turnouts</u> Installation of frame and pedestal for Rubicon at approximately one-half of the sites that deliver the largest volume of water. Volumetric delivery information will be stored in data logger. SCADA could be added in the future to collect flow and volumetric delivery data, if desired. Installation of frame for Rubicon FarmMeter at remaining sites. Rotate a FarmMeter between approximately 7 sites during a typical year to verify or re-calibrate each individual meter gate. Each FarmMeter to remain at a site for duration of at least one entire irrigation event. Once all meter gates have been verified with respect to accuracy or re-calibrated, rotation of FarmMeters will continue and each meter gate will be verified/re-calibrated at least every five (5) years. Any meter gates that can't be calibrated to within ±12% accuracy will be replaced. <u>Pipeline turnouts</u> Meter gate to be used for measurement. Hach or other portable meter will be used to verify or re-calibrate each individual meter gate. Once all meter gates have been verified or re-calibrated, Hach or other portable meter will continue to be used periodically to verify flow rates at each meter gate at least every five (5) years. Any meter gates that are found to have the measured flow rate outside ±12% accuracy will be replaced if meter gate can't be properly calibrated.

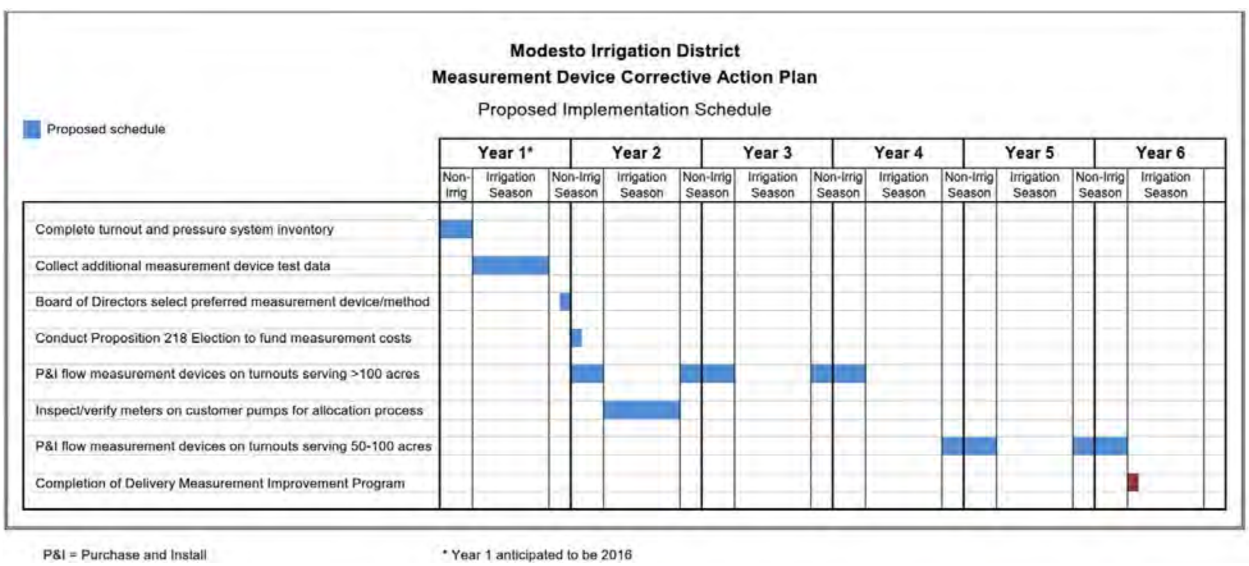
[1]Preliminary Selection of Measurement Method/Device based on experience and limited testing in 2015 with Pilot Program. These selections are subject to change based on budget considerations and as more information is obtained and as technology develops. Additional testing is planned for the 2016 irrigation season.
[2]Gardenhead parcels, which are typically less than five acres in size and separate or distinct from farm service parcels, are generally irrigated as a group with a standardized rotation.

ii) Schedule

The District has developed the schedule indicated below for implementation of its measurement device corrective action plan to comply with the measurement requirements of SBx7-7. As explained above, the District will utilize different levels of measurement depending on the acreage that is served by each delivery point and subsequent water use, but there are still approximately 300 locations that must be modified to accept a measurement device throughout the District for direct measurement or for re-calibration of the existing meter gate. Because of the large number of measurement devices that must be installed, the District has chosen a 5-year measurement device installation period, which results in approximately 60 devices being installed each year on average. Installation of measurement devices will begin following approval by the Board of Directors and a successful Prop 218 election to fund measurement costs. The anticipated time frame for compliance will be evaluated annually and may need to be revised depending on the availability of staff resources and funding needed to complete other programs and projects that MID is engaged in which also have a high priority, such as distribution system maintenance and other planned capital improvements consistent CWRMP.

Installation of measurement devices must occur during the non-irrigation season, generally mid-October to mid-March. Storm flows that are conveyed through the District distribution system may affect the ability to install measurement devices. Emphasis will be placed on installing measurement devices that serve the largest acreage first. The District’s proposed schedule for implementing a water measurement program at each delivery point is summarized below. Year 1 in the schedule below is assumed to be 2026 but purchase and installation of devices will not occur until the Board of Directors selects the preferred measurement device or method and the District conducts a successful Proposition 218 election to fund the program costs.

Table 62 – Proposed Implementation Timeline



iii) Finance Plan

The proposed water measurement implementation program may be funded through increased District assessments (fixed charge), which would require a Prop. 218 election. The cost to the District for the purchase and installation of the water measurement devices will be spread over time as measurement devices are installed each year during the anticipated 5-year installation period. The purchase of the water measurement devices will likely be funded by the District through a bond sale or from District reserves, and the fixed charges collected over time will pay the bond debt or reimburse the reserve fund.

iv) Budget

The District currently budgets $60,000 per year in its Water Operations Capital Budget program for measurement improvements. This annual budget must be substantially increased in order to fund the additional capital and O&M for water measurement that is required to comply with the measurement program set forth herein. Based on the meter pilot test program that was conducted and preliminary selection of desired measurement devices, the implementation cost for the measurement program is estimated to be approximately $4.5 million.

MID will monitor the measurement program activity on an on-going basis to determine whether or not this level of effort is sufficient and effective, and will make adjustments as needed to provide a technically sound, locally cost effective solution to improving water measurement at the farm-gate level.

As previously discussed, revised assessments and water toll charges that may be required to fund the measurement program are subject to Proposition 218. If the Proposition 218 election is unsuccessful, the District may not have sufficient funding available to implement the proposed water measurement program as set-forth herein.

Section IX: References

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16. Modesto Irrigation District Annual Crop Records (1910-2020).

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18. Stanislaus and Tuolumne Rivers Groundwater Basin Association. September 2004. Integrated Regional Groundwater Management Plan for the Modesto Groundwater Subbasin, September 2004.

19. United States Geological Survey. 2004. Scientific Investigations Report 2004-5232. “Hydrogeologic Characterization of the Modesto Area, San Joaquin Valley, California”.

20. United Stated Geologic Survey. 2015. Scientific Investigations Report 2015-5045. “Hydrologic Model of the Modesto Region, California, 1960-2004”.

21. United States Geological Survey. Water Resources Data-California (1905-2020).

MODESTO IRRIGATION DISTRICT

2020 AGRICULTURAL WATER MANAGEMENT PLAN

APPENDIX A

PUBLIC NOTICE OF PLAN PREPARATION

MID Website Information Regarding Draft AWMP

Updates to the MID AWMP are communicated to the public through the MID website: https://www.mid.org/water/awmp/default.html

SIGN IN REGISTER ABOUT MID NEWSROOM CAREERS CONTACT US

MID Modesto Irrigation District Water and Power

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- Irrigation Water
- Drinking Water
- Recreation
- Water Committee
- Domestic Water Quality Committee
- Ag Water Management Plan
- Joint Urban Water Management Plan
- Groundwater Information
- Current Reservoir Levels
- Irrigation Standard Construction Details
- Weather Data

Contact Us

Irrigation Operations
Mon. - Fri. 7am to 4pm
(209) 526-7639

Customer Service
Mon. - Fri., 8 a.m. to 5 p.m.
(209) 526-7337 or
(888) 335-1643 toll-free
customerservice@mid.org

Please be advised that MID may take up to one (1) business day to reply to all email correspondence.

Agricultural Water Management Plan

2020 Draft Agricultural Water Management Plan Now Available

MID has been actively involved in agricultural water management planning efforts since joining the Agricultural Water Management Council (AWMC) in the late 1990's. As such, MID's first Agricultural Water Management Plan (AWMP) was prepared in voluntary compliance with provisions of California Assembly Bill 3616 in 1999. MID's 1999 AWMP was submitted and approved by the AWMC on behalf of the California Department of Water Resources (DWR).

Legislation passed in 2009, commonly referred to as SBx7-7, made the once voluntary program mandatory and required an updated AWMP be completed in 2012, 2015 and every five years thereafter.

MID's 2012 AWMP describes MID's water supplies and irrigation demand, local conditions, facilities and operations, rules and policies and a variety of water management activities, including a series of efficient water management practices (EWMPs) designed to improve water use efficiency. In accordance with SBx7 and the Governor's Executive Order B-29-15, MID updated the AWMP in 2015.

MID's 2015 AWMP is intended to comply with these requirements as well as serve as a short-term strategic plan for the MID Irrigation Operations Division while complementing the ongoing long-range planning document - MID's Comprehensive Water Resource Management Plan.

2020 Draft Agricultural Water Management Plan

A draft copy of MID's 2020 AWMP is now available. MID is required to adopt the updated AWMP by April 1, 2021.The AWMP includes detailed background information about MID and its irrigation facilities, water supply and demand, programs, past and upcoming projects, policies and efficient water management practices being implemented now or planned in the upcoming years. The MID Board of Directors will hold a public hearing on Tuesday, March 23, 2021 at 9 a.m. to consider public comments on the proposed revisions to MID's AWMP.

Given current COVID-19 conditions, it's easiest to submit all comments via email at AWMP@mid.org. Written comments can also be mailed to the following:

> John B. Davids
> Modesto Irrigation District
> 1231 11th Street
> Modesto, CA 95354

Public comment will also be available at the March 23 public hearing.

For more information, please contact MID via email at AWMP@mid.org or call (209) 526-7459.

Sample Notice of Intent Letter to Local Public Agencies

Modesto Irrigation District
Water and Power

1231 Eleventh St.
P.O. Box 4060
Modesto, CA 95352
(209) 526-7373

February 12, 2021

Sent Electronically

Jim Alves
City of Modesto
P.O. Box 642
Modesto, CA 95353

Re: Notice of Intent to Adopt 2020 Agricultural Water Management Plan Update Modesto Irrigation District

Dear Mr. Alves:

This letter serves as notice that the Modesto Irrigation District (MID) intends to adopt an update to its current Agricultural Water Management Plan (AWMP). A hearing will be scheduled to occur near the end of March for comments. Comments may be submitted in writing before that time to awmp@mid.org

Please refer to our website www.mid.org/water for updates and posting of the draft plan when it becomes available. The draft is expected to be available after February 19th.

Following the public hearing, the MID Board of Directors will consider comments received, and may choose to consider adopting the plan on the day of the hearing.

Should you have any questions, please do not hesitate to contact Chad Tienken by email at awmp@mid.org. Thank you.

Sincerely,

John B. Davids, P.E.
Assistant General Manager, Water Operations

cc: Administration Files

ORGANIZED 1887 • IRRIGATION WATER 1904 • POWER 1923 • DOMESTIC WATER 1994

Sample Public Hearing Notice Letter to Public Agencies

Modesto Irrigation District
Water and Power

1231 Eleventh St.
P.O. Box 4060
Modesto, CA 95352
(209) 526-7373

March 5, 2021

Jim Alves
City of Modesto
P.O. Box 642
Modesto, CA 95353

Sent Electronically

Re: Public Hearing Notice – 2020 Agricultural Water Management Plan Update

Dear Mr. Alves:

The Modesto Irrigation District (MID) Board of Directors (Board) is scheduled to hold a public hearing on the proposed 2020 Agricultural Water Management Plan (AWMP) update at 9:00 AM on March 23, 2021. Due to the ongoing COVID-19 pandemic, members of the public may join the public hearing consistent with the instructions provided in the Board meeting agenda. The March 23, 2021 meeting agenda will be posted by March 19th and can be found at www.mid.org/about/board/agenda. At the hearing, the Board will receive public comments on the draft AWMP prior to consideration and possible adoption of the AWMP. All persons interested in this matter may provide input at the hearing or can submit their comments in writing to AWMP@mid.org prior to the hearing.

More information and a copy of the draft AWMP can be found at www.mid.org/water/awmp. Should you have any questions, please do not hesitate to contact Chad Tienken by email at AWMP@mid.org.

Sincerely,

John B. Davids, P.E.
Assistant General Manager, Water Operations

cc: Administration Files

ORGANIZED 1887 • IRRIGATION WATER 1904 • POWER 1923 • DOMESTIC WATER 1994

Public Hearing Notice – Modesto Bee

NOTICE OF
PUBLIC HEARING

The Modesto Irrigation District (MID) Board of Directors will hold a public hearing regarding the 2020 Agricultural Water Management Plan on Tuesday, March 23, 2021 at 9 a.m.

Legislation passed in 2009, commonly referred to as SBx7-7, required agricultural water agencies in California to prepare an Agricultural Water Management Plan (AWMP) in 2012, 2015 and every five years thereafter. The draft 2020 AWMP includes detailed background information about MID and its irrigation facilities, water supply and demand, programs, past and upcoming projects, policies and efficient water management practices being implemented now or planned in the upcoming years.

MID's public review draft of the 2020 AWMP may be reviewed online at www.mid.org/water/awmp. Given current COVID-19 conditions, we encourage that all comments be submitted via email at AWMP@mid.org. However, written comments can also be mailed to the following:

John B. Davids
Modesto Irrigation District
1231 11th Street
Modesto, CA 95354

Public comment will also be available at the March 23 public hearing. The Zoom webinar link will be provided in the Board meeting agenda packet.

MID Modesto Irrigation District — Water and Power

1231 11th Street | P.O. Box 4060 | Modesto, CA
www.mid.org

Public Hearing Notice – Waterford News

NOTICE OF PUBLIC HEARING

The Modesto Irrigation District (MID) Board of Directors will hold a public hearing regarding the 2020 Agricultural Water Management Plan on Tuesday, March 23, 2021 at 9 a.m.

Legislation passed in 2009, commonly referred to as SBx7-7, required agricultural water agencies in California to prepare an Agricultural Water Management Plan (AWMP) in 2012, 2015 and every five years thereafter. The draft 2020 AWMP includes detailed background information about MID and its irrigation facilities, water supply and demand, programs, past and upcoming projects, policies and efficient water management practices being implemented now or planned in the upcoming years.

MID's public review draft of the 2020 AWMP may be reviewed online at www.mid.org/water/awmp. Given current COVID-19 conditions, we encourage that all comments be submitted via email at AWMP@mid.org. However, written comments can be mailed to the following:

John B. Davids
Modesto Irrigation District
1231 11th Street
Modesto, CA 95354

Public comment will also be available at the March 23 public hearing. The Zoom webinar link will be provided in the Board meeting agenda packet.

MID Modesto Irrigation District
Water and Power

1231 11th Street | P.O. Box 4060 | Modesto, CA
www.mid.org

MODESTO IRRIGATION DISTRICT

2020 AGRICULTURAL WATER MANAGEMENT PLAN

APPENDIX B

RESOLUTION OF PLAN ADOPTION

RESOLUTION 2021-16

ADOPTING MODESTO IRRIGATION DISTRICT'S 2020 AGRICULTURAL WATER MANAGEMENT PLAN COMPLETED IN ACCORDANCE WITH THE AGRICULTURAL WATER MANAGEMENT PLANNING ACT (SECTION 1, PART 2.8, DIVISION 6 OF THE WATER CODE) INCLUDING AMENDMENTS BY THE WATER CONSERVATION ACT OF 2009 (SBX7-7), AB 1668 (MAY, 2018) AND SB 606 (MAY 2018) AND DIRECTING STAFF TO MAKE ANY NECESSARY CHANGES PRIOR TO SUBMISSION TO DWR

WHEREAS, Modesto Irrigation District has been actively involved in agricultural water management planning efforts since Modesto Irrigation District joined the Agricultural Water Management Council in the late 1990's; and

WHEREAS, Modesto Irrigation District's first Agricultural Water Management Plan was prepared in voluntary compliance with provisions of California Assembly Bill 3616 in 1999; and

WHEREAS, Modesto Irrigation District's 1999 Agricultural Water Management Plan was submitted and approved by the Agricultural Water Management Council on behalf of the California Department of Water Resources; and

WHEREAS, Legislation passed in 2009, commonly referred to as SBx7-7, made the once voluntary program mandatory; and

WHEREAS, Modesto Irrigation District prepared and adopted an Agricultural Water Management Plan in 2012 in compliance with SBx7-7; and

WHEREAS, under the new requirements, Modesto Irrigation District was required to update the plan in 2015 and then every five years thereafter; and

WHEREAS, Modesto Irrigation District's current Agricultural Water Management Plan was adopted in 2015 and describes Modesto Irrigation District's water supplies and irrigation demand, local conditions, facilities and operations, rules and policies and a variety of water management activities, including a series of efficient water management practices designed to improve water use efficiency; and

WHEREAS, in addition to the standard Agricultural Water Management Plan requirements, the draft revised Agricultural Water Management Plan also addresses the additional Agricultural Water Management Plan requirements established by the Governor's Executive Order B-29-15 (April 1, 2015) and Water Conservation and Drought Planning statutes AB 1668 (Friedman, Statute of 2018) and SB 606 (Hertzberg, 2018); and

WHEREAS, it is staff's intent to use this five-year planning document as a short-term strategic plan for the Water Operations Division; and

WHEREAS, the 2020 Agricultural Water Management Plan is a just a plan and local control and flexibility is retained by the MID Board; and

WHEREAS, Modesto Irrigation District released the draft 2020 Agricultural Water Management Plan for a 30-day public review period on February 19, 2021 and subsequently held a public hearing on

March 23, 2021 to hear and consider comments from the public on the draft 2020 Agricultural Water Management Plan.

BE IT RESOLVED, That the Board of Directors of the Modesto Irrigation District does hereby adopt Modesto Irrigation District's 2020 Agricultural Water Management Plan completed in accordance with the Agricultural Water Management Planning Act (Section 1, Part 2.8, Division 6 of the Water Code) including amendments by the Water Conservation Act of 2009 (SBx7-7), AB 1668 (May, 2018) and SB 606 (May 2018) and directing staff to make any necessary changes prior to submission to DWR.

Moved by Director Byrd, seconded by Director Gilman, that the foregoing resolution be adopted.

The following roll call vote was had:

Ayes:	Directors Blom, Byrd, Campbell, Gilman and Mensinger
Noes:	Director None
Absent:	Director None

The President declared the resolution adopted.

o0o

I, Angela Cartisano, Board Secretary of the Modesto Irrigation District, do hereby CERTIFY that the foregoing is a full, true and correct copy of a resolution duly adopted at a special meeting of said Board of Directors held the twenty-third day of March 2021.

Board Secretary of the
Modesto Irrigation District

MODESTO IRRIGATION DISTRICT

2020 AGRICULTURAL WATER MANAGEMENT PLAN

APPENDIX C

RULES AND REGULATIONS GOVERNING THE DISTRIBUTION OF IRRIGATION WATER WITHIN THE MODESTO IRRIGATION DISTRICT

RULES AND REGULATIONS GOVERNING THE DISTRIBUTION OF IRRIGATION WATER WITHIN THE MODESTO IRRIGATION DISTRICT

APRIL 2015

RULES AND REGULATIONS GOVERNING THE DISTRIBUTION OF IRRIGATION WATER WITHIN THE MODESTO IRRIGATION DISTRICT

PREAMBLE

These Rules and Regulations Governing the Distribution of Irrigation Water Within the Modesto Irrigation District are established pursuant to Water Code Section 22257 to ensure the orderly, efficient and equitable distribution, use and conservation of the water resources of the District. The District will endeavor to deliver irrigation water in a flexible, timely manner consistent with the physical and operational limits of the delivery system facilities.

In addition to these Irrigation Rules, the District may enter into agreements and develop policies and programs to enhance service to our customers. To receive further information, please contact:

Modesto Irrigation District
Irrigation Operations Division
P.O. Box 4060
Modesto, CA 95352
(209) 526-7563

This rules booklet supersedes "Rules and Regulations Governing the Distribution of Irrigation Water in the Modesto Irrigation District" (Last Revised April 2000)

MODESTO IRRIGATION DISTRICT MISSION STATEMENT

To deliver superior value to our irrigation, electric and domestic water customers through teamwork, technology and innovation.

IRRIGATION OPERATIONS DIVISION MISSION STATEMENT

To responsibly manage the water resources of the District to provide a safe, reliable and sustainable supply for our agricultural and urban community.

HISTORICAL NOTES

Signing of the Wright Act in March of 1887 allowed for the formation of irrigation districts in California and gave them the power to conduct elections, issue bonds and acquire property. The Modesto Irrigation District was the second irrigation district formed under the new law. The Wright Act was named for C.C. Wright, the Modesto assemblyman who introduced the law.

The District first delivered irrigation water in 1904; the availability of such water changed the nature of the farming in the area within a few years. Large tracts of wheat were replaced with orchards and vineyards. Today Stanislaus County ranks among the top 10 agricultural counties in the nation.

KEY DATES

Established	July 23, 1887
Irrigation service started	1904
Electrical service started	1923
Waterford Irrigation District-merger	January 1, 1978
Domestic water treatment started	1994

IRRIGATION FACTS

No. of acres in the District	101,683
Irrigated acres	64,000
No. of accounts	3,400
Miles of canals and pipelines	208
Water source	Tuolumne River
Average Annual Modesto Rainfall	12 inches

TABLE OF CONTENTS

SECTION 1: DEFINITIONS

1.1. "Agreement" includes any license agreement or agreement of any nature, application, request for permission, permit, petition or contractual obligation entered into by and/or between a Landowner or Irrigator and the District.

1.2. "Irrigation Operations Manager" is the Irrigation Operations Manager of the District or the Irrigation Operations Manager's authorized representative.

1.3. "Authorized agent / authorized representative" means a subordinate or other individual granted the authority to act on behalf of the District.

1.4. "Board" means the duly elected Board of Directors of the District.

1.5. "Canals" include canals, laterals, ditches, drains, flumes, pipelines, and all related water conveyance facilities.

1.6. "Canal Road" means the area within District Rights-of-Way maintained for the purpose of permitting the passage of District vehicles.

1.7. "Delivery Point" means the location at which the District transfers control of delivered water to the irrigator or group of irrigators.

1.8. "District" means the MODESTO IRRIGATION DISTRICT functioning under the Irrigation District Law of the California Water Code.

1.9. "District Canals" means Canals owned, operated and maintained by the District, but excluding Improvement District Facilities.

1.10. "District Facilities" means Facilities owned, operated and maintained by the District, but excluding Improvement District Facilities.

1.11. "District Rights-of-Way" includes all rights-of-way held by the District, in fee or by easement.

1.12. "Ditchtender" means the District employee, under the general direction of the Irrigation Field Services Manager, responsible for making direct irrigation deliveries to Landowners from the District's irrigation system.

1.13. "Facilities" include dams, structures, wells, canals, pumps, reservoirs, and all other facilities and appurtenances thereto used for or in connection with the delivery, conveyance or receipt of water.

1.14. "Gravity Water" means water delivered to the end-user by means of gravitational flow.

1.15. "General Manager" or "GM" is the General Manager of the District or the GM's authorized representative.

1.16. "Improvement District" is any sub-district involving two or more landowners within the District formed under the California Water Code and for the purpose of providing for the operation and maintenance of, and capital improvements to, Facilities not owned by the District.

1.17. “Improvement District Facilities” include all Facilities owned by an Improvement District.

1.18. “Irrigable” means all parcels with or without on-farm irrigation facilities that could be irrigated either by District or private water.

1.19. “Irrigation Field Services Manager” is the District employee, under general direction from the Irrigation Operations Manager, who is delegated the authority and responsibility to direct irrigation water deliveries and construction/maintenance of the District’s irrigation system.

1.20. “Irrigation Rules” means these Rules and Regulations Governing the Distribution of Irrigation Water Within the Modesto Irrigation District, as duly adopted by the Board, and all regulations, policies, notices and procedures promulgated in accordance therewith.

1.21. “Irrigation Season” means that portion of the calendar year where surface irrigation water is generally made available to District Landowners. The Irrigation Season typically extends from March 1 to October 31, but may be modified each year as directed by the Board.

1.22. “Irrigator” means the Landowner or Renter of a parcel of land who has the primary responsibility for irrigating the parcel. The term includes the Irrigator's officers, employees, contractors and agents.

1.23. “Landowner” means holder of title or evidence of title to land.

1.24. “Laws” includes all federal, state and local statutes and ordinances, and all rules and regulations promulgated, and all orders and decrees issued, in connection therewith.

1.25. “Policy” means Agreements, rules, regulations, guidelines, and Procedures that authorize District staff to act on behalf of the District.

1.26. “Pollutant” means any foreign or deleterious substance or material, including but not limited to garbage, rubbish, refuse, animal carcasses, matter from any barnyard, stable, dairy or hog pen, herbicides, pesticides, fertilizers or any other material which is offensive to the senses or injurious to health, or which pollutes or degrades the quality of the receiving water or any flammable, explosive, or radio active material, toxic substance, hazardous waste, hazardous material, hazardous substance, or the equivalent, as those terms may now or in the future be defined by common practice or by Law. Filter station backflush water shall be allowed back into District facilities so long as chemical injection occurs downstream of backflush location, proper backflow prevention is in place and the Landowner is in compliance with the irrigated lands regulatory program.

1.27. "Practice" is a customary activity or generally accepted method.

1.28. "Private Facilities" include all facilities owned by a person or entity other than the District or an Improvement District.

1.29. "Procedure" is an ordered series of steps developed by the District to guide interaction between District staff and the public.

1.30. "Program" is a plan or Procedure through which a Landowner may secure services, such as design, funding and/or financing, for irrigation system improvements.

1.31. "Renter" means a person or entity that leases, rents, or sharecrops land from a Landowner.

1.32. "Vehicle" means any motorized or self propelled vehicle, for air, water or land, including but not limited to boats, cars, motorcycles, bicycles, and all terrain vehicles.

1.33. "Water Allocation" means the quantity of water that is allocated annually by the Board for irrigation distribution to each acre of land within the District.

SECTION 2: FACILITIES

2.1. CONTROL OF FACILITIES:

2.1.1. District Facilities are under the exclusive direction, management and control of authorized District personnel. No persons other than authorized District personnel shall have any right to operate or interfere with said Facilities in any manner.

2.1.1.1. Each Irrigable parcel will be within an area assigned to a designated Ditchtender.

2.1.2. For assistance with Facilities, contact the Irrigation Field Services Manager at (209) 526-7637.

2.1.3. For emergency use of Facilities, contact the Irrigation Field Services Manager at (209) 526-7637.

2.2. ACCESS TO LANDS:

2.2.1. Every District director, officer, employee, and authorized agent or representative shall have the right, at all times, to reasonably enter any land irrigated with water from the District for any of the following purposes:

2.2.1.1. Inspecting District Facilities; the flow of water within and through such Facilities (including measurement thereof); and the use of water on the land;

2.2.1.2. Determining the acreage of crops irrigated or to be irrigated;

2.2.1.3. Maintaining or operating District Facilities;

2.2.1.4. Investigating any incident or report involving District Facilities, or water originating from any District Facility;

2.2.1.5. Responding to an emergency upon notification from law enforcement or other person; and

2.2.1.6. Performing any work contemplated under these Irrigation Rules.

2.2.1.7. Should entry for the purposes set-forth herein be unreasonably denied, the current irrigation event may be terminated and re-establishment of irrigation event shall be coordinated with the Ditchtender.

2.3. ENCROACHMENTS:

2.3.1. No trees, vines, crops or other vegetation shall be planted and no encroachments shall be installed, constructed or placed in, on, over, under or across any District Facility or Right-of-Way unless such encroachment is consistent with District Policy and the District has given specific written approval for such encroachment. In granting such approval, the District may impose such conditions (including reasonable fees) and/or restrictions as District deems appropriate.

2.3.2. Upon written notification from the District to the Landowner owning the land adjacent to any unauthorized encroachment, said Landowner shall immediately remove such encroachment. If such encroachment is not promptly removed, the District may take all reasonable action to remove the encroachment at the sole expense of the Landowner.

2.3.3. Encroachments in, on, over, under or across any District Facility or District Right-of-Way that interfere with the operation or maintenance of that Facility may be removed by the District without notice, at the sole expense of the encroacher or adjacent Landowner.

2.4. DESIGN AND CONSTRUCTION OF IRRIGATION FACILITIES:

2.4.1. No irrigation system improvements, including Delivery Points, weirs, pump intakes, mechanical screens or structures of a similar nature, shall be planted, installed, constructed or placed in, on, over, under or across any District Facility or Right-of-Way unless written permission has first been granted therefore by the District. No person or entity receiving such Permission (a "Permittee") shall acquire any rights in District's Facilities or Rights-of-Way other than those set forth in District's written permission. Permittees shall, at their own expense, promptly upon receipt of notice from District, relocate or remove any improvement. In the event Permittee fails to do so, the District may perform such relocation or removal at Permittee's sole expense.

2.4.2. Unless otherwise specified by Agreement, all improvements shall be at the Permittee's sole expense, built to current District construction and engineering design standards, and shall become the property of the District upon completion.

2.4.3. All Delivery Points shall be capable of measuring the volume of water delivered in compliance with the prevailing state law and regulations promulgated by the California Department of Water Resources or other regulatory agency as may be applicable.

2.4.4. If the work can or has the potential to affect the flow of water in District conduits, the work must be performed during times pre-approved in writing by District. Ordinarily, in the absence of an emergency, such work will not be permitted during the period of March 1 to November 1.

2.5. DESIGN AND CONSTRUCTION OF NON-IRRIGATION FACILITIES:

2.5.1. No improvements, including buildings, bridges, gates, cross canal pipes, or structures of a similar nature, shall be planted, installed, constructed or placed in, on, over, under or across any District Facility or Right-of-Way unless written permission has first been granted therefore by the District. No Permittee shall acquire any rights in District's Facilities or District Rights-of-Way other than those set forth in District's written permission. Permittees shall, at their own expense, promptly upon receipt of notice from District, relocate or remove any improvement. In the event, Permittee fails to do so, the District may perform such relocation or removal at Permittee's sole expense.

2.5.2. Unless otherwise specified by Agreement, all authorized improvements shall be at the Permittee's sole expense, built to current District construction and engineering design standards, and shall become the property of the District upon completion.

2.6. DESIGN AND CONSTRUCTION OF PRIVATE OR IMPROVEMENT DISTRICT FACILITIES:

2.6.1. All new Private or Improvement District Facilities used for flood irrigation purposes shall provide for a minimum gravity flow of fifteen (15) cubic feet per second. A variance from this minimum flow shall be evaluated by the District on a case-by-case basis based on the impact on the operation of the District's water delivery system.

2.6.2. All new Private or Improvement District Facilities used for delivering water to pressurized irrigation systems shall be designed to meet the flow requirements of the land served by the Facility without impacting the irrigation operations of the District or other landowners served by the Facility.

2.6.3. Any proposed change in use or modification to an Improvement District Facility requires approval of two-thirds of the Improvement District members and obtaining consent shall be the sole responsibility of the Landowner.

2.6.4. The Irrigator will be required to install, operate, and maintain lift pumps, at Irrigator's expense, to receive water where the District is unable to deliver gravity water.

2.6.5. The location and tie-in of gravity or pump Facilities to District Facilities must meet District construction and engineering design standards and be approved in writing by the District prior to construction.

2.6.6. All plans for the installation, construction and placement of Private and Improvement District Facilities shall be submitted to the District for review. No installation, construction, or placement shall commence until the District has reviewed the plans. The District's rights hereunder to review and accept the plans shall not impose any duties or obligations on the District, nor shall such rights relieve the Irrigator of the sole responsibility for the Facilities plans, schedules and installation, construction and placement work.

2.6.7. Pre-consultation with District Irrigation Operations Staff concerning the design and construction of improvements is strongly recommended.

SECTION 3: OPERATION OF DISTRICT FACILITIES

3.1. LIMITS OF LIABILITY:

3.1.1. The District's responsibility for the water shall absolutely cease when the water is diverted into any Private or Improvement District Facility or property.

3.1.2. The District shall not be liable for any nuisance or negligent, wasteful or other use or handling of water by any recipient or user thereof.

3.1.3. The District shall not be responsible for any trash, debris or other matter that may flow or accumulate in the water. The District shall not be responsible for any interference with, decrease in the operation or capacity of, or damage to Facilities as a result of such trash, debris or other matter.

3.1.4. The District is not a guarantor of service and shall not be liable for any damage any person may suffer as a result of water not being delivered.

3.2. CONTROL OF DELIVERY POINTS:

3.2.1. The District has sole right and responsibility to operate Delivery Points and valves within District Canals. The Ditchtender may authorize an Irrigator to operate a Delivery Point or valve during the period when the Irrigator is scheduled to receive water. In such event the authorized Irrigator shall follow any Delivery Point or valve operational instructions issued by the Ditchtender and shall operate the designated Facilities in a safe and prudent manner. The Irrigator shall be liable for any and all damage resulting directly or indirectly from the Irrigator's operation of District's Facilities.

3.2.2. The District may take any action it deems appropriate to secure District Delivery Points, valves and other Facilities, including the use of locks and chains. Irrigators or groups of Irrigators may install locks on District Facilities only with the prior consent of the District. No lock installed by any Irrigator shall interfere with District's use or operation of the Facility.

3.2.3. The District may seal or remove, or require a Landowner to seal or remove, at Landowner's sole expense, any Delivery Point or valve where service from that Facility is no longer required by the Landowner.

3.2.4. All Delivery Points from District Facilities shall have a point of positive shut-off easily accessible to the Ditchtender within the District Rights-of-Way.

3.3. PUMPING OF IRRIGATION WATER:

3.3.1. Water pumped from District Canals shall be subject to all rules and regulations governing the use of Gravity Water.

3.3.2. Water pumped from District wells shall be subject to all rules and regulations governing the use of Gravity Water.

3.4. DISTRICT PUMPS:

3.4.1. The District, within its sole discretion, shall determine when to run District owned irrigation and drainage pumps. The times of operation may depend upon a variety of circumstances, including the groundwater level near the pump, available supply, peak power load, and the quality of the water being pumped.

3.4.2. District drainage pumping Facilities will not be installed to serve individual acreage. Perched water table control on individual parcels is the responsibility of the Landowner.

3.4.3. District pumps shall be operated during the non-irrigation season, only at the District's discretion.

3.4.4. Irrigators may rent District pumps, as available, in accordance with the terms and conditions of District's Pump Rental Agreement.

3.5. INTERFERENCE WITH DISTRICT FACILITIES:

3.5.1. Any use of, interference with or damage to any District Facility, including Canals or Canal Roads, is, unless specifically permitted by these Irrigation Rules, prohibited.

3.5.2. No persons other than authorized District employees and agents, and persons permitted in accordance with these Irrigation Rules, shall:

3.5.2.1. Operate any District Facility.

3.5.2.2. Enter onto or into any District Facility

3.5.2.3. Attach, place or remove any boards, chains, ropes, or any other object to, on, in, or upon any District Facility or Canal Road.

3.5.2.4. Attach, place or remove any sign, board, post, fence, or gate to, on, in, or upon any District Facility or Canal Road.

3.5.2.5. Install, place, construct, operate or use any obstruction on, in, or upon any District Facility or Canal Road.

3.5.2.6. Operate, park, abandon or dispose of any Vehicle on, in, or upon any District Facility or Canal Road.

3.5.2.7. Use District property or Facilities for water sports or other recreational purposes, including without limitation surfing, skiing, boating, hunting or camping.

3.6. USE OF CANAL ROADS AND RIGHTS OF WAY:

3.6.1. Except as otherwise specifically permitted by the District in writing, no person shall cross any District Canal, including without limitation any weir, bridge or other crossing, except those clearly marked for public use.

3.6.2. No unauthorized vehicle shall be on or within District Canal Roads or Rights-of-Way. District Canal Roads and Rights-of-Way are for the exclusive use of authorized District employees and agents, and other authorized persons permitted in accordance with these Irrigation Rules. Persons requiring a specific use of a Canal Road or Right-of-Way may apply to the District for written permission prior to such use. Notwithstanding any permission granted by the District, use of District Canal Roads and Rights-of-Way is at the sole risk of the user.

3.6.3. The following persons have permission to operate a vehicle upon a District Canal Road or Right-of-Way consistent with District Rights-of-Way Policy 94-01.

3.6.3.1. Any District Director, officer, employee, or authorized agent in the performance of their duties.

3.6.3.2. Persons actively involved in farming a parcel of land adjacent to the specific District Canal Road or Right-of-Way.

3.6.3.3. Persons actively involved in farming who use the specific District Canal Road or Right-of-Way for access to irrigation facilities serving their parcel of land.

3.6.3.4. Persons whose property is directly adjacent to a District Canal and to whom permission for ingress and egress to the property has been granted by the District.

3.6.3.5. Private parties who have made temporary ingress-egress arrangements in writing with the District for property maintenance or construction purposes.

3.6.3.6. Any sheriff, police, fire, or public safety personnel on official business.

3.6.3.7. Any District contractor who needs to use a specific District Canal Road or Right-of-Way to perform work under its contract with the District.

3.6.4. All vehicles using District Canal Banks or Rights-of-Way shall be operated in a safe and lawful manner at all times.

3.7. USE OF FACILITIES FOR WASTEWATER

3.7.1. No Pollutant, shall be, or permitted to be, placed, drained, spilled or otherwise discharged into or onto any District Facility or Canal Road.

3.7.2. No District Facilities shall be used for transportation of manure or other livestock waste of any kind, except with the prior written approval of the District which shall not be granted except under special circumstance, consistent with the District's Water Quality Policy.

3.7.2.1. Any person who violates this rule may be subject to criminal prosecution and civil liability.

3.8. USE OF FACILITIES FOR OTHER WATERS

3.8.1. Nothing other than District water, shall be transported through District Facilities at any time, except with the prior written approval of the District. All water transported through District Facilities shall be of a quality and quantity acceptable to the District.

3.8.2. Permission to use District Facilities as set forth in this Section 3.8 is at the sole discretion of the District and the District may impose reasonable conditions on such permission, including but not limited to the right of the District to approve and monitor the transporter's water measurement facilities. Any permission granted shall be revocable by the District at any time.

3.8.3. A service charge will be made by the District for transporting the water of others through District Facilities. The amount of this service charge will be set from time to time by the Board. All costs of transporting the water of others through District Facilities shall be borne by the person whose water is being transported.

3.8.4. Gates and/or pumps from waste water lagoons that are connected to District Facilities, in any way, must have a District approved and functional backflow prevention device.

3.9. MAINTENANCE OF PRIVATE OR IMPROVEMENT DISTRICT FACILITIES:

3.9.1. Each active Improvement District shall appoint at least two Improvement District Committee members who shall be authorized to approve all required maintenance and repair work.

3.9.1.1. Facilities maintenance and repair work for an Improvement District is the responsibility of the Improvement District.

3.9.1.2. Improvement District Landowners shall procure and pay for all materials and labor related to such maintenance and repair work. Said costs shall be prorated on a per acre basis unless otherwise agreed by the Landowners.

3.9.1.3. The District may at its discretion, if requested by the Improvement District Committee, provide maintenance and repair services for Improvement District Facilities.

3.9.2. Private Facility maintenance and repair work is the responsibility of the Landowner(s) being served by the Private Facility.

3.9.3. Private or Improvement District Facilities may be cleaned or repaired by the District at the Landowner or Improvement District's expense when the District determines such action is necessary for the District's operations.

Maintenance and repair of irrigation valve structures on District or Improvement District Facilities are the responsibility of the Landowner of the property being served by those Facilities.

3.10. FLOW THROUGH PRIVATE AND IMPROVEMENT DISTRICT FACILITIES:

3.10.1. All Private and Improvement District Facilities must be free from weeds and other obstructions, and properly maintained, to permit sufficient capacity to carry the flow of water requested by any Irrigator, without the danger of levee breaks, overflow, or undue seepage.

3.10.2. The District may curtail or terminate the delivery of water to any Private or Improvement District Facility not meeting the above requirements and require the Facility to be cleaned, repaired, or reconstructed before water delivery is restored.

SECTION 4: DUTIES OF IRRIGATOR

4.1. IRRIGATOR RESPONSIBILITIES:

4.1.1. All land to be irrigated must be properly prepared to efficiently receive the water.

4.1.2. Landowners and Renter shall ensure that there is an Irrigator on the land at all times that water is made available to the land by the District.

4.1.3. The Irrigator shall be responsible for and shall attend and control the water at all times after it leaves District Facilities.

4.1.4. The Irrigator shall use the water continuously, day and night, from the commencement of water delivery until the completion of irrigation.

4.1.5. The Irrigator shall ensure that all irrigation Facilities are in working condition and ready to receive water at the irrigation start time, including but not limited to the opening and closing of valves and gates as needed.

4.1.6. The Irrigator is responsible for priming the pipeline prior to use. Priming shall be limited to 3” of stem opening or as directed by the Irrigation Field Services Manager; more than 3” of stem opening and landowner will be charged for water delivered, as determined by District.

4.1.7. The Irrigator shall close all gates and valves on the Irrigator's Private Facilities at the end of each irrigation.

4.1.8. The Irrigator shall call the Ditchtender immediately after each irrigation to report the irrigation start and stop times. If the Irrigator does not call promptly, irrigation time may be estimated by the District.

4.1.9. As directed by the Ditchtender, the Irrigator shall, at the end of the irrigation, call and notify the next Irrigator receiving water.

4.2. USE OF WATER:

4.2.1. All water must be applied efficiently and used reasonably and beneficially.

4.2.2. Except as otherwise expressly permitted by these Irrigation Rules, all water shall be used solely for irrigation purposes; provided, however, that an Irrigator may use District water for crops related to cultural practices through the normal irrigation schedule.

4.2.3. The District may refuse to deliver District water to any Irrigator who misuses or wastes water either willfully or carelessly, in any way, including but not limited to the following:

4.2.3.1. Flooding of roads, vacant land, or land previously irrigated.

4.2.3.2. Defective or inadequate non-District Canals or Facilities.

4.2.3.3. Inadequately prepared land.

4.2.3.4. Flooding any part of any land to an unreasonable depth or amount, including for the purpose of irrigating other portions of the land.

4.2.3.5. Flooding across one parcel to irrigate another parcel.

4.2.4. Any person, through acts or omissions, allowing water to discharge upon a public road or highway is liable for any resulting damages and may be subject to fines and/or penalties.

4.3. LIABILITY FOR DAMAGE:

4.3.1. The Irrigator is responsible and liable for any damage caused by the Irrigator's failure to fulfill each of the obligations set forth in these Irrigation Rules, by the Irrigator's negligent or careless use or control of water, or by the Irrigator's improper operation or maintenance of any Facility for which the Irrigator is wholly or partially responsible.

SECTION 5: DELIVERY OF IRRIGATION WATER

5.1. WATER ALLOTMENT AND CHARGES:

5.1.1. Each year the Board of Directors shall establish the quantities of water available for each acre of service, the charges for water, the terms for the transfer of water, and any other provisions or charges for service as the Board may find appropriate.

5.1.2. Parcels less than or equal to ten acres in size may sign-off consistent with the District's Irrigation Water Activation and Reactivation Policy.

5.1.3. All water charges, Improvement District charges and assessments, and other irrigation or drainage related charges shall be due and payable as stated by Board Resolution and notices in billing statements.

5.2. FAILURE TO PAY CHARGES:

5.2.1. The District may refuse to furnish water to any parcel of land if outstanding charges for water or services already furnished or rendered to such land (including any accrued interest and penalties) have not been paid in full by the District's prescribed payment date.

5.2.2. All charges placed on an individual parcel of land are the responsibility of the Landowner. In accordance with the provisions of Section 25806 of the Water Code, delinquent water service charges and/or assessments, together with all imposed penalties, for a parcel of land will be made a lien on the subject real property.

5.3. WATER USER INFORMATION:

5.3.1. No later than May 1 of each year, each Landowner or designee shall provide to the District a signed statement, on the District's form, of the kinds of crops and number of acres of each crop that will be irrigated on each parcel of land, and such other relevant information as the District may reasonably require on the same statement. After May 1 of each year, no changes to the amount of irrigated acreage or non-irrigated acreage will be allowed, but the kind of crop that is going to be planted may be changed at any time.

5.4. IRRIGATION SERVICE:

5.4.1. To schedule an irrigation, the Irrigator must place an order with the Ditchtender. The Ditchtender will generally schedule the water to be delivered within 5 days, subject to system limitations. In the event that an Irrigator is not ready to receive the water at the scheduled time, the Irrigator will be required to wait until the Ditchtender can reschedule water to the parcel.

5.4.2. Where possible, irrigation water will be provided to the Irrigator based on an arranged demand delivery, under which the delivery rate is fixed, but the frequency and duration of use are requested by the Irrigator.Where the capacity of the system is limited, rotation delivery may be used by the Ditchtender. The Ditchtender may, at the Ditchtender's discretion, alter the rotation or cause water to be delivered upon request. Advance notice for rotation deliveries will be made with an appropriate amount of warning time to take into consideration the preparation needed to commence irrigation.

5.4.3. Any Irrigator who desires irrigation water on a tailored delivery schedule is required to submit a detailed application to the District for consideration. Ditchtender will endeavor to meet the tailored delivery schedule, but District does not and cannot guarantee deliveries in accordance with the tailored delivery schedule.

5.4.4. The Ditchtender will inform each Irrigator of the anticipated date and time of water delivery to each of the Irrigator's parcel(s) of land. The Ditchtender will provide information on flows, Delivery Point(s) and valve operation, and any special instructions related to the delivery sequence.

5.4.5. In the event that an Irrigator cannot be contacted, located, or otherwise reasonably notified of the availability of water, the Ditchtender may move that water to another Irrigator. In doing so, the Ditchtender will make all reasonable efforts to make water re-available to the Irrigator as soon as feasible within the capacity limitations of the District's Facilities while maintaining efficient and equitable water distribution among Irrigators.

5.4.6. The Ditchtender will endeavor to meet the scheduled time of delivery within the capacity limitations of the District's Facilities while maintaining efficient and equitable water distribution among Irrigators.

5.4.7. The District shall not be required to raise water in its Canals to any height in order to deliver irrigation water to lands or ditches deemed by the District to be of unusually high elevation.

5.4.8. The District will strive to supply water of sufficient quality to those crops which are sensitive to certain constituents or parameters. However, the District does not and cannot guarantee the quality of water that is delivered to any irrigator and therefore shall not be liable for any damages that may result from the application of supplied irrigation water.

5.5. MEASUREMENT OF WATER:

5.5.1. All measurements of water delivered by the District to an Irrigator shall be made by the District at the Delivery Points or valve in District's Canal, or at such other appropriate location as the District may determine. The District shall maintain records of the names of each Irrigator, the parcel(s) of land that each Irrigator has irrigated, the number of acre feet of water delivered to each parcel, and other information deemed appropriate by the District.

5.5.2. The District has the authority to install or require the installation and maintenance of irrigation flow measurement devices or structures at all District Delivery Points in compliance with the prevailing state law and regulations promulgated by the California Department of Water Resources or other regulatory agency as may be applicable.

5.6. REFUSAL OF WATER BY IRRIGATOR:

5.6.1. If an Irrigator fails or refuses to continuously use the full head of water delivered to a parcel of land or scheduled for delivery, then the following shall apply:

5.6.1.1. The full amount of water normally delivered will be charged to the Irrigator;

5.6.1.2. The Irrigator shall not be entitled to use the unused portion of water at any other time;

5.6.1.3. The Irrigator will be required to reschedule for delivery of water.

5.7. INTERRUPTIONS OF SERVICE:

5.7.1. When a break occurs in any water distribution facility requiring an interruption of irrigation service, the Irrigator whose irrigation was interrupted, shall be allowed to finish irrigating when service is restored and shall not claim another irrigation during the affected irrigation cycle or rotation.

5.7.2. Upon completion of the repair, and provided there is no conflict with current usage, the Ditchtender will endeavor to re-establish service based on the original schedule. Where use conflict occurs, service will be restored at the discretion of the Ditchtender.

5.8. SERVICE TO PRIVATE OR IMPROVEMENT DISTRICT SYSTEMS:

5.8.1. Water deliveries to Irrigators who use Private or Improvement District Facilities shall be delivered to the Delivery Point of these Facilities by the Ditchtender.

5.8.2. Caution is required when priming, operating and closing canal gates in order to avoid damage to Facilities and the disruption of service caused by such damage.

5.8.3. Landowners shall be responsible for the actions of their Irrigators when taking water through and from Private or Improvement District Facilities.

5.9. IRRIGATION OF GARDENHEAD PARCELS:

5.9.1. Gardenhead parcels, which are typically less than five acres in size and separate or distinct from farm service parcels, will be irrigated as a group, where possible, with a standardized rotation irrigation flow consistent with the capacity of the gardenhead parcel irrigation Facilities. The gardenhead irrigation rotation is normally established by the Ditchtender given the annual allocation, and is subject to modifications by the Ditchtender.

5.9.2. Deliveries of water for irrigation of gardenhead parcels will be scheduled by the Ditchtender and may be subject to interruption when water is in short supply or otherwise when it is necessary for the proper irrigation of farm service areas.

5.9.3. Such service to gardenhead parcels shall not interfere unreasonably with the regular irrigation of farm service areas.

5.10. UNAUTHORIZED USE OF WATER:

5.10.1. Any person who uses District water without the District's permission may be assessed a $1,500 fine for unauthorized use of water as determined by the Board..

5.10.2. Any person who uses District water without the District’s permission a second time as determined by the Board, may lose any remaining allocation.

5.10.3. Unauthorized use of water constitutes failure to comply with Rules or Regulations and enforcement of this section shall be consistent with Section 8.1.

5.10.4. Any and all conditions for re-establishment of service shall be as set-forth in Section 8.2.1.

5.10.5. Following decision by Board as set-forth in Section 5.10.1 or 5.10.2 an appeal may be made to the Board.

5.10.6. Following a decision to uphold the fine by the Board, such unauthorized use may be posted on District’s public website.

SECTION 6: DRAINAGE TO DISTRICT FACILITIES

6.1. DRAINAGE:

6.1.1. Notwithstanding any other provisions of these Irrigation Rules, no surplus irrigation water, storm water, wastewater, tile drainage, or any other water or substance shall be drained, dumped, pumped, siphoned or otherwise discharged into any District Facility without the prior written agreement of the District. In granting permission to discharge, the District may impose reasonable conditions, including, without limitation, the right of the District to approve and monitor the discharger's measurement facilities. Permission to discharge shall be revocable by the District at any time and for any reason.

6.1.2. Water and other substances discharged into District Facilities shall meet all applicable federal, state and local water quality standards.

6.1.3. Filter station backflush water shall be allowed back into District facilities so long as chemical injection occurs downstream of backflush location, proper backflow prevention is in place and the Landowner is in compliance with the irrigated lands regulatory program.

6.1.4. The rate and quantity of discharge into any District Facility may be subject to limitations based on the capacity of the Facility and the quality of the water or other substance being discharged.

6.1.5. All discharge Facilities shall be constructed at the discharger's sole expense to and must meet the District's construction and engineering design standards.

6.1.6. All existing field drainage Facilities not currently covered by an agreement shall be subject to the District's current terms and conditions.

6.1.7. Gates and/or pumps from waste water lagoons that are connected to District Facilities, in any way, must have a District approved and functional backflow prevention device.

6.2. TRANSPORTATION:

6.2.1. No person shall transport any water or other substance through District Facilities without the prior written agreement of the District. In granting permission to transport water or other substances, the District may impose reasonable conditions, including, without limitation, the right of the District to approve and monitor the transporter's measurement facilities. Permission to transport shall be revocable by the District at any time and for any reason.

6.2.2. Water and other substances transported through District Facilities shall meet all applicable federal, state and local water quality standards.

6.2.3. The rate and quantity of water and other substances transported through any District Facility may be subject to limitations based on the capacity of the Facility and the quality of the water and other substances being transported.

6.2.4. All transport Facilities shall be constructed at the transporter’s sole expense and must meet the District’s construction and engineering design standards.

6.2.5. All existing transportation Facilities not currently covered by an agreement shall be subject to the District’s current rate, quantity, quality and other terms and conditions.

6.3. DRAINAGE AND TRANSPORTATION CHARGES

6.3.1. All costs of discharging into or transporting through District Facilities, as well as costs of associated carriage loss, shall be borne and paid by the discharger or transporter. A service charge will be assessed by the District for discharging or transporting through District Facilities. The amount of this service charge will be set from time to time by the Board of Directors.

SECTION 7: POLLUTION ABATEMENT

7.1. POLLUTION:

7.1.1. No Pollutant shall be placed, carried, transported, drained, dumped, pumped, siphoned, discharged, or otherwise allowed to enter into, onto, over, under or across any District Facility or associated Right-of-Way without the consent of the District.

7.1.2. Any person who violates this Rule may be subject to criminal prosecution and/or civil liability.

7.2. CLEANUP:

7.2.1. Any person who willfully or negligently causes or permits any Pollutant to be placed, carried, transported, drained, dumped, pumped, siphoned, discharged, or otherwise allowed into, onto, over, under or across any District Facility or associated Right-of-Way without the prior written consent of the District shall immediately notify the District and take all action to mitigate the effects of such Pollutant. Such person shall, at that person's sole expense, unless otherwise directed by the District, perform or cause to be performed all necessary remediation to the District's satisfaction and in compliance with all applicable laws. Such person shall cooperate with the District to complete the remediation and shall reimburse the District for all costs and expenses incurred in connection with the remediation, including but not limited to administrative, investigative, and legal costs, fines and penalties.

7.2.2. No water shall be delivered to any parcel of land from which the pollutant originated or to any other parcel of land owned, rented, leased or irrigated by the person who caused or permitted any Pollutant into, onto, over, under or across any District Facility or associated Right-of-Way, until the remediation required in Section 7.2.1 is complete, all damages, costs and expenses, arising out of such event have been paid, and action satisfactory to the District has been taken to ensure that such event will not be repeated.

SECTION 8: ENFORCEMENT OF IRRIGATION RULES AND REGULATIONS

8.1. FAILURE TO COMPLY WITH RULES OR REGULATIONS:

8.1.1. Failure or refusal of any Landowner, Renter or Irrigator to comply with any of these Irrigation Rules or applicable regulations, or any part thereof, may be sufficient cause for curtailment or termination of delivery of District water to the lands of such Landowner, Renter or Irrigator.

8.1.2. Interference by any Landowner, Renter or Irrigator with a District employee, agent or official in the discharge of their duties may be sufficient cause for curtailing or terminating delivery of District water to the lands of such Landowner, Renter or Irrigator.

8.1.3. The District may immediately terminate the delivery of District water supplied to any parcel of land if the condition of the land or irrigation Facility present an immediate danger to any person, to the general public, or to any property, including but not limited to the flooding of property.

8.1.4. Compliance with each and all of these rules shall be a condition precedent to the delivery of water to any Irrigator. The Board retains the authority to make determinations regarding continued irrigation service in all instances that are not specifically contained in these rules and regulations.

8.2. RESTORATION OF SERVICE:

8.2.1. Water delivery shall not be restored until full compliance with requirements established by these Irrigation Rules and Regulations is established and any other conditions for re-establishment of service as determined by the Board.

8.3. APPEAL OF A DECISION TO TERMINATE DELIVERY

8.3.1. From a decision of the Ditchtender, an appeal may be made to the Irrigation Field Services Manager. From any decision of the Irrigation Field Services Manager, an appeal may be made to the Irrigation Operations Manager. From any decision of the Irrigation Operations Manager, an appeal may be made to the GM. From any decision of the GM, an appeal may be made to the Board. If an appeal from any decision is not made within fourteen (14) days of the date of the decision, the decision will be deemed final and the failure to appeal a decision in the manner and within the time period set forth above shall constitute a waiver of all rights to further protect, judicial or otherwise.

PROCEDURES TO ORDER WATER:

A. Prepare your field to receive water.

B. Contact your Ditchtender to place an order.

C. Your Ditchtender will inform you of the time sequence, and other details regarding water delivery.

IRRIGATION EQUATIONS:

$$\text{inches of water} = \frac{(\text{cfs flow}) \times (\text{hours irrigated})}{\text{acres served}}$$

$$\text{hours irrigated} = \frac{(\text{inches of water}) \times (\text{acres served})}{\text{cfs flow}}$$

$$\text{cfs flow} = \frac{(\text{inches of water}) \times (\text{acres served})}{\text{hours irrigated}}$$

$$\text{acre feet} = \text{cfs (hours irrigated /24) (1.983)}$$

$$\text{number of acres} = \frac{(\text{cfs flow}) \times (\text{hours irrigated})}{\text{inches of water}}$$

For example, a 20 acre parcel with a standard cfs irrigation flow will receive 6 inches of water in an 8 hour period.

$$\text{6 inches} = \frac{(\text{15 cfs flow}) \times (\text{8 hours})}{\text{20 acres}}$$

COMMON CONVERSIONS:

1 cubic foot per second (cfs) = 449 gallons per minute

1 cubic foot per second for 12 hours = 1 acre foot

1 acre foot = 325,900 gallons

1 acre foot = 43,560 cubic feet

An acre foot is the amount of water needed to cover 1 acre with 12 inches of water.

APPENDIX "A"

Pertinent Provisions of law:

Water Code Section 22257 provides in part as follows:

> "Each district shall establish equitable rules for the distribution and use of water, which shall be printed in convenient form for distribution in the district. A district may refuse to deliver water through a ditch which is not clean or not in suitable condition to prevent waste of water and may determine through which of two or more available ditches it will deliver water."

> "A district may close a defective gate in a community water distribution system used for irrigation purposes and may refuse to deliver water through the defective gate if the landowner fails to repair the gate or outlet to the satisfaction of the district within a reasonable time after receipt of notice from the Board through its authorized water superintendent, manager, or ditchtender to repair the gate outlet."

Water Code Section 22282.1 provides that:

> "A district may refuse service to any land if outstanding charges for services already rendered such land have not been paid within a reasonable time."

Penal Code Section 592 provides that:

> "Every person who shall, without authority of the owner or managing agent, and with intent to defraud, take water from any canal, ditch, flume or reservoir used for the purpose of holding or conveying water for manufacturing, agricultural, mining, irrigating or generation of power, or domestic uses, or who shall without like authority, raise, lower of otherwise disturb any gate or other apparatus thereof, used for the control or measurement of water, or who shall empty or place, or cause to be emptied or placed, into any such canal, ditch, flume or reservoir, a rubbish, filth or obstruction to the free flow of the water, is guilty of a misdemeanor."

MODESTO IRRIGATION DISTRICT

2020 AGRICULTURAL WATER MANAGEMENT PLAN

APPENDIX D

IRRIGATION RATE STRUCTURE

MODESTO IRRIGATION DISTRICT
Irrigation Rate Structure
(Pre-Volumetric Pricing)

Updated By: Carrie L
Date: 8/27/15

Year	Base Allotment[1] (inches)	Groundwater Recharge Component[2] (inches)	Base Water Charge[3] ($/acre)	Excess Water[4] Tier #1 (inches)	Excess Water Tier #1 ($/AF)	Supplemental Groundwater[5] Tier #2 (inches)	Supplemental Groundwater Tier #2 ($/AF)	Drought Surcharge[6] ($/acre)
1988	Unlimited	-----	$6.00	-----	-----	-----	-----	-----
1989	42"	-----	$6.50	Over 42"	$14.00	-----	-----	-----
1990	42"	-----	$7.00	18"	$3.50	-----	-----	-----
1991	33"	-----	$7.50	12"	$7.50	-----	-----	-----
1992	33"	-----	$7.75	12"	$7.50	-----	-----	-----
1993	42"	-----	$8.00	12"	$4.00	-----	-----	-----
1994	36"	-----	$8.50	12"	$4.25	-----	-----	-----
1995	42"	-----	$9.00	18"	$6.50	-----	-----	-----
1996	42"	6"	$9.50	24"	$8.25	72" & up	$19.00	-----
1997	42"	6"	$10.10	24"	$8.75	72" & up	$20.00	-----
1998	36"	6"	$11.10	30"	$9.00	72" & up	$20.00	-----
1999	42"	12"	$12.20	18"	$10.10	72" & up	$20.00	-----
2000	42"	6"	$13.40	24"	$6.70	72" & up	$20.00	-----
2001	42"	-----	$13.90	30"	$7.35	72" & up	$20.00	-----
2002	42"	-----	$13.90	30"	$7.35	72" & up	$20.00	-----
2003	39"	6"	$15.30	30"	$7.65	66" & up	$20.00	-----
2004	42"	-----	$17.00	30"	$8.50	72" & up	$20.00	-----
2005	42"	6"	$18.70	24"	$9.35	72" & up	$20.00	-----
2006	42"	6"	$20.50	24"	$10.25	72" & up	$20.00	-----
2007	36"	6"	$21.50	36"	$10.75	72" & up	$20.00	-----
2008	36"	-----	$23.50	36"	$11.75	72" & up	$20.00	-----
2009	36"	-----	$25.50	6"	$12.75	42" & up	$20.00	
2010	42"	6"	$27.00	12"	$13.50	60" & up	$20.00	-----
2011	48"	6"	$27.00	12"	$13.50	60" & up	$20.00	-----
2012	36"	-----	$29.50	6"	$14.75	42" & up	$30.00	-----
2013	36"	-----	$29.50	12"	$14.75	42" & up	$30.00	-----
2014	24"	-----	$32.50	-----	-----	-----	-----	$11.91

Notes:

1 City of Modesto (Domestic 1995 forward) receives equivalent allotment. Allotments started in 1989, before then water was unlimited.

2 Additional available water to encourage groundwater recharge (soft cap) at no cost

3 Facilities and Maintenance charge ½ of base water charge ($/acre)

4 Water used in excess of base allotment

5 Water pumped above excess water

6 Only applies to irrigated acerage

MODESTO IRRIGATION DISTRICT

Irrigation Rate Structure

(Volumetric Pricing)

Year	Base Allotment[1] (inches)	Fixed Charge[2] ($/AC)	Tier 1 (≤ 24”) ($/AF)	Tier 2 (24” to 36”) ($/AF)	Tier 3 (36” to 42”) ($/AF)	Tier 4 (≥ 42”) ($/AF)	Drought Surcharge[3] ($/AC)
2015	16”	$40.00	$1.00	$2.00	$3.00	$10.00	$16.00
2016	36”	$44.00	$2.00	$5.00	$11.25	$40.00	-
2017	Uncapped	$44.00	$2.00	$5.00	$11.25	$40.00	-
2018	Uncapped	$44.00	$2.00	$5.00	$11.25	$40.00	-
2019	Uncapped	$44.00	$2.00	$5.00	$11.25	$40.00	-
2020	42”	$44.00	$2.00	$5.00	$11.25	$40.00	-

[1]City of Modesto (domestic) receives equivalent allotment

[2]Facilities and Maintenance charge ½ of fixed water charge ($/AC)

[3]Only applicable to irrigated acreage

MODESTO IRRIGATION DISTRICT

2020 AGRICULTURAL WATER MANAGEMENT PLAN

APPENDIX E

GROUNDWATER MANAGEMENT PLAN – EXECUTIVE SUMMARY

Executive Summary

Introduction

The Modesto Groundwater Subbasin lies between the Stanislaus River on the north and the Tuolumne River on the south and between the San Joaquin River on the west and crystalline basement rock of the Sierra Nevada foothills on the east. The surface area of the subbasin is 247,000 acres.

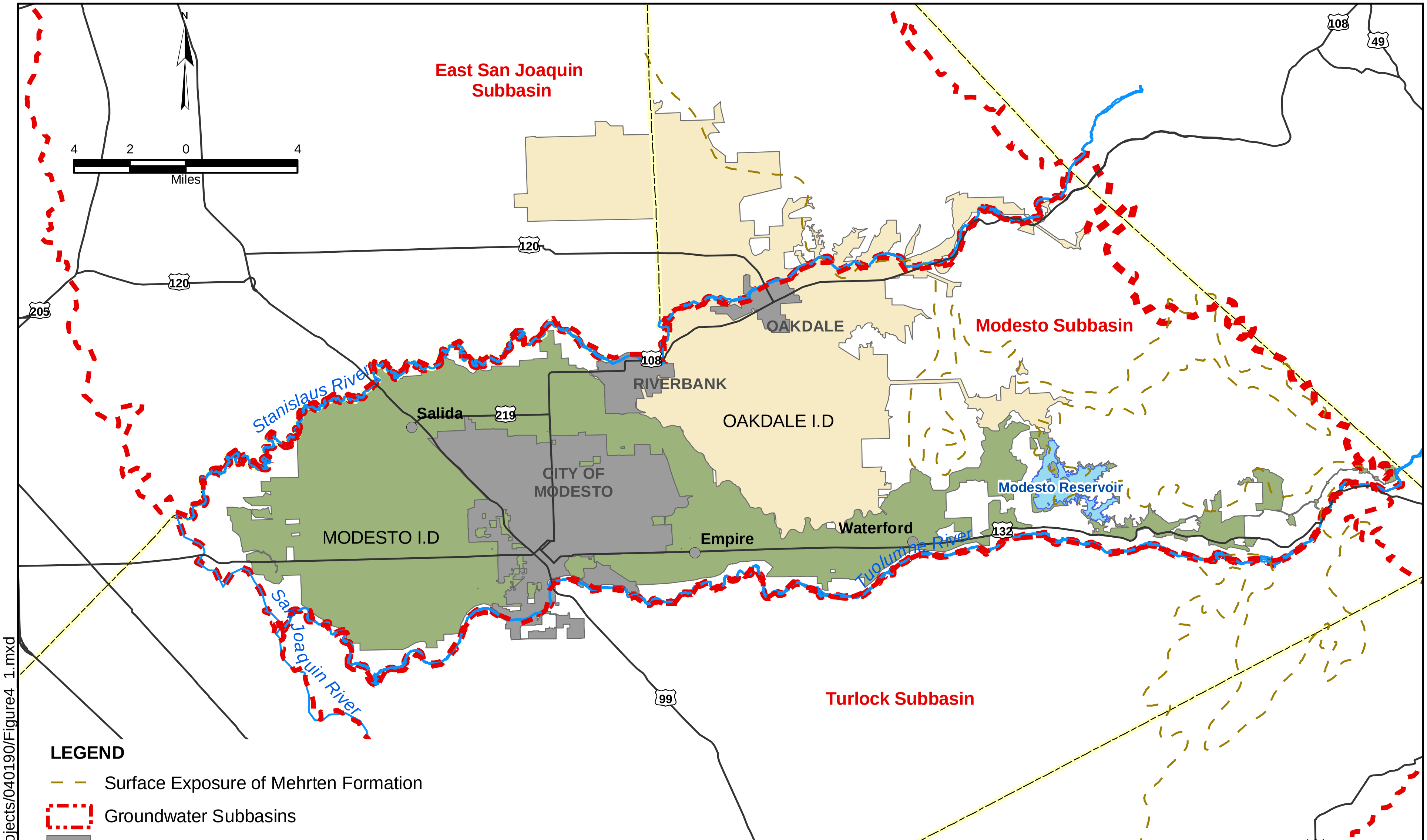
The northern, western, and southern boundaries are shared with the Eastern San Joaquin, Delta-Mendota, and Turlock Groundwater Subbasins, respectively. The major water purveyors in the planning area include the Modesto Irrigation District (MID), the Oakdale Irrigation District (OID), and the Cities of Modesto, Riverbank, and Oakdale.

In April 1994, the five water purveyors were joined by a sixth agency, Stanislaus County, to form the Stanislaus and Tuolumne Rivers Groundwater Basin Association (Association). The Association provides a forum for the coordinated planning and management of the Modesto Groundwater Subbasin and encourages the development of projects and programs that will improve water supply reliability and water quality within the subbasin. Figure ES-1, a map of the subbasin, shows the boundaries of the six agencies.

Since its formation, the Association has been actively engaged in the management of the subbasin. The Association provides its members a vehicle for coordinated planning to make the best use of groundwater and to satisfy the mutual interests of the member agencies. Specific purposes of the Association are to:

- Determine and evaluate the subbasin's groundwater supply
- Promote the coordination of groundwater management planning
- Develop a hydrologic groundwater model of the groundwater basin
- Determine the subbasin's need for additional or improved water extraction, storage, delivery, conservation, and recharge facilities
- Provide information and guidance for the management, preservation, protection, and enhancement of groundwater quality and quantity in the subbasin

In late 2003, the Association began developing an Integrated Regional Groundwater Management Plan (IRGMP) in compliance with the Groundwater Management Planning Act of 2002 (SB 1938) and the Integrated Regional Water Management Planning Act of 2002



SOURCES: City of Modesto, Modesto Irrigation District, City of Oakdale, Oakdale Irrigation District, City of Riverbank, CA Dept of Water Resources Groundwater Basins, 2002, California Spatial Library.

Bookman-Edmonston
A Division of GEI Consultants

INTEGRATED REGIONAL GROUNDWATER MANAGEMENT PLAN FOR THE MODESTO BASIN

Management Areas and Agencies

JUNE 2005

FIGURE ES-1

05-10-04 S:/GIS/Projects/040190/Figure4_1.mxd

(SB 1672). Throughout the planning process, other interested parties within the subbasin as well as state agencies have been encouraged to participate in the plan's development.

Planning Area

Developed land uses within the Modesto Groundwater Subbasin are concentrated in two major categories: irrigated agricultural and urban land uses. The largest jurisdiction within the subbasin is MID with a service area of 101,700 acres and an irrigated area of approximately 62,000 acres. Nested within MID are the communities of Waterford, Empire, and Salida and parts of Del Rio and Riverbank. Also lying largely within MID is the city of Modesto, which occupies approximately 40 square miles or 25,600 acres. Modesto is in the southwestern portion of the subbasin, and a portion of the city is located south of the Tuolumne River in the Turlock Groundwater Subbasin.

The cities of Oakdale and Riverbank lie in the north-central portion of the subbasin. The southern 60 percent of OID is in the Modesto Groundwater Subbasin and the remaining 40 percent is in the Eastern San Joaquin Groundwater Subbasin.

The Modesto Groundwater Subbasin underlies all of MID, the City of Oakdale, and the City of Riverbank. However, a portion of OID overlies the Eastern San Joaquin Groundwater Subbasin, and a portion of the City of Modesto service area overlies the Turlock Groundwater Subbasin.

Because OID's jurisdictional boundaries reach beyond the boundaries of the Modesto Groundwater Subbasin, the study area has been extended to include OID's complete jurisdiction. A similar water planning effort is under way in the Turlock Groundwater Subbasin, and the portion of the City of Modesto service area within the Turlock Subbasin is covered in the Turlock groundwater planning process.

The entire subbasin and planning area lies within Stanislaus County.

Description of the IRGMP

This IRGMP has been prepared in accordance with requirements of SB 1672 (California Water Code Section 10540 *et seq.*) and SB 1938 (California Water Code Section 10750 *et seq.*). As such, the plan includes components of AB 3030, SB 1938, and SB 1672.

The purpose of this IRGMP is to provide a framework for coordinating groundwater and surface water management activities into a cohesive set of management objectives and for implementing the actions necessary to meet those objectives.

The goal of the IRGMP is to integrate the use of groundwater and surface water within the Modesto subbasin to ensure the reliability of a long-term water supply that will meet current and future beneficial uses including agricultural, industrial, and municipal water requirements while protecting the environment. Attaining this goal requires measures that enable the efficient use of groundwater and surface water and measures that protect water quality.

The overriding objective of the IRGMP is to improve the regional and local management of water resources through the formulation and implementation of Basin Management Objectives (BMOs).

Regional Priorities

The IRGMP recognizes that the most effective approach to managing a basin’s water resources is enlisting the cooperation of the agencies whose political boundaries match the basin’s physical boundaries. For this reason, the IRWMP frames specific water management projects in the context of an integrated regional strategy. Although the plan emphasizes groundwater management, elements of the plan address the use of surface water supplies, water conservation, and water recycling and blending to meet demands that have previously been met with groundwater. This integration of surface water and groundwater resources leads to a more comprehensive management of water supplies and provides a lucid framework for complying with state and federal water quality standards. The primary regional objective is the preservation and protection of the basin’s water resources for the benefit of inhabitants of the region. Specific regional objectives include:

- Improve local water supply reliability
- Protect the groundwater resources of the region
- Improve water quality
- Foster prudent stewardship of water resources
- Facilitate compliance with local, state, and federal water quality and public health regulations.

Local Priorities

In addition to the statewide and regional priorities, the IRGMP addresses local issues by presenting BMOs that have been developed to meet the particular management needs of each of the participating agencies. Local BMOs are specific approaches to water management goals including groundwater supply, groundwater quality, and protection against inelastic land surface subsidence. Because they are presented within the context of a basin-wide plan, the local BMOs illustrate the degree to which many BMOs are common to more than one of the participating agencies. This suggests that in certain instances, implementation of local BMOs may best be achieved through cooperation among participating agencies. The most prominent of the local priorities is protection of groundwater quality through monitoring and control of contaminant plumes.

Statewide Priorities

Implementing the IRGMP will enable the Association and its member agencies to respond to a range of statewide water management initiatives. Key among these is the increasing emphasis placed on developing integrated regional solutions to water management problems and coordinating the conjunctive management of surface water and groundwater to improve water supply reliability and water quality.

In particular, by promoting effective water use in the Modesto Groundwater Subbasin, the implementation of the IRGMP will:

- Increase California's water supply reliability
- Reduce conflicts among water users
- Contribute to meeting Delta water quality objectives
- Assist in the implementation of Regional Water Quality Control Board Watershed Management Initiatives chapters, plans, and policies

Regional BMOs

Specific water management strategies developed during the formulation of the IRGMP are expressed by the regional BMOs agreed upon by all of the participating agencies. The following specific regional BMOs are presented in the IRGMP:

- **Identification of Natural Recharge Areas:** Groundwater recharge has diminished because the expansion of urban areas and trends in agricultural irrigation practices have reduced the deep percolation of applied water. These trends underscore the need to identify and protect remaining natural recharge areas.
- **Development of a Basin-Wide Water Budget:** A basin-wide water budget will describe the pathways by which water enters and leaves the basin. This budget will offer a tool for comparing inflows, outflows, and changes in storage under historical and present conditions with flows and changes in storage that may exist after the implementation of specific BMOs.
- **Feasibility Evaluation of Artificial Recharge Projects:** The basin-wide water balance will reveal whether the basin is in overdraft and will illustrate trends in groundwater recharge and groundwater use. If the water balance demonstrates either that the basin is in overdraft or is likely to fall into overdraft in the near future, artificial recharge basins may be needed to supplement recharge from natural recharge areas.

- **Management and Optimization of Well Field Operation:** A component of improved groundwater management is the optimization of well operations to accomplish specified management objectives. For example, each well in a well field can be instrumented and controlled so that a group of wells can be operated to meet single- or multiple-objective functions.

  In addition, well field optimization can support water quality objectives by reducing agricultural outflows to streams and by blending groundwater with surface deliveries. For example, agencies within the basin could evaluate an expansion of the blending program in order to control shallow groundwater and improve downstream water quality.

- **Identification and Feasibility Study of Conjunctive Use Projects:** Many of the management actions described above can be viewed as components of a broader conjunctive management program whose goal is an integrated approach that balances surface water and groundwater use. Implementation of a conjunctive management strategy may involve reduced groundwater pumping in some parts of the basin and broad controls on pumping to meet target groundwater levels. An important regional conjunctive use initiative is the Modesto Regional Water Treatment Plan, which has reduced demand for groundwater by storing and treating surface water. Because of its success, this project is being expanded.

- **Support of Public Health Programs:** Well construction and demolition standards are designed specifically to protect groundwater quality. Management actions to assist local agencies in complying with public health standards include the following components:

  - Installation of sanitary well seals on all new wells in accordance with the California Well Standards

  - Abandonment of wells in accordance with the California Well Standards

  These actions will be particularly valuable in unincorporated areas not served by a water purveyor.

- **Water Quality Management:** The protection of groundwater quality is of increasing concern because the basin's population is growing. This management action would include a detailed geologic assessment of the basin that would focus on the areas with poor water quality and identify the sources of the contaminants. This assessment would result in coverage on a GIS system for mapping recharge areas and would be used to develop strategies to control the migration and movement of poor quality water into and throughout the basin.

- **Groundwater Monitoring and Subsidence Monitoring Program:** Groundwater monitoring and analysis and the archiving of collected data will be needed to implement several of the recommended management actions (e.g., conjunctive management and optimized operation of well fields) and to meet the reporting requirements of the plan. The Association is developing a database to facilitate the storage, retrieval, and archiving of groundwater data. Monitoring data will be important in the development and calibration of the basin-wide groundwater model that will be used to evaluate the effects of proposed projects and management actions.

  The Association plans to monitor and measure the rate of inelastic land surface subsidence within the basin. Given the ongoing efforts by Association members to prevent groundwater overdraft and conditions that might lead to subsidence, it appears unlikely that the insignificant subsidence that has occurred historically within the basin will be accelerated. However, the Association plans to monitor and document any future changes in land surface elevations and, if inelastic subsidence is observed, may recommend necessary actions.

- **Policy Assessment:** Several of the technical management actions introduced above have clear policy requirements and implications. For example, effective protection of natural recharge areas will require coordination and communication with entities responsible for land use policies. Similarly, annexations to expand agencies' service areas as part of an in-lieu recharge program presume clear policies regarding annexation and a process to evaluate the impacts of annexation on groundwater levels and groundwater quality.

  The development of consistent policies would be assisted by a regional groundwater forum such as the Association. The Association could promote interagency relationships that would foster coordination and cooperation among participating agencies to manage the Modesto Groundwater Subbasin and would provide a framework for the formulation of regional projects and programs for the protection and use of the subbasin's water resources.

  For example, given the mutual concern of agencies within the basin regarding preserving natural recharge areas and protecting these areas from pollutants, local agencies could work together to inform one another about land use practices that may contribute to groundwater degradation and the importance of reducing the occurrence of these land use practices.

- **Promoting Cooperation and Coordination Between Water Entities:** The Association will continue to coordinate water management activities within the basin and to work cooperatively for the implementation of agreed-upon BMOs. It will also develop an outreach and educational program to engage other water interests in the management of the basin. One example of such outreach will be working cooperatively with industrial water users to improve water levels and water quality in the basin and to reduce localized well interference.

Water Management Strategies

The regional BMOs described above have been developed to support a comprehensive approach to managing water resources in the Modesto Groundwater Basin. In particular, these BMOs provide a framework for developing projects that will advance the following water management strategies:

- **Increase Local and Regional Water Supply Reliability and Water Use Efficiency:** BMOs supporting conjunctive management, policy assessment, and development of a basin-wide water budget will be key to the implementation of this strategy.

- **Promote Groundwater Recharge and Management:** BMOs encouraging the identification of natural recharge areas and the evaluation of artificial recharge areas will be used to implement this strategy.

- **Support Water Conservation:** Development of a basin-wide water budget will be used to identify water conservation opportunities, and the management and optimization of well field operations will be used to reduce spillage from irrigation distribution systems.

- **Implement Watershed Management Programs:** This strategy will be implemented through policy assessment, identification of natural recharge areas and evaluation of artificial recharge projects.

- **Promote Water Recycling:** Management and optimization of well field operations, groundwater monitoring, and development of artificial recharge projects offer opportunities for the management and use of recycled water generated by municipalities and industries in the planning area.

- **Foster Conjunctive Use:** The BMO dedicated to the identification and study of conjunctive use projects focuses on developing conjunctive management in the Modesto Groundwater Subbasin. Other BMOs addressing natural and artificial recharge, groundwater monitoring, well field optimization, and policy assessment will also contribute to planning and implementation of conjunctive use.

- **Improve Water Quality:** The water quality management BMO, groundwater monitoring, and the management and optimization of well field operations will all be important BMOs for improving water quality.

- **Improve Storm Water Capture and Management:** BMOs that support public health programs and that call for capturing storm water in dry wells and in natural and artificial recharge facilities will reduce storm water discharges.

Other regional water management elements such as provisions for recreation and environmental and habitat protection are addressed in other planning documents prepared by the participating agencies.

Public Involvement

The six agencies forming the Association share groundwater and surface water resources and worked together to formulate this management plan. Throughout this planning process, other interested agencies and entities within the subbasin were encouraged to participate. The Association will work with its member agencies and other entities to implement the components of this plan. The County of Stanislaus, as a member of the Association, represented other self-supplied groundwater producers. An extensive public involvement process was also followed during the IRGMP's development to enable stakeholder participation in the planning process.

In addition to public stakeholders, key local, state, and federal government agencies have contributed to the IRGMP. In mid-2004, the Association engaged in discussions with the Department of Water Resources to initiate a cooperative relationship for the conjunctive management of the basin. As a result of these discussions, the Association and the Department of Water Resources signed a Memorandum of Understanding to work together to develop conjunctive use projects.

For the last several years, the Association has been working cooperatively with the U.S. Geological Survey to study the geology and aquifers of the Modesto Groundwater Subbasin. The Association and the U.S. Geological Survey have entered into an agreement, under the National Water-Quality Assessment Program, to map the subsurface geology of the basin and to develop a data network and three-dimensional model of the basin.

The Association's member cities are also working with the Department of Health Services on issues related to compliance with Title 22, Drinking Water Quality Standards.

Plan Implementation

A key feature of the IRGMP implementation is the establishment of linkages among program actions. These linkages transform individual implementation activities into a coherent program where the whole is greater than the sum of the parts with respect to achieving regional water management objectives.

Implementation of the actions recommended in the IRGMP is scheduled in three phases:

- **Phase I—Near Term Projects**: These projects are intended to be implemented within the next three years and include:
  - Management of the well fields: A decision support system to assist the districts to optimize groundwater production from their well fields, based on a set of established objectives
  - Additional water blending projects: To help agencies meet their water quality objectives while increasing the beneficial use of groundwater
  - Water conservation projects, including agricultural and urban water conservation projects
  - Identification of conjunctive use project concepts
  - Increase treatment capacity for the City of Modesto
  - Development of a three-dimensional groundwater model
- **Phase II—Mid-Term Projects:** These projects are planned for implementation in four to seven years:
  - Identification of groundwater recharge areas
  - Rock well monitoring
  - Development of conjunctive use projects
  - Development of the in-lieu recharge projects, including evaluation of annexation options to reduce groundwater pumping
  - Development of a basin-wide database
- **Phase III—Long-Term Projects:** These projects are scheduled for implementation beyond seven years in the future and include:
  - Installation of subsidence monitoring station if needed
  - Water exchange program
  - Update water budget
  - Feasibility evaluation of artificial recharge projects

Other water management actions may continue throughout the planning horizon, including:

- Monthly Association meetings
- Preparation of annual progress reports
- Groundwater monitoring and data sharing
- Coordination and cooperation with water entities, neighboring basins, and state and federal agencies
- Periodic review of groundwater monitoring and groundwater management

Progress toward the implementation of the IRGMP is contingent upon securing funding to complete the program. Two available avenues are grant funding and funds generated internally by the Association members.

MODESTO IRRIGATION DISTRICT

2020 AGRICULTURAL WATER MANAGEMENT PLAN

APPENDIX F

CONSERVATION PROGRAM GUIDELINES

MODESTO IRRIGATION DISTRICT

CONSERVATION PROGRAM GUIDELINES

AUGUST 2015

TABLE OF CONTENTS

INTRODUCTION

Background

The Modesto Irrigation District (MID or District) Conservation Program (Program) provides partial funding to qualifying MID landowners for projects that conserve water and improve water management after the eligible project is completed. Projects must meet certain eligibility criteria and be pre-approved by MID. These guidelines provide information on eligible projects, applicant eligibility, available funding, the application process, project ranking criteria, contractual obligations, and the anticipated annual schedule. The Program will be an annual program that is subject to funding and approval by the Board of Directors (Board) on an annual basis.

Objectives

The objective of the Program is to encourage landowners, through financial incentives, to invest in physical improvements and management practices that conserve water and improve water management. The long-term goal of the Conservation Program is to improve water management within the District.

Role of Modesto Irrigation District

The role of MID in the Program includes, but isn't limited to:

- Review of applications for conformance with guidelines
- Ranking of applications and selection of projects for funding
- Review adequacy of project designs
- Recommendation and approval of contractors, consultants and equipment suppliers
- Monitoring during construction
- Performing final inspection
- Making reimbursement payment in accordance with funding agreement after completion of work and approval by MID
- Verification of project performance one-year after construction

If you have any questions about the Program please contact the MID Irrigation Operations office at (209) 526-7373.

ELIGIBLE PROJECTS

Physical Improvements

Physical improvements that are eligible for funding include:

- New pipelines, sidegates, control gates and control boxes from District conveyance system to pump intake of private landowner facilities (components related to conversion from flood irrigation to pressurized irrigation system)

- Replacement of leaky cast-in-place concrete pipelines
- Conversion of canals to pipelines
- Flow measurement
- Land leveling for improved flood irrigation
- Unlined regulating reservoirs in areas where groundwater recharge is desired and practical

Management Practices

Management practices that are eligible for funding include:

- Scientific irrigation scheduling (using approved consultant)
- Soil moisture monitoring (using approved equipment manufacturer)

Landowner Proposed Projects

Landowners may propose other conservation measures that are not listed above. These conservation measures must have quantifiable benefit in terms of water conservation or water management. MID will review applications for other proposed conservation measures and determine eligibility for funding on a case-by-case basis.

Ineligible Projects

Most on-farm irrigation system improvements aren't eligible for District funding as these projects may be funded by other programs such as the Natural Resources Conservation Service (NRCS) Environmental Quality Incentives Program (EQIP).

Projects not eligible for funding under the Program include the following:

- Irrigation system components for drip, micro-spray, sprinkler or flood irrigation. These include, but are not limited to: power source, electrical devices, chemical injection tanks and equipment, on-farm irrigation control valves, prescreening (i.e. trashracks), pumps, pump intake piping, piping after pumps, filters, distribution system, emitters, dripline or drip tape
- Engineering design
- Easements
- Land acquisition
- Deep ripping/tillage
- Components related to a conversion from sprinkler to drip irrigation
- Repairs to, or modification of, existing irrigation system not listed herein or under eligible physical improvements
- Pipe relocations and/or improvements to facilitate development or for more efficient on-farm practices.

ELIGIBILITY

Applications can be submitted by an individual landowner or a group of landowners (i.e., Improvement District). Applicants must satisfy the following eligibility criteria to be considered for funding:

- Must have control of the land as a landowner (lessees cannot apply)
- Landowner must have an active irrigation account with MID in good standing
- Must be in good standing with the Irrigated Lands Regulatory Program
- Eligible lands must be entirely or partially within MID
- Benefitting land must have irrigation history in at least 2 of the last 5 years

AVAILABLE FUNDING

The total amount of funding available for the Program will vary each year based on MID's approved budget. The table below shows the anticipated project funding that may be available annually.

Table 1 – Available Funding

Fundable Projects	Percent Funded	Maximum Funding[1]
Physical Improvements	50%	$60,000
Management Practices	50%	$5,000

[1] Maximum funding may vary based on Board approval

If a project serves property that is only partially located within MID's irrigation boundary, then project funding will be proportionate to the acreage within MID's irrigation boundaries. For example, if 80% of the acreage, as determined by MID, is within MID's irrigation boundary, then only 80% of the total project cost would be eligible for 50% funding.

APPLICATION PROCESS AND PAYMENT PROCEDURES

The application and payment procedures are summarized as follows:

1. Landowner submits application package for review (including attached application form, design plans and information, cost estimate, contractor/consultant/manufacturer information, 5 year average water use per acre, and estimate of water savings and operational benefits)
2. MID considers project for funding based on ranking all submitted applications that year

3. MID prepares reimbursement agreement if project is approved
4. Landowner executes agreement
5. MID monitors during construction
6. Landowner completes project
7. MID performs final inspection
8. Landowner submits final pay request, record drawings, and itemized invoices for qualifying project expenses
9. MID makes reimbursement payment in accordance with agreement
10. MID may perform post-project monitoring 1 year after construction to verify performance as intended

PROJECT RANKING CRITERIA

MID Irrigation Operations staff will rank projects based on the information submitted and projects will be funded up to the amount allocated by the Board for that year. Selection won't be on a first come – first served basis. Rather, all projects submitted by the annual deadline will be considered. Preference will be given to projects that meet the following criteria:

1. High water conservation value relative to the project cost (cost/acre-foot conserved)
2. Projects benefitting multiple landowners versus a single landowner
3. Applicants that have historically high water use as determined by MID
4. Applicants that haven't participated before in the Program
5. Replacement of existing infrastructure versus installation of new infrastructure
6. Lands entirely within versus partially within MID's irrigation boundary

CONTRACTUAL OBLIGATIONS

General Obligations

- Landowner must agree to maintain an active irrigation account for at least 5 years following project completion
- Minimum field size of 10 acres for overall project (smaller fields considered on a case-by-case basis)
- MID must pre-approve consultants, contractors and equipment manufacturers
- Project design shall be reviewed by MID prior to construction, and when relevant, prepared by a California Registered Civil Engineer or certified by an Irrigation Association Certified Irrigation Designer
- All projects shall adhere to the attached Conservation Program Design Requirements as applicable.
- Design and construction must meet applicable District standards in accordance with current MID Irrigation Rules and Regulations (Section 2.6)

- MID shall inspect project during construction to ensure conformance with current MID Irrigation Rules and Regulations

Flow Measurement Requirements

- Flow measurement is required for all conveyance projects
- Flowmeters must be Seametrics AG2000 Irrigation Magmeter or McCrometer Mag 3000. Meter with 4-20mA output is required.
- Landowner agrees to provide District permanent access to flow measurement device
- MID shall have the right to install telemetry in the future, if desired
- Landowner agrees to repair, modify, calibrate or replace flow measurement device to ensure accuracy in accordance with MID Irrigation Rules and Regulation then in effect as required by the District. District shall also have the right to repair, modify, calibrate or replace flow measurement device at landowners expense.

ANTICIPATED ANNUAL SCHEDULE

The anticipated annual schedule for implementing the Program is shown below. The schedule may vary from year to year based on available funding and the availability of District staff to administer the Program.

Table 2 – Anticipated Annual Schedule

Description	Date
Applications Released	May 1
Applications Due	August 1
Project Rankings Released	September 1
Deadline for Submitting for Reimbursement	March 1 of following year

ATTACHMENT A

SUGGESTED DESIGN REQUIREMENTS

MODESTO IRRIGATION DISTRICT
CONSERVATION PROGRAM
SUGGESTED DESIGN REQUIREMENTS

FOR USE BY SYSTEM DESIGNERS OR ENGINEERS

A. General Project Requirements
   1. See Design and Construction of Private and Improvement District Facilities (Section 2.6) of MID Rules and Regulations Governing the Distribution of Irrigation Water with the MID.

B. Project Drawing Requirements
   1. Scalable drawing with a scale not to exceed 1" = 60'.
   2. General project vicinity map, north arrow, and legend.
   3. Minimum paper size of 11" X 17" for irrigation projects having a pipe length greater than 500 feet.
   4. Plan view depicting existing roads, property lines, MID irrigation facilities, and Improvement District facilities, as each facility is known by the public or District.
   5. All proposed project facilities to be labeled based on type, size, and distances from existing facilities if applicable.
   6. Legible copies of MID original standard engineering details related to project shall be incorporated into plan view drawing or additional drawing pages as needed. MID engineering standard detail number to be referenced on plan view drawing(s) at all locations where the MID engineering standard detail is utilized.
   7. For irrigation pipelines having a length greater than 500 feet the project designer must provide a profile drawing view of pipeline and related irrigation facilities.

C. Project Design Requirements (To be provided on drawing)
   1. Water elevation datum with respect to existing District irrigation facility as determined by project designer.
   2. Total required flow (15 cfs minimum required for flood irrigation systems only).
   3. For pressurized systems determine maximum flow, duration, and frequency of irrigation events during maximum crop evapotranspiration. Pressure systems designed with existing flood irrigation users or MID infrastructure constraints should be designed to operate no more than twice a week with the duration not to exceed 48 hrs. Alternative designs exceeding these rates will require the designer to gain written approval by an MID representative.
   4. Provide minimum pipeline cover of two (2) feet at all times
   5. Minimum Polyvinyl chloride pipe rating of 100 psi for all critical crossings such as but not limited to MID pipelines, MID canals, roads and driveways. Minimum Polyvinyl chloride pipe rating of 80 psi for all agricultural fields.
   6. For all pipelines having a length greater than 500 feet, the project designer shall graphically show the static water line from the existing District distribution facility. The hydraulic grade line must be graphically shown based on the maximum required design flow with respect to the water elevation datum from the existing District distribution facility, as determined by the designer.

ATTACHMENT B

LANDOWNER APPLICATION FOR CONSERVATION PROGRAM FUNDING

For District Use Only
Date Received:_______________

LANDOWNER APPLICATION FOR CONSERVATION PROGRAM FUNDING

(applications due by August 1 of each year)

Instructions

The Modesto Irrigation District (MID) Conservation Program provides partial funding to MID landowners for projects that conserve water and improve water management after the eligible project is completed. Projects must meet certain eligibility criteria and be pre-approved by MID. Please carefully read the MID Conservation Program Guidelines before submitting an application. Application must be submitted by the deadline to be considered for funding. All applications will be reviewed and ranked by MID. Funding is not guaranteed for all applications. If you have any questions about the Conservation Program please contact the MID Irrigation Operations office at (209) 526-7373.

General Information

Landowner Name: ____________________
Farm Name (if applicable): ____________________
Email: ____________________
Mailing Address: ____________________
Telephone: ____________________
Assessor's Parcel Number(s) (APN): ____________________
Design Engineer: ____________________
Contractor(s): ____________________
MID Delivery Location (Lateral, Sidegate or Turnout No., Improvement District, etc.):
____
MID Customer ID: ____________________
Parcel Size (acres): ____________________
Crop: ____________________
Future Design Flow: ____________________
Future Irrigation Schedule: ____________________

Have you received MID Conservation Program Funding for any projects in the past 5 years?

☐ Yes ☐ No

Have you applied for funding for these conservation measures, or a portion of related conservation measures, under any other program, such as NRCS EQIP?

☐ Yes ☐ No

If yes, what portion of project? ____________________

Eligibility

- Must have control of the land as a landowner (lessees cannot apply)
- Must have an active irrigation account with MID in good standing

- Must be in good standing with the Irrigated Lands Regulatory Program
- Eligible lands must be entirely or partially within MID
- Benefitting land must have irrigation history in at least 2 of the last 5 years
- Minimum field size of 10 acres for overall project (smaller fields considered on a case-by-case basis)
- Project must be on approved list of eligible project types (see Conservation Program Guidelines)

Proposed Physical Improvements (Check all that apply)

☐ New pipeline, sidegate, control gates and/or control boxes from District conveyance system to pump intake of private landowner facilities (components related to conversion from flood irrigation to pressurized irrigation system)
☐ Conversion from flood to drip/micro system
☐ Replacement of leaky cast-in-place concrete pipeline
☐ Conversion of canal to pipeline
☐ Flow measurement
☐ Land leveling for improved flood irrigation
☐ Unlined regulation reservoir
☐ Other (provide brief description below, see section titled "Other Conservation Measures")

____

Proposed Management Improvements (Check all that apply)

☐ Scientific irrigation scheduling
☐ Soil moisture monitoring
☐ Other (provide brief description below, see section titled "Other Conservation Measures")

____

Other Conservation Measures

Modesto Irrigation District will consider other conservation measures that can result in water conservation or improved water management. If you are proposing a conservation measure that isn't listed above then please attach the following:

1. Description of conservation measures to be implemented, including physical changes to the field and/or irrigation management changes
2. Sketch showing field and project location, and physical changes to the field
3. Description of how the proposed conservation measure will result in water conservation or better water management

Other Relevant Notes Regarding Project (please add any other relevant information below)

____
____
____
____
____
____

5-Year Avg. Water Use: _______________ AF/AC

Estimated Water Savings: _______________ AF/AC

Identified Operational Benefits: ______________________________
____
____

Requested Funding[1]

Total Project Cost: $ ________________

Total Requested Funding $ ________________

[1]MID will fund up to 50% of project costs with normal maximum funding of $60,000 for physical improvements and $5,000 for water management practices

Attachments

Please attach the following to your application:

1. Design drawings (for physical improvements)
2. Cost estimate (be sure to separate eligible and ineligible costs)
3. Calculation of estimated water savings and operational benefits
4. Information on proposed irrigation consultant (scientific irrigation scheduling)
5. Information on proposed contractors
6. Information on equipment manufacturer (flowmeters and soil moisture monitoring)

______________________ Please Print Name	______________________ Landowner Signature
	______________________ Date

Please Submit Application to:

Modesto Irrigation District
Irrigation Operations Division
P.O. Box 4060
Modesto, CA 95352-4060

FOR OFFICE USE ONLY				
Received by Civil Engineering Dept.	Initials:	__________	Date:	__________
Application Deemed Complete:	Initials:	__________	Date:	__________
Approved by Irrigation Field Services Manager:	Initials:	__________	Date:	__________
Approved by Civil Engineering Manager:	Initials:	__________	Date:	__________

MODESTO IRRIGATION DISTRICT

2020 AGRICULTURAL WATER MANAGEMENT PLAN

APPENDIX G

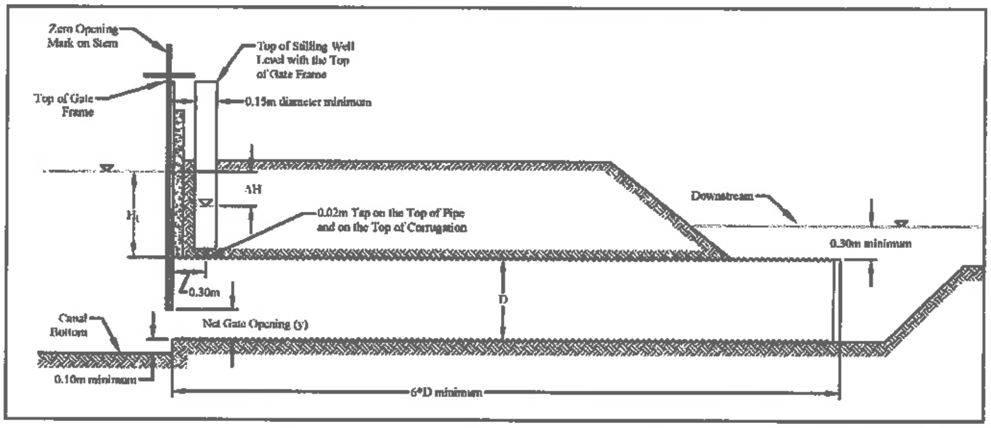
ITRC WATER MEASUREMENT REPORTS

- **IMPROVING FLOW MEASUREMENT ACCURACY AT FARM DELIVERY GATES IN CALIFORNIA – JULY 2015**
- **FLOW MEASUREMENT OPTIONS FOR CANAL TURNOUTS – DECEMBER 2014**
- **SBx7 FLOW RATE MEASUREMENT COMPLIANCE FOR AGRICULTURAL IRRIGATION DISTRICTS – AUGUST 2012**

ITRC
moving water in new directions

IRRIGATION
TRAINING &
RESEARCH
CENTER

Improving Flow Measurement Accuracy at Farm Delivery Gates in California



Technical Report

California State University
Agricultural Research Institute

July 2015

IRRIGATION
TRAINING &
RESEARCH
CENTER

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Irrigation Training & Research Center
July 2015

ACKNOWLEDGEMENTS

This work was funded by a grant (13-01-005) from the California State University Agricultural Research Institute (CSU ARI). The authors would also like to acknowledge the support provided by San Luis Canal Company, including the donation of rectangular gates. The Armco-type gates were provided by Fresno Valves and Castings, Inc. (Selma, CA). The authors would like to acknowledge Evan Geer (former water engineering graduate student) for his help in developing the net open area equations. This work could not have been completed without the hours of work provided by Cal Poly water engineering and irrigation graduate students and construction efforts by ITRC student employees from the BioResource and Agricultural Engineering Department.

DISSEMINATION

The information developed in this report has led to several peer-reviewed journal articles, thesis project, and conference papers and presentations listed below. In addition, the BRAE 533 (Irrigation Project Design) and the ITRC Flow Measurement Books have been updated to include the recommendations outlined in this report. This information is being taught in industry short courses (2 per year) and Cal Poly undergraduate and graduate courses (BRAE 236 and BRAE 533).

Publication of Final Results:

Howes, D. J. and C. M. Burt (2015a). "Accuracy of Round Meter Gates for On-Farm Deliveries." ASCE Journal of Irrigation and Drainage Engineering, in press.

Howes, D. J. and C. M. Burt (2015b). "Rating Rectangular Farm Delivery Meter Gates for Flow Measurement." ASCE Journal of Irrigation and Drainage Engineering, in press.

Howes, D. J., C. M. Burt, and J.M. Thorburn (2015). "Supply Channel Velocity Influence on Farm Delivery Meter Gate Flow Measurement." In progress

Thorburn, J.M. (2015). *Hydraulic Effects of Water Approach Velocity on Meter Gate Flow Measurement* (Master's thesis). In progress

Burt, C.M. and D.J. Howes (2015). "Practical Guide for Meter Gates". ITRC Report Number: 15-001. Irrigation Training and Research Center, San Luis Obispo, CA.

Feist, K. and C.M. Burt. (2014). Flow Measurement Options for Canal Turnouts. Paper presented at USCID Water Management Conference, Dec. 2-5, 2014. Denver, CO.

Presentations and Publication of Preliminary Results:

Howes, D.J. 2014. "Calibrating Orifice Flow Turnout Gates for SBx7-7 Compliance." California Irrigation Institute Conference on Building a Water and Energy Efficient California, January 23-24, 2014. Sacramento, CA.

Howes, D.J. and R. Fulton. (2013). "ITRC metergate calibration testing for farm turnout delivery." Paper presented at USCID Water Management Conference, Oct. 22-25 2013. Denver, CO.

Fulton, R. (2013). *Meter Gate Calibration and Accuracy Analysis* (Senior Project). California Polytechnic State University, San Luis Obispo.

EXECUTIVE SUMMARY

Recent California legislation requires irrigation water agencies larger than 25,000 acres to measure volumetric water deliveries within specified levels of relative uncertainty. Although the meter gate is one of the most widely used flow measurement devices in California, little investigation has been conducted into the accuracy, limitations, and uncertainties of the rating tables developed over 60 years ago.

The Cal Poly Irrigation Training and Research Center (ITRC), through a CSU ARI grant, constructed a meter gate testing facility (see *Attachment A*) and tested five gates of various sizes and designs. The gate testing was conducted by varying the multiple parameters including upstream and downstream head, supply channel velocity, gate opening, and head above the gate. Data was also collected at various locations on the downstream side of the gate. In total, ITRC staff collected over 10,000 points of data during this evaluation.

Using the new rating tables for the three gates examined, the relative uncertainty is less than ±5 to ±7% at the 95% confidence level with the new rating tables, as compared to less than ±10% at a 95% confidence level using common published tables. Uncertainties are lower than the required estimated 10.7% instantaneous flow rate uncertainty that will be needed to meet current SB X7-7 requirements. However, in order to ensure accurate flow measurement using these devices, they must be designed and operated within a certain set of recommended conditions. The remainder of this *Executive Summary* will describe the recommendations developed from this study. These recommendations and final rating tables can be found in *Attachment B – Practical Guide for Meter Gates.*

Recommendations for Design and Operation of Meter Gates

As with any flow measurement device, there are constraints and recommendations that must be followed to obtain accurate results. The following guidelines combine some current installation standards, authors' experience, and results found in this study.

1. Traditionally, the upstream head above the top of the turnout pipe (H_1) was recommended to be equivalent to one pipe diameter. However, results in this study show that $H_1 \geq 0.5 \times D$ provide accurate results. This will increase the number of sites that could potentially utilize meter gates accurately.

2. The range of gate openings should be maintained between 25% and 75% open (the relationship between gate opening and A_o/A_p can be found in Table 4). If the stilling well is in the correct location, higher gate openings can be used but should always remain below fully open. For smaller 0.30 m (12-inch) gates, the minimum opening should be increased to 30% to 40%. If smaller gate openings are used for only a portion of the season and larger openings for the remainder, the volumetric uncertainty (accuracy) over the season may not be greatly impacted. It is likely that more significant volume will be delivered with the larger gate openings because of the higher flow rates. The volumetric uncertainty caused by the flow rate uncertainty will be proportional to the volume

delivered at a specific gate opening. Therefore, the overall instantaneous flow rate uncertainty can be taken as the weighted average uncertainty at gate openings used weighted by the volumes delivered.

3. Sufficient upstream submergence is needed on the downstream end of the turnout pipe. The pipe downstream of the meter gate needs to be full. The water level needs to rise to some measurable level in the downstream stilling well. The downstream submergence should be at least 0.30 m (12 inches). However, more submergence may be needed so that a ΔH of approximately 0.76 m (30 inches) is not exceeded. Previous recommendations limit the head loss to 0.46 m (18 inches) but head losses greater than this performed well in this study.

4. All rating tables and C_d values presented here require knowledge of the net gate opening, as measured by the shaft opening. The "zero" gate opening must be properly determined and marked on the gate shaft. This is not a trivial detail. Specific points are:
   a) All measurements of gate opening, as well as the initial marking, must be made after the gate stem has been opened (on the upswing). This is because there is some slack or movement between the shaft and the gate itself.
   b) The gate stem will move up some distance before the gate plate itself reaches the bottom of the pipe. The C_d values developed in this study and traditional rating tables depend on knowing the gate opening, not the movement from the gate seating position. The gate must be closed beyond the bottom of the pipe to seal off completely. That sealed position is not the "zero" position.
   c) There must be some specific way to measure the shaft position when the bottom of the gate just barely clears the bottom of the pipe – in other words, when there is a "zero opening". This is fairly easy to set and measure if the canal is empty or if a new gate is being installed. The gate is opened until a narrow strip of paper can be inserted between the bottom of the gate and the bottom of the pipe (zero position). If the canal is full, special calipers can be used to determine the actual net gate opening and the zero point on the gate stem can be identified from that.
   d) The gate stem needs to be marked in a clear manner so that operators know where the "zero" opening is for the gate when they open the gate. In the field it is often easiest to cut into the stem about 1 cm (0.5 inches) with a grinder at the top of the gate lift nut. Then the operator should always measure the gate opening on the upswing from the top of the lift nut to the bottom of the notch.

5. The stilling well needs to have sufficient diameter to dampen the turbulence, and so that operators can see into it. The authors recommends a stilling well of 0.15 m – 0.21 m (6 inches – 8 inches) diameter, with a tap hole of about 0.016 m or 0.019 m (5/8 inch or 3/4 inch) diameter. The stilling well to tap hole diameters should be greater than 7:1.

6. The tap hole must be on the top of the pipe and should be 0.305 m (12 inches) downstream of the downstream face of the gate. However, the stilling well does not need to be centered over the access hole in the top of the discharge pipe. In general, it is good to have the stilling well close to the gate frame/bulkhead, so that it can be supported.

7. If the stilling well is less than 0.30 m (12 inches) from the face of the gate for larger gates, the error in measurement will be low if the gates remain less than 75% open. For 0.30 m gates and probably smaller, there is a high likelihood of substantial error with different tap locations. It is recommended that the tap location at these sites be moved to the correct location or the correction factor (F_{tap}) should be multiplied by the flow rate obtained from tables based on the 0.305 m (12-inch) tap location as described.

8. The tap hole should also be on the top of a corrugation if corrugated pipe is used. The closest peak to the 0.305 m (12-inch) ideal tap location will be sufficient.

9. To simplify the measurement for head difference (ΔH) use the same datum (elevation) for both measurements. See Figure 1 in the body of this report for a stilling well with the top correctly placed at the same elevation as the gate frame, and with a proper diameter. The top of the stilling well should be at the same elevation as the top of the gate frame (where the bottom of the lift nut rests). Then the upstream measurement should be taken from the top of the gate frame to the water level. The downstream measurement should be taken from the top of the stilling well to the water level in the well. The ΔH is the difference between the upstream and downstream measurements from the datum (reference) to the water levels.

10. In many cases having the stilling well top at the same elevation as the top of the gate frame will prevent debris and soil from falling into the well and plugging the tap hole. This can occur during maintenance of the canal bank and road. If the top of the gate frame is still low enough that debris can fall in, a cap should be placed over the well when measurements are not being taken.

11. Volumetric accuracy can be improved if:
    a) Additional instantaneous flow measurements are taken during the irrigation event. An example would be taking flow measurements every 24 hours at open turnouts even if adjustments are not being made. This will reduce U_{Hu} and U_{Hd}.
    b) The time the delivery starts and stops is properly recorded. If operators open and close turnout gates this can be done without additional work.

The new C_d values from this study for the five gates examined presented in Table 4 in the body of this report should be used for creating new rating tables for these gates. While a best-fit polynomial can be created for each gate, it is more appropriate to interpolate between these values to estimate C_d values for other gate openings. Utilizing variables outside of those tested in a regression equation can lead to significant error in the computed C_d ($\hat{C}_d$). Linear interpolation or a more advanced interpolation method can be used. If an advanced interpolation is used the values should be plotted with those reported in this report to ensure that the results conform.

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INTRODUCTION

Accurate flow measurement of water from irrigation projects delivered to farms is important for a number of reasons. Farmers use the flow measurement and volumes delivered to know how much water was applied to fields; the amount applied must be known for irrigation scheduling and management. Irrigation projects have been shifting from assessment-based fees to volumetric billing (often there is some combination of both). Irrigation district operators also need good turnout flow measurement to properly operate canals.

On November 9, 2009, the California Senate enacted Senate Bill (SB) X7-7 mandating water conservation and water use efficiency targets for urban and agricultural water suppliers. As part of this legislation, agricultural water suppliers serving areas greater than 25,000 acres were required to have a tentative plan in place for how irrigation districts will measure water deliveries volumetrically within mandated levels of accuracy by July 31, 2012. The districts' plans are to be officially updated in 2015. Over the last year of this process the lead agency, the California Department of Water Resources (DWR), held a number of public hearings and meetings to clarify issues to water users about flow measurement from open channels (through turnouts). Dr. Charles Burt and Dr. Stuart Styles, Chairman and Director, respectively, of the Irrigation Training and Research Center (ITRC), California Polytechnic State University, San Luis Obispo have been active participants in this process. Dr. Burt is a member of the Agricultural Stakeholders Committee (ASC) and has provided his expertise on turnout flow measurement through a number of presentations and documents (www.water.ca.gov/wateruseefficiency/sb7/committees/ag/a2/).

Specific regulation for agricultural irrigation water agency turnout flow measurement includes (DWR 2011):

- If there is an existing flow measurement device, the volumetric accuracy must be within ±12%.
- For new flow measurement devices, the volumetric accuracy must be within a laboratory rated ±5% or ±10% in the field if laboratory ratings are not available.

Because of the vast array of conditions in the field, there is no single hardware solution that will economically meet the SB X7-7 requirements in all agricultural water delivery locations throughout California. In most cases, the regions that can use simple solutions already utilize potentially accurate volumetric flow measurement devices such as propeller meters. The challenge is finding solutions for the difficult situations. These include areas with high sediment loads, aquatic weeds, little available head loss (where the water levels upstream and downstream of a turnout gate are similar), and high flow rates.

"Volumetric accuracy" is defined in the SB X7-7 regulations as the percent error between the measured volume and the actual or true volume. The measurement device provides the measured volume (volumes may be computed from a measured flow rate and the duration of delivery) and the actual volume is determined through laboratory or field testing (DWR 2011).

A second term used in this report is "uncertainty", which is the proper term to use when describing the range of values within which the actual value lies for a stated confidence level. In other words, "on the average" a measured number may equal 0.625, which is identical to the "true" value. However, any single measured value may be different.

In some cases volumetric measurements are made directly by the meter (e.g., propeller meter with totalizing capability). However, instantaneous flow rate is often measured and volumes are estimated based on the duration of the delivery. Since the instantaneous flow rate (Q) may have only been measured at one or more instances during the duration of the delivery, there is some uncertainty beyond the flow meter uncertainty of the volume computed from the device that will influence the volumetric measurement accuracy.

There are several factors that will influence the combined uncertainty of the volumetric measurement from devices such as meter gates, where volumes are computed based on instantaneous flow measurement and the duration of the water delivery. Flow measurement accuracy is a major component of the volumetric accuracy and was investigated for meter gates (special submerged orifice) in this work. The change in supply channel water level between flow measurement reading events will influence the head on the turnout gate and therefore influence the flow rate. Water level variation downstream of the orifice will influence the head loss across the gate, which can change the flow rate. Finally, inaccuracy in determining the correct duration of the irrigation event will influence the computed volumetric accuracy. These are discussed in the *Flow Measurement Errors and Uncertainty* section.

One of the most commonly used farm delivery (i.e., turnout) flow measurement devices in California is a meter gate (ITRC 2000; ITRC 2002). Meter gates provide a number of advantages if these devices can meet the volumetric accuracy requirements. A major advantage is that thousands of these devices are already installed; water agencies may not need to invest in new devices. Water quality issues including high sediment loads and aquatic weeds do not cause significant problems, and annual maintenance and calibration costs are low with meter gates.

As will be discussed, rating tables exist for common meter gates. One purpose of this work was to compare existing rating table values for several gate sizes against laboratory evaluations. Another was to provide improved gate discharge equations, if found, and to expand the equations to cover a wider range of configurations. Additionally, there was a need to provide clear rules on the installation and operation of these devices to meet the accuracy requirements in SB X7-7. Finally, new rating tables were developed for two rectangular gate sizes commonly installed as new or replacement gates for irrigation turnout delivery.

BACKGROUND

The meter gate is a special type of rated orifice (sluice gate) that generally uses a round gate to control water flowing into a round pipeline. Meter gates are submerged and the downstream head is typically measured 0.30 m (12 inches) downstream of the back face of the gate through an access hole in the top of the pipeline connected to a stilling well. Irrigation agency operators use rating tables for a particular gate size, with measurements of the head loss (ΔH) between the supply channel and the downstream water level, and the net gate opening (y) to obtain a flow rate through the gate. Rating table development started around 1918 when Modesto Irrigation District began an investigation into calibrating standard gate designs and installations. Modesto ID selected the Calco Slide Headgate Model 101 as its standard gate.

Calco (California Corrugated Culvert Company, Berkeley, CA) was a division of Armco (American Rolling Mill Company); the gates became known as the Armco Model 101. The basic design of the round gate on a round pipe is generally referred to as the Armco-type gate. The Armco Model 101 was acquired by Fresno Valves and Casting, Inc. (Selma, CA) and is still being manufactured as the Series 6600 Model 101C. Other, similar round canal turnout gates by other manufacturers include the Waterman Industries (Exeter, CA) C-10 canal gate and XCAD (Paul, ID) X-GATE™ W-type. It should be noted that the gates by themselves are not meter gates. It is necessary to properly install the tap and stilling well downstream of the gate as well as identify the zero openings to measure flow rates, as will be discussed.

The original Modesto ID ratings were based on submerged gates with different lengths of pipe downstream (Armco 1949). Since the pipe lengths can vary depending on installation, in the mid-1920's Fresno Irrigation District constructed a facility and began developing rating tables using a standard downstream head measurement of 0.30 m (12 inches) behind the face of the gate, which was also a Calco (Armco) Model 101 (Fresno Irrigation District 1928). Fresno ID conducted tests for gate sizes from 0.20 m to 0.61 m (8-inch to 24-inch). These rating tables were published by Armco for the Model 101 meter gate until approximately 1951, when the U.S. Bureau of Reclamation (USBR) completed another set of meter gate ratings for gate sizes ranging from 0.20 m to 1.22 m (8 inches to 48 inches) (Summers 1951). The reason for the USBR rating table development was that the USBR found errors in the Fresno ID ratings of up to 18% (Summers 1951).

Since the USBR rating development (Summers 1951), very little work has been conducted to examine the accuracy of Armco-type meter gates. Other researchers have used the data collected during the USBR investigation without examining the accuracy of the original data (Cadena and Magallanez 2005).

Prior recommendations on installation of meter gates can be found in the USBR Water Measurement Manual (USBR 1997) and in the Armco Rating Table booklet (Armco Steel Corporation 1975). In the field, there can be a variety of installations that do not conform to either set of recommendations and may have been a result of confusion from alternative instructions or mistakes. The issues seen in the field may be attributed to differing recommendations. For example, the Armco Rating Table booklet and Summers (1951) recommend that the stilling well tap for the downstream head measurement be placed 0.305 m (12 inches) behind the face of the turnout gate. However, the USBR Water Measurement Manual and Ball (1961; 1962) state a preferred distance of one-third of the turnout pipe diameter downstream. The result is a variety of downstream head measurement locations.

Figure 1 shows the recommended installation of a meter gate with some modifications to the stilling well and pressure tap recommendations based on the authors' experiences with these devices. The stilling well in Figure 1 is taller than those shown in the USBR Water Measurement Manual and the Armco Rating Table booklet, which show the top of the well nearly level with the top of the channel bank. Raising the well above the bank prevents debris from depositing in the well when the channel bank road is being graded.

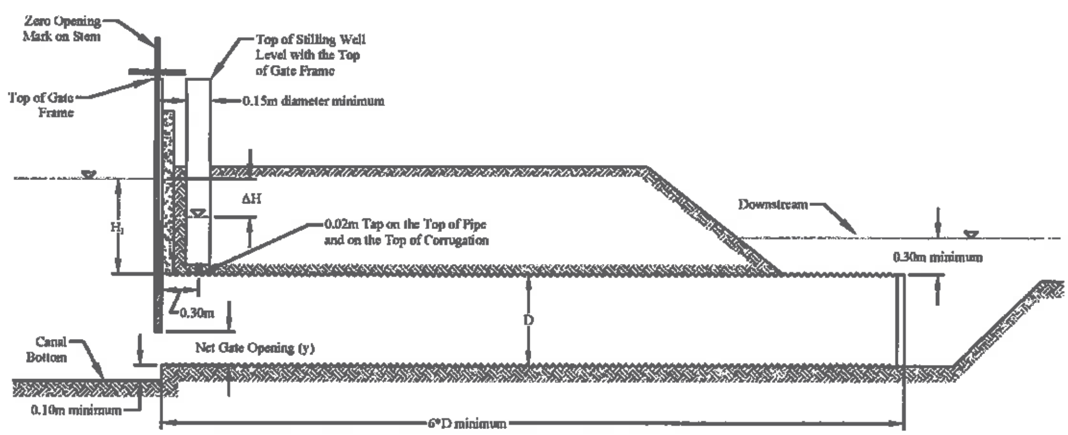

Figure 1. Recommended meter gate installation (Howes and Burt, 2015a)

In addition, the top of the stilling well should be level with the top of the gate frame. This allows the operator to measure down from the top of the gate frame and the top of the stilling well to the water surfaces to obtain the head loss (*ΔH*). This is an alternative to the typical meter gate well assemblies that can be purchased from manufacturers and those shown in the literature discussed. It is common to see two wells on the downstream side of the gate with the same top elevations. One well is connected to the top of the pipe as shown in Figure 1 and the other is connected with a horizontal pipe to the upstream canal. The authors have found that this horizontal pipe plugs easily and is very difficult to clean out with water in the upstream canal. In most cases the upstream water level does not fluctuate significantly so the stilling well for the upstream reading is not necessary.

The stilling well and tap sizes are usually not specified in published meter gate installation recommendations. A stilling well (inside diameter) to (tap diameter) ratio of no less than 8:1 is recommended to dampen the downstream water level fluctuations.

The typical recommendation for the upstream head above the top of the pipe (H_1) is a minimum of one pipe diameter (D). The USBR manual and Armco booklet recommend not having a head loss (ΔH) greater than 0.46 m (18 inches) and the Armco tables do not show values for ΔH greater than this. An updated set of recommendations will be presented in the *Results and Discussion* and *Application* sections.

The original USBR testing setup for the meter gate ratings was oriented so that the supply water entered the meter gate straight on (parallel to the meter gate discharge pipe) (Summers 1951). The testing conducted for the work presented here had the gates oriented perpendicular to the supply channel flow, which is common in field installations.

Flow Measurement Errors and Uncertainty

Several primary factors influence the combined uncertainty of the volumetric measurement from meter gates: flow measurement accuracy, the change in supply channel water level between flow measurement readings, water level variation downstream of the orifice, and inaccuracy in determining the correct duration of the irrigation event. A good discussion on each of these components can be found in Burt and Geer (2012). Since the accuracies of each component are independent, they were combined (Burt and Geer 2012) using the root-sum-of-squares method (Taylor and Kuyatt 1994) to compute the volumetric uncertainty as:

$$U_V = 100 \times \left[\sqrt{\left(\frac{U_Q}{100}\right)^2 + \left(\frac{U_{Hu}}{100}\right)^2 + \left(\frac{U_{Hd}}{100}\right)^2 + \left(\frac{U_T}{100}\right)^2} \right] \quad (1)$$

Where U_v is the percent (relative) volumetric expanded uncertainty where the resulting value describes the range within which true values lie both in the positive and negative around the measured value with a 95% confidence level or within two standard deviations (i.e., expanded uncertainty of the volumetric measurement is $\pm U_v$); U_Q is the instantaneous flow measurement accuracy; U_{Hu} is the accuracy in flow rate estimated due to variable upstream supply canal water levels; U_{Hd} is the accuracy in flow rate estimated due to variable downstream water levels; and U_T is the accuracy of the delivery duration estimate. SB X7-7 does not provide a standard coverage factor (number of standard deviations) or confidence level for uncertainty. It should be noted that in the U.S., some organizations base uncertainty and standard error reporting on one standard deviation (67% confidence level). In this report, two standard deviations (i.e., k = 2 and 95% level of confidence) will be used based on international recommended standards (Taylor and Kuyatt 1994).

An evaluation of upstream supply channel variability for operating turnouts was conducted at San Luis Canal Company (Los Banos, CA) during the summer of 2012 (Burt and Geer 2012). Canal water levels were recorded on an hourly basis at 22 sites, collecting data for approximately 90 irrigation deliveries. The channel conditions and structures are typical of many upstream channel distribution systems in the western U.S. with flashboard weir check structures for water level control and submerged orifice turnouts. The results of this evaluation showed that under submerged flow conditions, the uncertainty of flow measurement due to supply channel water level variation (U_{Hu}) was within ± 2% with a 95% level of confidence.

U_{Hd} and U_T are influenced by farming practices and irrigation water agency operational rules. Burt and Geer conservatively estimated the expanded U_{Hd}, or the uncertainty due to change in backpressure on the gate, as ±3% based on field experience. Additional research is needed to evaluate this uncertainty parameter, and it would depend upon the average elevation change between the supply canal and the farm ditch. The U_T of ±4% was based on a conservative estimate that the difference between actual and recorded duration would be within ±1 hour within a 24-hour delivery period. In many cases irrigation delivery durations are longer than 24 hours, which would result in a smaller U_T if a ±1 hour error is recorded versus actual duration.

Rearranging Eq. 1 and solving for U_Q based on $U_{Hu} = 2\%$, $U_{Hd} = 3\%$, $U_T = 4\%$, and the SB X7-7 requirement of $U_v = 12\%$, the relative instantaneous flow measurement uncertainty (U_Q) that can be tolerated is computed to be ±10.7%. The uncertainty of instantaneous flow measurement (U_Q) for meter gates was the focus of the work presented here.

The overall objectives of the study were to check the accuracy of the existing Armco rating tables, provide corrected or more accurate rating tables if necessary, provide laboratory-verified accuracy under a clearly defined set of installation and operational standards, expand the operational range of meter gate rating tables if possible (so that these can be used in a wider range of sites), examine how supply channel velocities influence accuracy, and, when installations do not conform to standards, determine what if any influence this will have on accuracy.

PROCEDURES

The standard discharge equation for a submerged orifice is:

$$Q = C_d A_o \sqrt{2g\Delta H} \tag{2}$$

Where Q is the flow rate (cubic meters per second (CMS)), C_d is the coefficient of discharge, A_o is the net gate opened area (m^2), g is the gravitational acceleration (9.81 m/s^2), and ΔH is the head loss across the gate (meters). The coefficient of velocity (C_v) has been neglected since the velocity of approach is close to zero because these gates are typically installed perpendicular to the supply channel velocity streamlines.

The C_d value can be computed from Eq. 2 as:

$$C_d = \frac{Q}{A_o\sqrt{2g\Delta H}} \tag{3}$$

As will be discussed, a new meter gate testing facility was constructed. Measurements for Q, A, and H will be discussed in the following sections.

Meter Gate Testing Facility

A meter gate testing facility was constructed at the Cal Poly Irrigation Training and Research Center (ITRC) Water Resources Facility. Photos of the construction can be found in *Attachment A*. The new testing facility was added to an existing elevated flume near its upstream end (Figure 2). Prior to modification, the rectangular flume was 1.21 m wide by 1.21 m in height on a 0.002 slope. A portion of the flume wall was raised from 1.21 m to 1.83 m for this testing. If the recirculation pump is used, 0.85 cms can be supplied through the flume. The recirculation pump has a variable frequency drive (VFD) on a 100 horsepower (HP) motor. Flow is measured exiting the pump by a calibrated 0.762 m McCrometer UltraMag magnetic meter on the supply pipeline (not shown in Figure 2). This water enters a basin at the head of the flume through a 0.762 m steel pipeline. Flow rates into the flume are controlled by adjusting the VFD to match the target. The flow through the 0.762 m UltraMag (Q_1), the supply channel dimensions, and upstream water level (d_1) were used to compute the supply channel Froude number (F_1) was computed as:

$$F_1 = \frac{V_1}{\sqrt{gd_1}} \tag{4}$$

As shown in Figure 2, the meter gates were attached to the flume perpendicular to the flume flow. The meter gate was connected to the side of the flume with a removable steel bulkhead so that the gate frame was attached flush to the side of the steel. The frame and gate protruded slightly into the flow the width of the gate frame as can be found in many field installations. The bottom of the gate was set at least 0.10 m (4 inches) above the bottom of the channel as recommended by the USBR. A corrugated discharge pipe, sized to match the gate diameter, connected the gate to the downstream sump as it would be in a typical field installation. The sump on the downstream end of the corrugated pipe had a top elevation equivalent to the top of the flume walls so that a full range of head differentials could be tested.

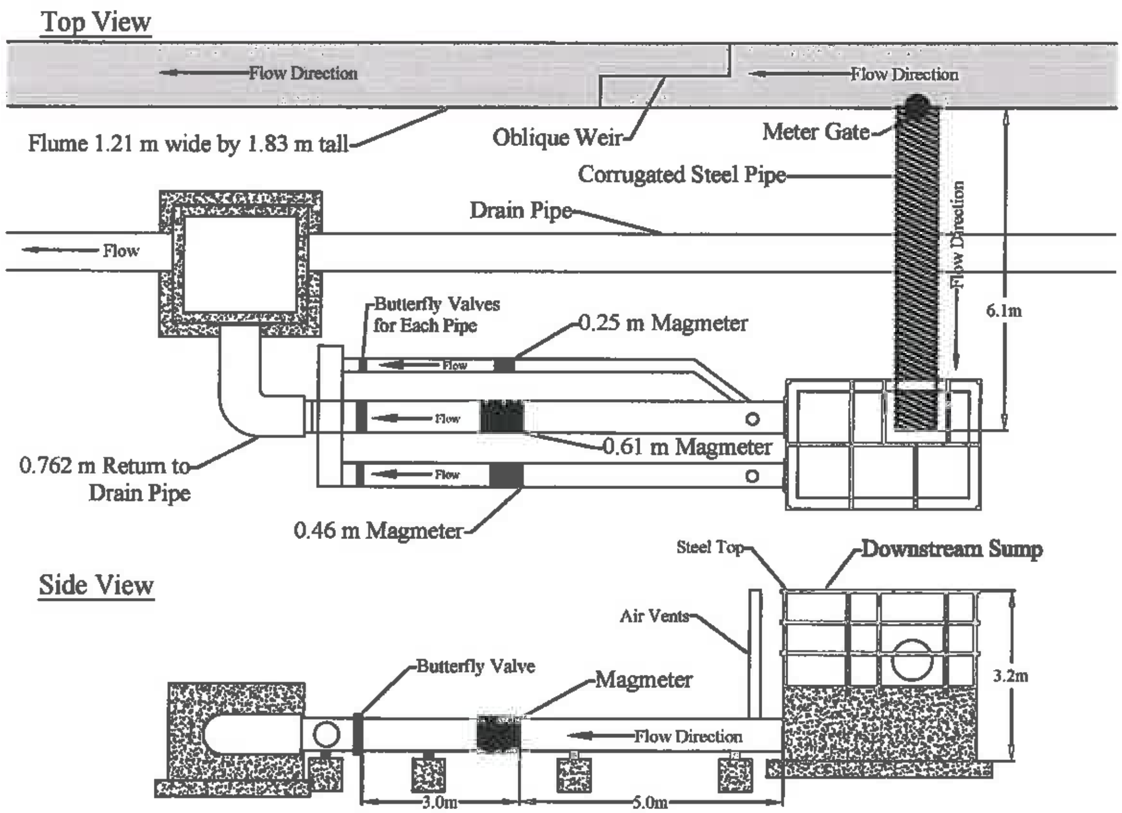

Figure 2. Layout of the testing facility constructed at the Cal Poly Water Resources Facility. (Howes and Burt, 2015a)

The Armco and other gate rating tables require the user to measure the net gate stem opening from the zero opening. The zero opening is the point at which the bottom of the gate is level with the bottom of the pipe. To prevent leakage when the gate is closed, the gate plate diameter is larger than the pipe diameter, and the bottom of the gate seats closed in a position below the inside bottom of the pipe. The gate must open some distance, which varies by gate size and manufacturer, before the zero opening is reached. When a new gate was installed for testing, the stem on each gate was marked to identify the zero opening. A procedure for marking the zero opening is described in the *Application* section.

Three steel discharge pipes were connected to the bottom of the downstream sump (Figure 2). Each pipe had a calibrated magnetic flow meter (mag meter) with the same inside diameter as the steel pipes; these flow meters were used to determine the flow rate (Q) in Eq. 3. The nominal magnetic (mag) meter sizes are shown in Figure 2. A discussion on the calibration and operation of these mag meters will be discussed in the next section.

Butterfly valves were installed at the downstream end of each of the mag meter pipes to control the water level in the sump and ensure that the pipe flowed full. These valves were operated manually. The flow leaving the mag meter pipelines entered a manifold where it was discharged into a drain line to be recirculated back to the head of the flume. The drain line ran from an emergency spill at the upper supply sump (to the right of the meter gate in Figure 2 approximately 18 meters) down to a sump at the tail end of the flume where the recirculation pump is located.

In the flume, a 3.7 m long oblique weir was used to control the water level (head) upstream of the meter gate. The weir crest elevation was manually adjusted by adding or removing wood boards (flashboards). All flow passing through the VFD and the 0.762 m mag meter entered the flume and either passed through the meter gate or went over the weir. The 0.762 m mag meter was used to measure the flow rate entering the flume so that the velocity of the water in the flume could be known. The results presented in this report utilize very low velocities in the flume to negate the impacts of supply channel velocity on the results and to provide a baseline. Since supply channel velocity will depend on entrance conditions and the channel, it is anticipated that if adjustments are necessary, they would be applied to the baseline ratings developed here.

Flow Rate through the Meter Gate (Q)

Three magnetic meters were installed downstream of the meter gate to determine the flow rate standard (Q) shown in Eq. 3. The 0.61 m (24-inch) and 0.46 m (18-inch) McCrometer UltraMag mag meters and the 0.25 m (10-inch) Seametrics AG2000 were installed to provide a range of flow testing capabilities. For the results that will be presented here, only one mag meter was used for one test.

Calibration of each meter involved installing it in a pipeline within and parallel to the flume (at different times) prior to the meter gate testing. The meter readings were compared against the flow rate computed from a National Institute of Standards and Technology (NIST) traceable weigh tank at the downstream end. At least nine different flow rates were tested for each meter and the weigh tank flow rate was compared to the readings from the mag meter. A best-fit linear regression was developed for each gate and used to compute the calibrated flow. The r-squared value for all three calibration equations was greater than 0.999.

The pre-calibration average percent error of the 0.61 m mag meter was -4.43%. Post-calibration the error was 0.14% with a root mean squared error (RMSE) of 0.0029 cms and a coefficient of variation of the RMSE (CVRMSE) of 0.014. The pre-calibration average percent error for the 0.46 m mag meter was -0.67%. Post-calibration the average percent error was 0.07% with a RMSE of 0.0012 cms and a CVRMSE of 0.007. Pre-calibration average percent error was for the 0.25 m mag meter was 3.37%. Post-calibration for the 0.25 m mag meter was -0.12% with a RMSE of 0.0017 cms and a CVRMSE of 0.043.

Each mag meter had a digital display showing flow rate. Readings were recorded manually during the testing four times for each test after steady state conditions were reached. The calibration equations for each meter gate were applied to the raw flow rates recorded from the digital displays during post-processing of the data.

Net Gate Opening Area (A_o)

In this study, the actual gate opening area (A_o) was used to compute the C_d. The original USBR calibration computed C_d based on the full pipe area (A_p), not the actual opening area. Therefore, the C_d values from this study and the USBR work are not directly comparable. The full pipe C_d incorporates the loss across the gate, resulting in C_d values that approach zero as the gate opening becomes smaller. The actual gate opening was used here so that differences in actual C_d values could be compared between gate openings and different gate sizes. It should be noted that Cadena and Magallanez (2005) computed C_d values from the USBR meter gate tests based on an area approximation presented by Hager (Hager 1987). However, that area approximation performs poorly at gate openings less than 25% and greater than 55%, so the C_d values computed by Cadena and Magallanez will also not be comparable to those presented in this report.

Round Gate Opening Area

An (opening area) to (gate opening position) relationship was derived for a circular gate on a circular pipe. To ensure that the gate seats completely over the pipe, the radius of the gate (R_g) is larger than the radius of the pipe (R_p). The relationship will depend on the gate manufacturer and the gate size. Figure 3 shows key measurements used to compute the gate opening area.

The following is the relationship between net gate open area (A_o) and net gate opening (y):

$$A_o = A_i - A_{subtracted} \quad (5)$$

Where:

$$A_i = R_p^2 \times \cos^{-1}\left(\frac{O}{R_p}\right) + O \times \sqrt{R_p^2 - O^2} \quad (6)$$

$$A_{subtracted} = R_g^2 \times \cos^{-1}\left(\frac{P-O}{R_g}\right) + (O-P) \times \sqrt{R_g^2 - O^2} \quad (7)$$

$$P = y + R_g - R_p \quad (8)$$

$$\text{Offset} = y + R_g\text{-}R_p(12) \quad (9)$$

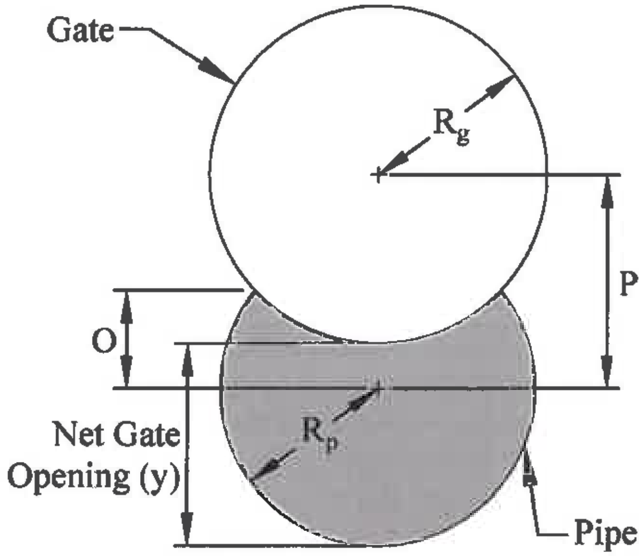

Figure 3. Round gate (white) on a round pipe showing variables used to compute the net gate open area (gray) for a round gate on a round pipe (Howes and Burt 2015a).

From Figure 3, y is the net gate opening, R_g is the outside radius of the gate, R_p is the inside radius of the pipe, O is the distance from the centerline of the pipe to the intersection of the pipe and gate, and P is the distance from the center of the pipe to the center of the gate. In Eq. 4-6, A_i is the pipe area at the gate opening if the gate bottom was flat along a geometric chord where the gate intersects the pipe on both sides, and $A_{subtracted}$ is the area of the circular portion of the gate protruding into the pipe area below this chord. The net gate opening (also referred to as the stem height) is a critical measurement from the bottom of the inside diameter of the pipe to the bottom of the gate. This measurement is often mistaken in the field and as will be discussed, care must be taken to identify the correct zero opening just as the gate breaches the bottom of the pipe.

The previous equations for round gate opening area are equivalent to those used by Skogerboe and Merkley (1996). However, users of that text should be aware of an error in one of the equations presented (Equation 10.37) and refer to an example on the following pages of that chapter to determine the correct equation.

Rectangular Gate Opening Area

The following is the relationship between net gate open area (A_o), pipe radius (R_p), and net gate opening (y) from Skogerboe and Merkley (1996):

$$A_o = \frac{R_p^2}{2} \times \left[2 \times \cos^{-1}\left(1 - \frac{2 \times y}{R_p}\right) - \sin\left(2 \times \cos^{-1}\left(1 - \frac{2 \times y}{R_p}\right)\right)\right] \quad (10)$$

Where y is the net gate opening and R_p is the pipe inside radius shown in Figure 3. Since the ratings are based on net gate opening (also referred to as the stem height), correct measurement is critical. The correct procedure for this measurement is from the bottom of the inside diameter of the pipe to the bottom of the gate. The gate stem (above the frame) must be marked to indicate the correct zero opening, which occurs just as the gate breaches the bottom of the pipe, while the gate is being opened (not closed). The distinction between measurement during the action of opening or closing the gate is necessary because the stem-gate connection almost always has free movement.

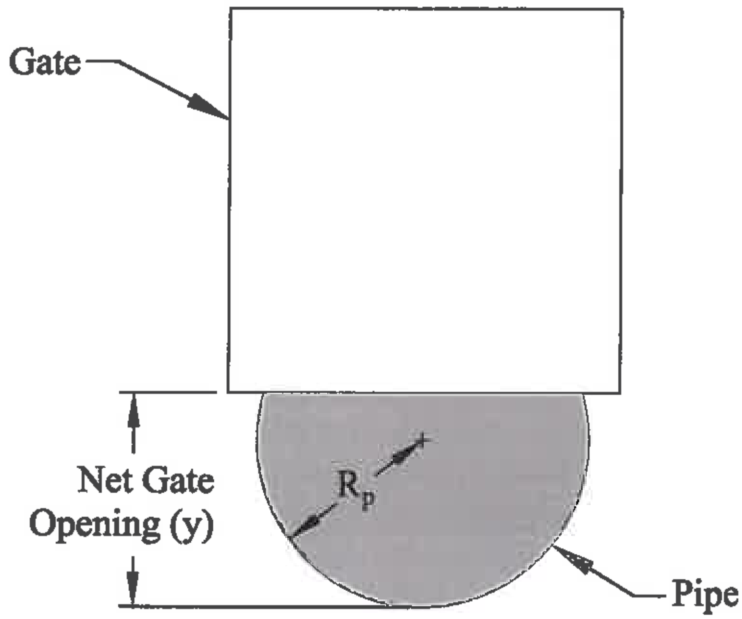

Figure 4. Rectangular gate on a round pipe showing variables used to compute net gate opening area (shaded gray) (Howes and Burt 2015b).

Pressure Head Testing Design

In order to determine the ΔH from Eq. 3, the difference in head upstream and downstream of the gate is needed. For this evaluation, multiple locations downstream from the back face of the gate were examined to determine the effect that location of the downstream measurement had on the estimated flow. For a standard meter gate design, the Armco water measurement tables state that the ΔH is the difference in head between the upstream water level and the water level measured in a stilling well that is connected to the turnout pipeline tapped 0.305 m (12 inches) downstream from the face of the gate (Armco Steel Corporation 1975). This standard location was used for the baseline rating (to compare existing Armco Rating Tables). Figure 5 shows the locations where downstream head was measured for various readings, including at the 0.305 m location.

At the top of the closest corrugation to the locations shown in Figure 5 (0.15, 0.20, 0.305, 1.22, 2.44, 4.88 m), 0.019 m (3/4") holes were tapped for the head measurements along the pipe. In addition to these locations, head measurements were made for the upstream water level through a 0.019 m hole in the bulkhead at the same elevation as the top of the corrugated pipe.

Stilling wells were required because of the fluctuation in pressure head in the pipeline; proper sizing is critical, as will be noted in the *Discussion* section. The stilling wells were grouped together for ease of leveling and measurement and were located on the side of the downstream sump wall. The holes were connected to the 0.152 m (6-inch) PVC stilling wells using 0.016 m clear flexible plastic hose that was sloped slightly upward from the head measurement location to the stilling wells. Clear plastic hose was used so that air bubbles were visible and could be removed.

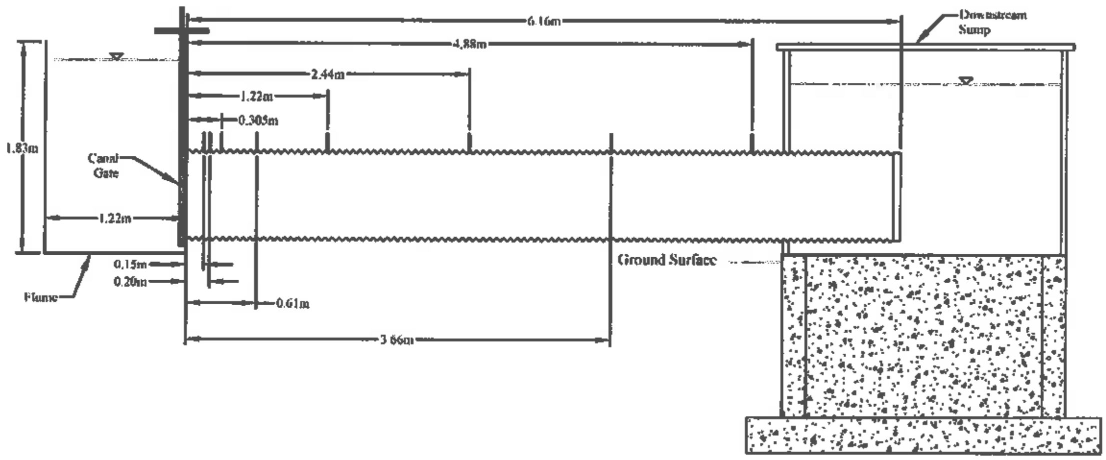

Figure 5. Side view of meter gate testing facility showing the pressure tap locations where measurements were taken.

The *ΔH* was measured directly by using a SMAR-LD301 pressure differential transmitter/transducer (SMAR, Houston, TX). The LD301 is temperature compensating and the differential range was modified to decrease the output uncertainty to within ±1 mm. The stilling well from the tap connected to the water level in the flume (upstream head) on one side of the differential pressure transducer. The other side of the transducer was connected to a manifold. The manifold connected stilling wells for each downstream head location so that one head measurement location could be isolated with valves and compared to the upstream head for each measurement. The testing personnel would sequentially turn valves on and off and manually take *ΔH* readings for each head measurement location.

As redundancy, staff gauges were connected to each stilling well and referenced to the same datum. The staff gauge increments were approximately 1.5 mm. These visual readings were used to manually compute *ΔH* to check that the pressure differential transducer was functioning properly. If the *ΔH* from the LD301 differed from manual readings by more than 1%, the pressure transducer was zeroed and the test was repeated.

Meter Gate Testing Scenarios

Testing involved examining a wide array of conditions to examine effects that these conditions have on C_d. Conditions that were varied included upstream water level in the flume, water level in the downstream sump, gate opening, supply channel velocity, gate size, and gate type. Additionally, as discussed, downstream head measurements were taken at multiple locations downstream of the gate. In total, over 10,000 individual points of data were collected in this study

Armco-type (round) gates examined were manufactured and provided by Fresno Valves and Casting, Inc. Three common gate sizes were examined, nominally 0.30 m (12-inch), 0.46 m (18-inch), and a 0.61 m (24-inch) Model 101C. These are the same designs as the Armco gates used in the original Fresno Irrigation District and USBR studies. Two commonly used rectangular canal gate sizes (0.46 m (18-inch) and 0.61 m (24-inch)) were examined under various conditions. These rectangular gates were manufactured by Mechanical Associates (Visalia, CA) and were donated for testing by San Luis Canal Company (Dos Palos, CA).

Table 1 shows the testing range for the different tests conducted as part of the meter gate evaluation under low supply channel velocity. The low supply channel velocity runs were used as a baseline. Other supply channel velocities were also tested as will be discussed. The low supply channel testing had velocity in the supply channel, downstream of the meter gate was always less than 0.2 meters per second (m/s).

The goal of this evaluation was to collect data over a wide range of scenarios for each gate size. In large-scale testing it was not feasible or important to match a predetermined water level or head loss target exactly. Therefore, a target range was attempted for each scenario (e.g., an actual ΔH of 0.11-0.19 m would be satisfactory for a test with a target ΔH of 0.15 m) and the results are presented for the actual measured variables. As Table 1 indicates, a variety of head differences were evaluated. The actual head difference (head loss) was varied depending on the upstream head available. With Low upstream head, the limited head available typically resulted in a small head loss.

Upstream head was varied from a classification of Very Low, upwards. Very Low would be less than the recommended 1 pipe diameter (corrugated turnout pipe) head above the pipe. Typically this was about 0.5 pipe diameter. The water level for the Low target was typically 1 pipe diameter above the top of the corrugated pipe. The Middle through Very High upstream head ratings were incrementally increased up to the maximum water level that could be safely obtained with the flume wall heights. For the 0.61 m gate there is no Very High upstream head since the large gate size limited the maximum water level that could be achieved in the flume.

During each of the tests shown in Table 1, the gate openings were changed. For the 0.30 m gate, gate openings in increments of 0.025 m were used from 0.025 m to fully open. For the 0.46 m and 0.61 m gates, gate openings in increments of 0.05 m (2 inches) were used from 0.05 m open to fully open.

Table 1. Tests conducted under low supply channel velocity for the meter gate testing.

Gate Type	Nominal Gate Size (m)	Relative Upstream Head	Relative Head Loss	Upstream Head (H_1) Range (m)	ΔH Range (m)
Armco	0.30	Very Low	Very Small	0.251 - 0.111	0.062 - 0.041
Armco	0.30	Very Low	Small	0.251 - 0.111	0.108 - 0.086
Armco	0.30	Low	Medium	0.383 - 0.359	0.182 - 0.131
Armco	0.30	Middle	Small	0.643 - 0.595	0.351 - 0.305
Armco	0.30	Middle	Medium	0.643 - 0.595	0.427 - 0.378
Armco	0.30	Middle	Large	0.643 - 0.595	0.181 - 0.107
Armco	0.30	High	Small	0.97 - 0.845	0.446 - 0.369
Armco	0.30	High	Medium	0.97 - 0.845	0.661 - 0.613
Armco	0.30	High	Large	0.97 - 0.845	0.347 - 0.310
Armco	0.30	Very High	Medium	1.235 - 1.194	0.599 - 0.563
Armco	0.30	Very High	Large	1.235 - 1.194	0.863 - 0.736
Armco	0.46	Very Low	Small	0.241 - 0.203	0.070 - 0.011
Armco	0.46	Low	Medium	0.489 - 0.457	0.216 - 0.156
Armco	0.46	Middle	Small	0.692 - 0.597	0.048 - 0.032
Armco	0.46	Middle	Medium	0.692 - 0.597	0.310 - 0.263
Armco	0.46	Very High	Small	0.953 - 0.806	0.185 - 0.116
Armco	0.46	Very High	Large	0.953 - 0.806	0.401 - 0.358
Armco	0.46	Very High	Very Large	0.953 - 0.806	0.589 - 0.538
Armco	0.61	Very Low	Small	0.359 - 0.283	0.051 - 0.025
Armco	0.61	Low	Medium	0.448 - 0.427	0.212 - 0.172
Armco	0.61	Middle	Small	0.694 - 0.594	0.054 - 0.029
Armco	0.61	Middle	Medium	0.694 - 0.594	0.348 - 0.260
Armco	0.61	Middle	Large	0.694 - 0.594	0.435 - 0.396
Armco	0.61	High	Small	0.953 - 0.841	0.147 - 0.112
Armco	0.61	High	Large	0.953 - 0.841	0.435 - 0.357
Armco	0.61	High	Very Large	0.953 - 0.841	0.666 - 0.540
Rectangular	0.46	Very Low	Small	0.246 - 0.232	0.059 - 0.027
Rectangular	0.46	Low	Small	0.416 - 0.322	0.151 - 0.062
Rectangular	0.46	Standard	Small	0.73 - 0.457	0.191 - 0.143
Rectangular	0.46	Standard	Large	0.73 - 0.457	0.262 - 0.19
Rectangular	0.46	High	Small	0.66 - 0.584	0.319 - 0.184
Rectangular	0.46	High	Large	0.66 - 0.584	0.353 - 0.266
Rectangular	0.46	Very High	Small	0.819 - 0.775	0.323 - 0.22
Rectangular	0.46	Very High	Large	0.819 - 0.775	0.573 - 0.305
Rectangular	0.61	Very Low	Small	0.449 - 0.249	0.054 - 0.038
Rectangular	0.61	Very Low	Medium	0.449 - 0.249	0.263 - 0.151
Rectangular	0.61	Low	Medium	0.529 - 0.379	0.263 - 0.151
Rectangular	0.61	Low	Large	0.529 - 0.379	0.382 - 0.309
Rectangular	0.61	Standard	Small	0.7 - 0.667	0.051 - 0.03
Rectangular	0.61	Standard	Medium	0.7 - 0.667	0.221 - 0.171
Rectangular	0.61	Standard	Large	0.7 - 0.667	0.407 - 0.305
Rectangular	0.61	High	Small	0.798 - 0.745	0.049 - 0.032
Rectangular	0.61	High	Medium	0.798 - 0.745	0.215 - 0.167
Rectangular	0.61	High	Large	0.798 - 0.745	0.438 - 0.329

In addition to the tests shown in Table 1, Table 2 lists the different velocities and Froude Numbers (F_1) tested. In general there were 3 sets of tests conducted for each scenario listed in Table 1 (Low, Medium, and High supply channel flow). Table 2 lists the range of the velocities and F_1 (computed based on Eq. 4) tested for each of the upstream head conditions.

The supply channel velocity upstream of the meter gate was varied between 0.071 m/s and 0.941 m/s (0.23 ft/s and 3.09 ft/s, respectively). The maximum flow possible in the Cal Poly flume was 0.85 m^3/s (30 cfs), so the maximum velocity was limited for the larger gate sizes because of minimum depths that could be tested. Thereby, the highest velocities and Froude numbers occurred at the lowest upstream depth scenarios for the smaller gate sizes.

Most irrigation distribution canals in California are earthen, and typically have velocities less than 0.91 m/s (3 ft/s). Concrete (or other lined) canals can have velocities greater than this, although many used for irrigation deliveries remain at 0.91 m/s (3 ft/s) or less (Scobey 1939). Therefore, even with the limited testing velocities, the results presented here will be applicable for many (if not most) meter gate installations.

Table 2. Range of supply channel depths, velocity, and Froude numbers evaluated for each gate type and size. The round gate type refers to the Armco-Type gate.

Gate Type	Nominal Gate Size (m)	Relative Upstream Head	Upstream Channel Depth (d) Range (m)	Upstream Channel Velocity (V) Range (m/s)	Upstream Channel F_1 Range
Round	0.3	Low	0.789 - 0.865	0.078 - 0.941	0.027 - 0.309
Round	0.3	Middle	1.078 - 1.133	0.120 - 0.633	0.036 - 0.193
Round	0.3	High	1.318 - 1.453	0.075 - 0.520	0.020 - 0.145
Round	0.3	Very High	1.670 - 1.721	0.075 - 0.404	0.018 - 0.099
Round	0.46	Very Low	0.813 - 0.902	0.122 - 0.769	0.043 - 0.259
Round	0.46	Low	1.014 - 1.340	0.255 - 0.693	0.078 - 0.220
Round	0.46	Middle	0.597 - 1.305	0.071 - 0.558	0.020 - 0.160
Round	0.46	Very High	1.416 - 1.562	0.081 - 0.461	0.022 - 0.121
Round	0.61	Very Low	1.019 - 1.114	0.157 - 0.658	0.050 - 0.201
Round	0.61	Low	1.164 - 1.284	0.164 - 0.561	0.048 - 0.165
Round	0.61	Middle	1.343 - 1.467	0.083 - 0.509	0.022 - 0.138
Round	0.61	High	1.513 - 1.743	0.086 - 0.454	0.022 - 0.118
Rectangular	0.46	Very Low	0.841 - 0.857	0.090 - 0.739	0.025 - 0.256
Rectangular	0.46	Low	0.932 - 1.030	0.105 - 0.581	0.033 - 0.184
Rectangular	0.46	Middle	1.067 - 1.340	0.134 - 0.474	0.039 - 0.142
Rectangular	0.46	High	1.194 - 1.311	0.127 - 0.498	0.036 - 0.140
Rectangular	0.46	Very High	1.384 - 1.545	0.085 - 0.417	0.023 - 0.108
Rectangular	0.61	Very Low	1.013 - 1.199	0.090 - 0.657	0.025 - 0.208
Rectangular	0.61	Low	1.116 - 1.321	0.107 - 0.481	0.030 - 0.138
Rectangular	0.61	Middle	1.373 - 1.437	0.079 - 0.521	0.021 - 0.142
Rectangular	0.61	High	1.481 - 1.641	0.083 - 0.471	0.022 - 0.123

Evaluation of Flow Computed from Different Calibration Sources

Coefficient of discharge (C_d) values were computed for each net gate opening under each scenario in Table 1. Relationships between various testing parameters and the C_d will be discussed. The uncertainty of the new C_d values as well as the original Armco tables were evaluated by examining the percent error between the actual flow rate measured and that determined using the new rating or Armco table values. Percent error is computed as:

$$E_{Qi} = \frac{Q_i - Q}{Q} \times 100 \tag{11}$$

Where E_{Qi} is the percent error between the estimated flow (Q_i) and the actual flow (Q). The estimated flow (Q_i) was based on the Armco Rating Table (Q_{Armco}) for the round gates and the C_d from the USBR Flow Measurement Manual for the rectangular gates (Q_{Rect}). The $Q_{improved}$ was computed from the new C_d values developed from this work. The instantaneous flow measurement relative expanded uncertainty (95% confidence level) was developed based on multiple independent tests with the same gate at each gate opening for the existing Armco tables and the flow rate using C_d values from this study. Standard uncertainty of the meter gate (U_Q) was computed as the standard deviation of the error (Q_i-Q) at each gate opening. A coverage factor of k = 2 (i.e., ±2 standard deviations) was applied for the expanded uncertainty to the 95% confidence level (U_{Q_95}) as:

$$U_{Q\_95} = 2U \tag{12}$$

The relative expanded uncertainty (RU_{95}) was computed as:

$$\mathrm{RU}_{95} = \frac{U_{Q\_95}}{Q_{mean}} \tag{13}$$

Where Q_{mean} is the mean flow rate for the tests for that gate opening. More discussion on the methods used can be found in a number of references (Taylor and Kuyatt 1994; USBR 1997; Lozano et al. 2009).

Values from hardcopy Armco tables (Armco Steel Corporation 1975) provided by Fresno Valves and Casting, Inc. were entered into a spreadsheet. Q_{Armco} was determined for each net gate opening and ΔH by linear interpolation between the two closest ΔH values for each net gate opening.

The USBR Flow Measurement Manual contains a graph showing the recommended C_d value (based on the full pipe area) for rectangular gates. This C_d value was used to compute the flow rate (Q_{rect}) to compare with the actual flow. This will also be compared to the new C_d values obtained from this work.

RESULTS AND DISCUSSION

One of the primary reasons for testing the same gates under a variety of conditions, even those outside of the ranges shown in the Armco Flow Measurement Tables, is to examine the limitations for the accurate use of meter gates. Potential relationships exist between ΔH, H_1, Reynolds number in the turnout pipe (Re_{pipe}), fraction of net gate opening (A_o/A_p) and supply channel Froude number (F_1).

Correlation between C_d and Testing Variables

The C_d computed for all scenarios is shown in Figure 6 for each of the three Armco-type gate sizes examined related to gate opening area. All gate sizes show variability in C_d values at the low gate openings. This was also found by Summers (1951) with round gates, and others have reported greater uncertainty at smaller gate openings with rectangular orifice experiments (Lozano et al. 2009).

Figure 6a (0.30 m gate) also shows significant variability in C_d values at different fractions of gate opening areas. This variability can be attributed to the Low and Very Low upstream head (H_1) conditions where the upstream head was less than 0.5 times the pipe diameter. However, the 0.46 m and 0.61 m gates performed well for upstream heads as low as 0.5 times the pipe diameter. The "Tests Not Excluded" in Figure 6a, b, and c represent C_d values without upstream head values below 0.5 times the pipe diameter above the top of the pipe for the 0.30 m gate and gate openings below 20% for all gates. Additionally, several of the C_d values in Figure 6a (0.30 m gate) at gates openings of 30% not associated with Very Low upstream head were above 1.0. While this is theoretically not possible since there must be energy loss, there are several possible reasons for the inconsistency. Gate leakage is one possibility since the leakage would be a higher percentage of the total flow at the lower gate opening. Measurement error is another possibility. Finally, it should be noted that Eq. 2 and 3 assume hydrostatic conditions at the upstream and downstream measurement locations. However, these conditions may not necessarily be assumed at the 0.305 m pressure tap location, specifically at the lower gate opening when the velocity in the vertical direction may be significant close to the gate. This will be investigated in future work. At this point measurement error will be assumed and the values above 1.0 have been removed from further analysis.

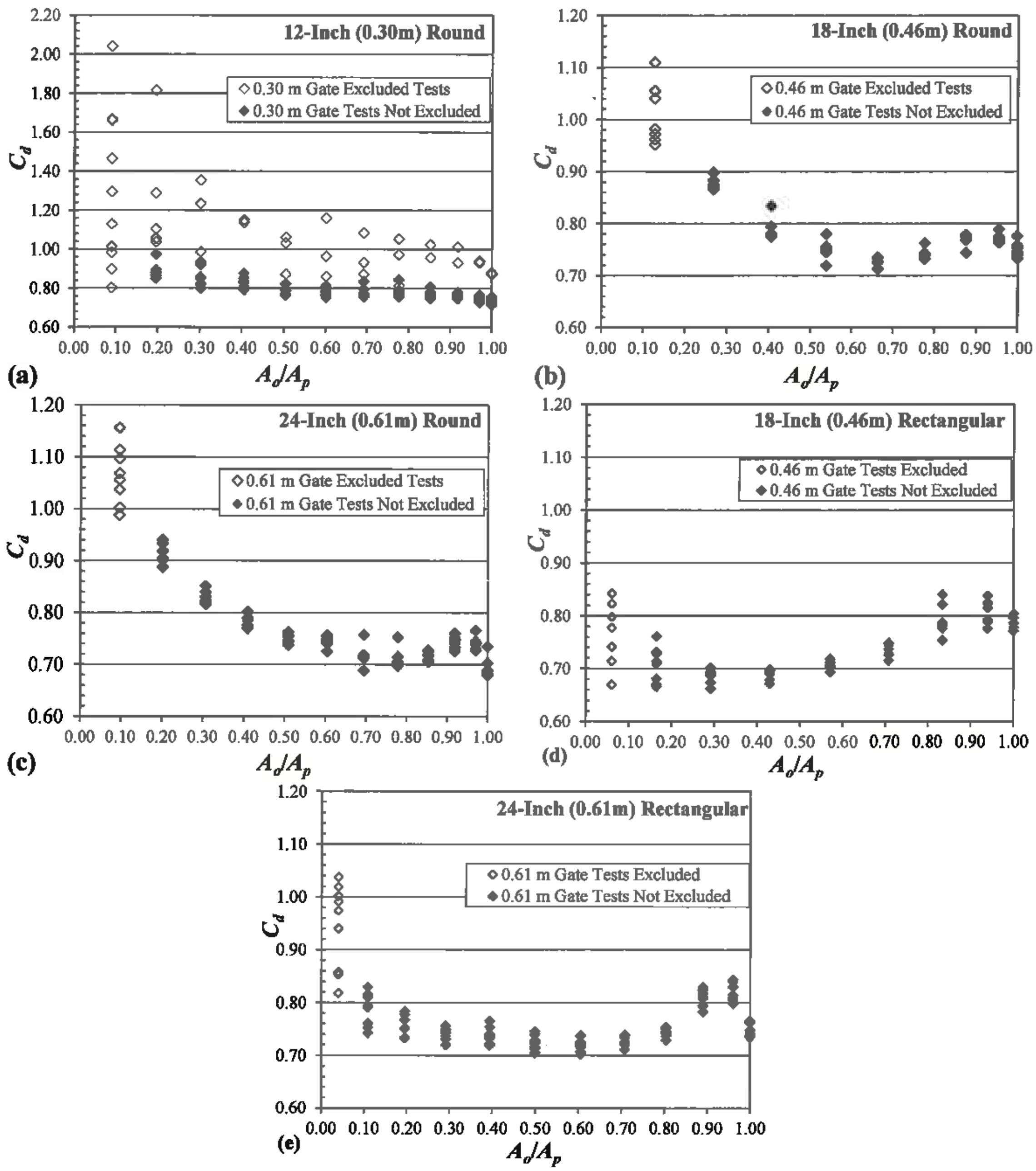

Figure 6. Coefficient of discharge (C_d) for the three round gates (a-c) and the two rectangular gates (d-e) for the low supply channel velocity testing with the downstream head measurement taken 12-inches (0.305 m) downstream of the face of the gate.

Multiple regression analysis was examined on the non-excluded data relating A_o/A_p, H_1/D and $\Delta H/H_1$ supply channel Froude number (F_1) to C_d using the model:

$$\hat{C_d} = \beta_6\left(\frac{A_o}{A_p}\right)^3 + \beta_5\left(\frac{A_o}{A_p}\right)^2 + \beta_4\left(\frac{A_o}{A_p}\right) + \beta_3\left(\frac{H_1}{D}\right) + \beta_2\left(\frac{\Delta H}{H_1}\right) + \beta_1(F_1) + \beta_0 \qquad (14)$$

where, $\hat{C}_d$ is the predicted discharge coefficient, β_0 through β_6 are the regression coefficients, A_o/A_p is the relative gate opening, H_1/D is relative upstream head, $\Delta H/H_1$ is relative change headloss, and F_1 the supply channel Froude number. Residual analysis was used to confirm the assumptions (normality, homoscedasticity, and independence of the errors) required for the multiple regression. The multiple regression coefficients and corresponding P-values for each gate size tested are shown in Table 3.

Table 3. Multiple regression coefficients and corresponding P-values for each gate size tested

		0.30 m Round[a]		0.46 m Round[b]		0.61 m Round[c]		0.46 m Rectangular[d]		0.61 m Rectangular[e]	
Predictor	Coefficient	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
$(A_o/A_p)^3$	β_6	-1.324	0.000	-1.041	0.000	-0.589	0.001	-1.484	0.000	-0.299	0.049
$(A_o/A_p)^2$	β_5	2.745	0.000	2.555	0.000	1.536	0.000	3.014	0.000	0.881	0.002
(A_o/A_p)	β_4	-1.911	0.000	-2.031	0.000	-1.359	0.000	-1.733	0.000	-0.679	0.000
H_1/D	β_3	-0.001	0.686	-0.016	0.000	-0.022	0.000	-0.005	0.327	-0.002	0.817
$\Delta H/H_1$	β_2	0.023	0.008	0.003	0.721	0.007	0.306	0.006	0.657	-0.013	0.213
F_1	β_1	0.054	0.031	-0.086	0.022	-0.108	0.023	-0.047	0.255	-0.051	0.371
Constant	β_0	1.213	0.000	1.293	0.000	1.155	0.000	0.995	0.000	0.890	0.000

Note: P-values >0.01 indicate the variable does not influence C_d at an α-level = 0.01
[a] $R^2 = 76.7\%$
[b] $R^2 = 86.1\%$
[c] $R^2 = 77.9\%$
[d] $R^2 = 78.5\%$
[e] $R^2 = 36.4\%$

It can be concluded that A_o/A_p (for all gates) and H_1/D (for the two larger round gates) have some influence on C_d, while statistically, $\Delta H/H_1$ and F_1 do not affect C_d. at an α-level of 0.01. We do not recommend using this multiple regression to compute the C_d values because the H_1/D and A_o/A_p values that may be used could be outside of the values used in the multiple regression. Alternative recommendations for determining C_d values will be discussed.

Relative upstream head (H_1/D or upstream head above the pipe divided by the pipe diameter) did have some influence on C_d (Table 3) for the two larger round gates although the coefficients are low, indicating the influence is relatively small (2-3% when H_1/D is included using Eq. 12 compared to without). This is represented visually in Figure 6, which shows a relatively constant C_d for the same relative gate opening. As indicated in Figure 5, the lower gate openings generally had higher C_d values. Figure 7 shows that the upstream head above the top of the pipe (H_1) as low as 0.5 times the pipe diameter performed similar to higher heads at and above the recommended minimum head of 1 pipe diameter above the pipe. This indicates that it should be possible to obtain accurate flow measurement in situations where upstream head is less than the recommended 1 pipe diameter, but it should be greater than 0.5 times the pipe diameter.

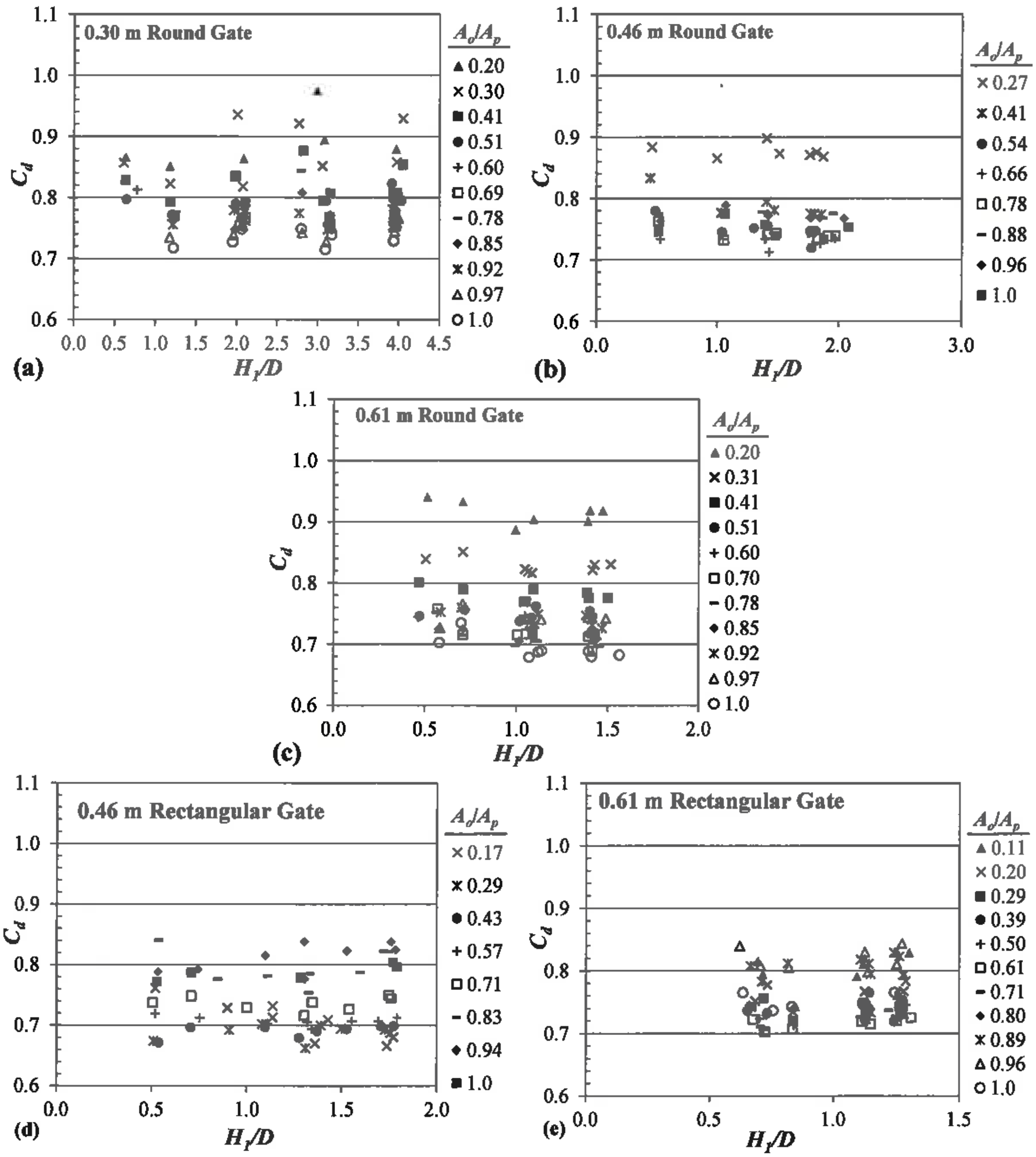

Figure 7. C_d related to the fraction of upstream head to turnout pipe diameter for the low supply channel velocity scenarios.

Figure 8 shows the relation between relative head loss ($\Delta H/H_1$) to C_d. From this data, there is no indication that discharge coefficient is negatively influenced by increased headloss. Therefore, the current recommendation of a maximum ΔH of 0.46 m (18 inches) can be exceeded at least with the gates tested in this study. For the 0.30 m gate (12-inch), 0.46 m gate (18-inch), and 0.61 m (24-inch) gate, maximum ΔH values of 0.86 m, 0.59 m, and 0.67 m were tested, respectively.

During testing ΔH values were attempted at $\Delta H/H_1$ greater than 0.75-0.8. However, at this point the downstream head in the stilling well would typically drop below the level of the pipe and readings could not be made at the 0.305 m stilling well (or the closer wells). In field applications, this issue would lead to improper measurements or an inability to take the downstream head measurement.

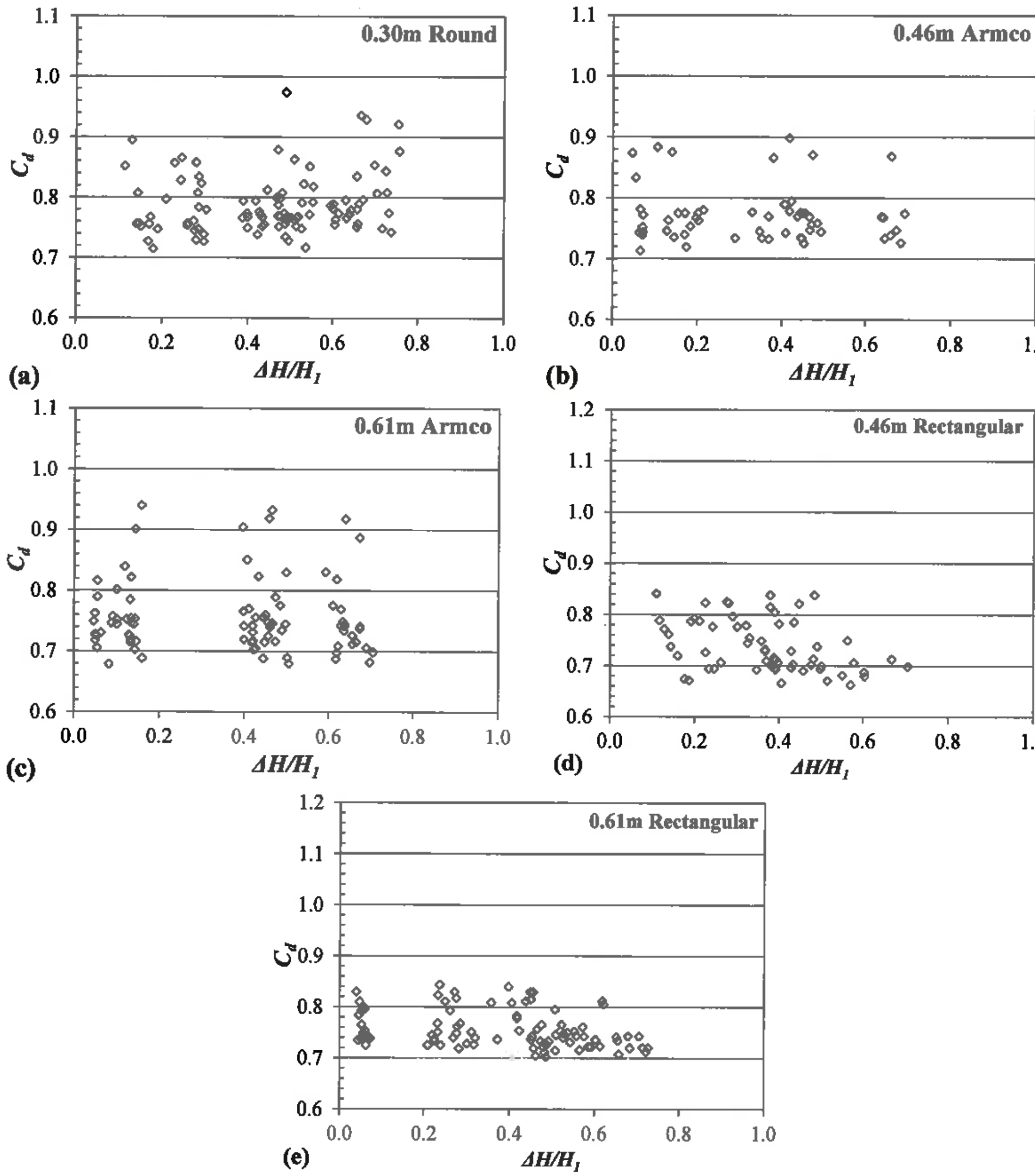

Figure 8. C_d related to the relative change in head ($\Delta H/H_1$) for all gates tested for the low supply channel velocity with the downstream head measured at the 0.30 m (12-inch) pressure tap location.

Figure 9 shows the relationship between Reynolds numbers in the corrugated pipe (Re_{pipe}) to C_d. The correlation between C_d values and Reynolds numbers can be attributed to the high correlation between C_d and relative gate openings (Figure 6). Therefore, this variable was not investigated independently (because it is not independent of gate opening). The data is shown only for general information.

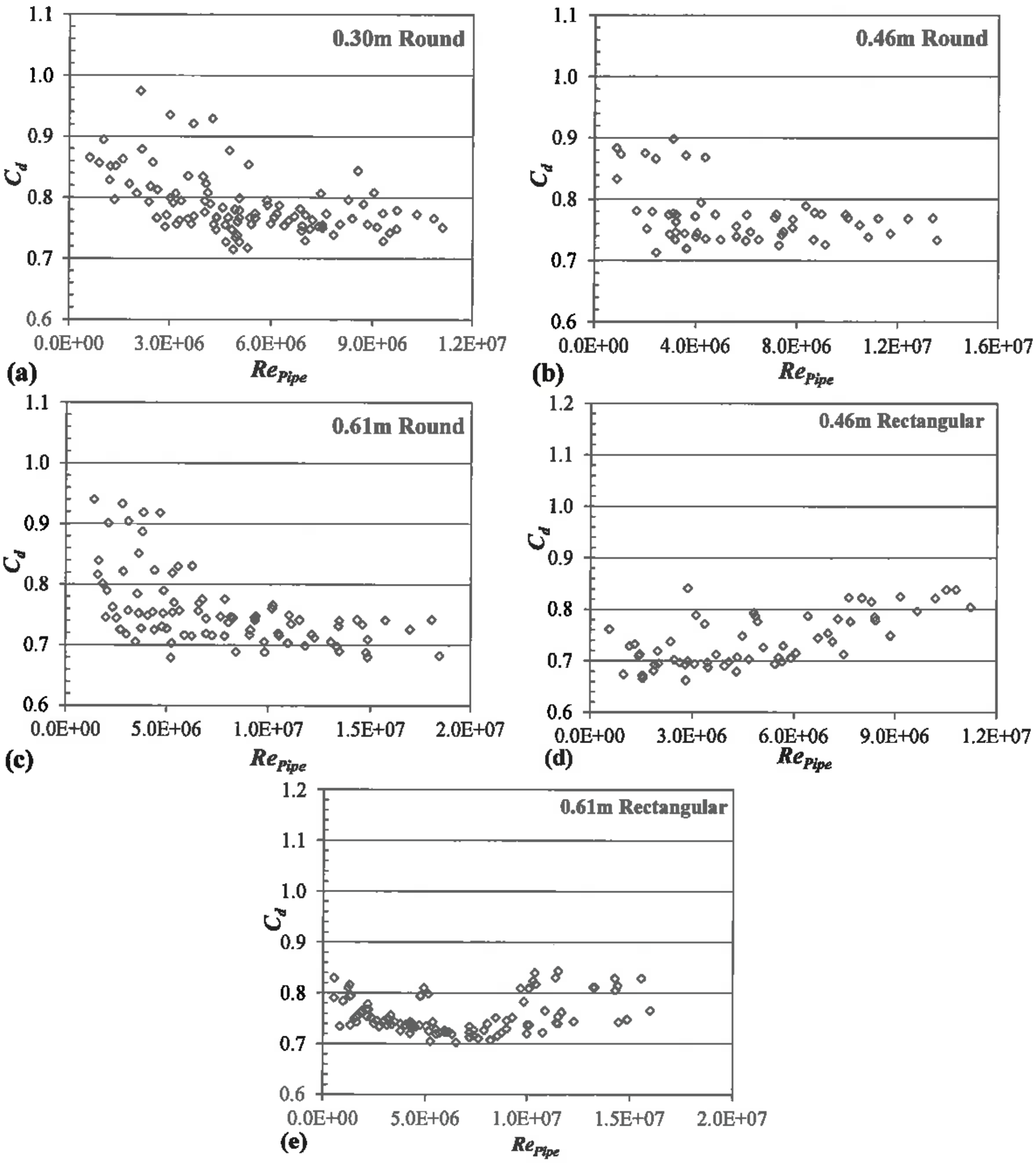

Figure 9. Relationship between C_d and Reynolds Number in the discharge pipe for the low velocity testing conditions and the downstream head measurement at the 0.305 m (12-inch) pressure tap location.

ITRC New Coefficient of Discharge (C_d) Values

The average C_d for each gate, and each gate opening fraction, was averaged to develop the final C_d recommended for using. Only the low supply channel velocity tests were used for the recommended Cd values. The higher supply channel velocities will be investigated in a subsequent section. Figure 10 and Table 4 contain the final recommended C_d values by fraction of gate opening (A_o/A_p).

Figure 10 shows the average C_d by fraction of gate opening area for each gate. Interestingly, the C_d values for the 0.46 m and 0.61 m gates are similar when open areas are less than 0.75 (75%). The C_d for the 0.30 m gate is consistently higher than the larger gates when the net open areas are less than 0.75 (75%). At net open areas greater than 0.75, the C_d values seem to consistently stay at approximately 0.75. For most of the gates there is a dip in C_d when the gate reaches full open (A_o/A_p = 1.0). This is likely due to hydraulic effects as water enters the pipe, with and without gate obstruction, influencing the pressure at the 0.305 m stilling well.

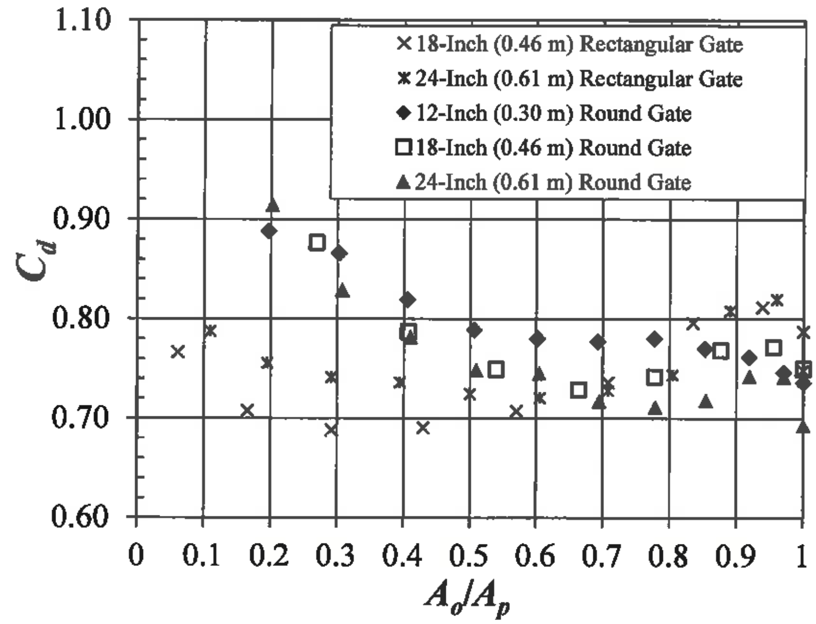

Figure 10. Average discharge coefficient by gate opening for the different gate sizes and types investigated based on the 0.305 m (12-inch) pressure tap location for downstream head measurements.

Table 4 shows C_d by actual gate opening (y) in meters and inches, fraction of gate opening (y/y_p) and fraction of opening area (A_o/A_p). Since it is common to have tables showing the net opening (as opposed to fraction of open area), this table presents information to help users implement this information. As previously mentioned, using a regression equation to "fit" the C_d by gate opening or fraction of open area (or any other variable) is NOT recommended. A more appropriate method would be to simply interpolate (linear interpolation) between the C_d values in Table 4.

Table 4. Recommended new C_d values from this study by net gate opening (y) and fraction of net opening area (A_o/A_p).

Gate Size	y (m)	y (inches)	y/y_o	A_o/A_p	*ITRC* C_d
0.30 m *12-inch Round*	0.051	2	0.167	0.197	0.958
	0.076	3	0.250	0.303	0.878
	0.102	4	0.333	0.406	0.819
	0.127	5	0.417	0.506	0.789
	0.152	6	0.500	0.602	0.780
	0.178	7	0.583	0.693	0.770
	0.203	8	0.667	0.777	0.780
	0.229	9	0.750	0.853	0.770
	0.254	10	0.833	0.919	0.762
	0.279	11	0.917	0.971	0.746
	0.305	12	1.000	1.000	0.736
0.46 m *18-inch Round*	0.102	4	0.222	0.269	0.876
	0.152	6	0.333	0.407	0.787
	0.203	8	0.444	0.540	0.749
	0.254	10	0.556	0.664	0.729
	0.305	12	0.667	0.778	0.742
	0.356	14	0.778	0.877	0.769
	0.406	16	0.889	0.956	0.772
	0.457	18	1.000	1.000	0.750
0.61 m *24-inch Round*	0.102	4	0.167	0.202	0.915
	0.152	6	0.250	0.307	0.829
	0.203	8	0.333	0.410	0.782
	0.254	10	0.417	0.510	0.749
	0.305	12	0.500	0.605	0.745
	0.356	14	0.583	0.695	0.717
	0.406	16	0.667	0.779	0.711
	0.457	18	0.750	0.854	0.718
	0.508	20	0.833	0.920	0.743
	0.559	22	0.917	0.971	0.741
	0.610	24	1.000	1.000	0.692
0.46 m *18-inch Rectangular*	0.102	4	0.222	0.165	0.708
	0.152	6	0.333	0.292	0.688
	0.203	8	0.444	0.429	0.690
	0.254	10	0.556	0.571	0.707
	0.305	12	0.667	0.708	0.736
	0.356	14	0.778	0.835	0.796
	0.406	16	0.889	0.939	0.812
	0.457	18	1.000	1.000	0.788
0.61 m *24-inch Rectangular*	0.102	4	0.167	0.110	0.788
	0.152	6	0.250	0.196	0.756
	0.203	8	0.333	0.292	0.741
	0.254	10	0.417	0.394	0.736
	0.305	12	0.500	0.500	0.725
	0.356	14	0.583	0.606	0.721
	0.406	16	0.667	0.708	0.728
	0.457	18	0.750	0.804	0.744
	0.508	20	0.833	0.890	0.808
	0.559	22	0.917	0.960	0.820
	0.610	24	1.000	1.000	0.748

Error Using Original Rating Tables or Charts

Of importance to meter gate users is the uncertainty (accuracy) of the existing rating tables (specifically the Armco Rating Table Booklet) and the C_d values computed in this study shown in Figure 10. Only the three most commonly used gates were investigated. There is a variety of other sizes from 0.20 m to 1.22 m that have rating tables. If good agreement exists between the 0.30 m, 0.46 m, and 0.61 m Armco tables then it might be inferred that similar agreement exists for the other size gates.

Figure 11 shows the average relative error at each gate opening with the relative expanded (95% confidence level) uncertainty shown bounding the relative error.

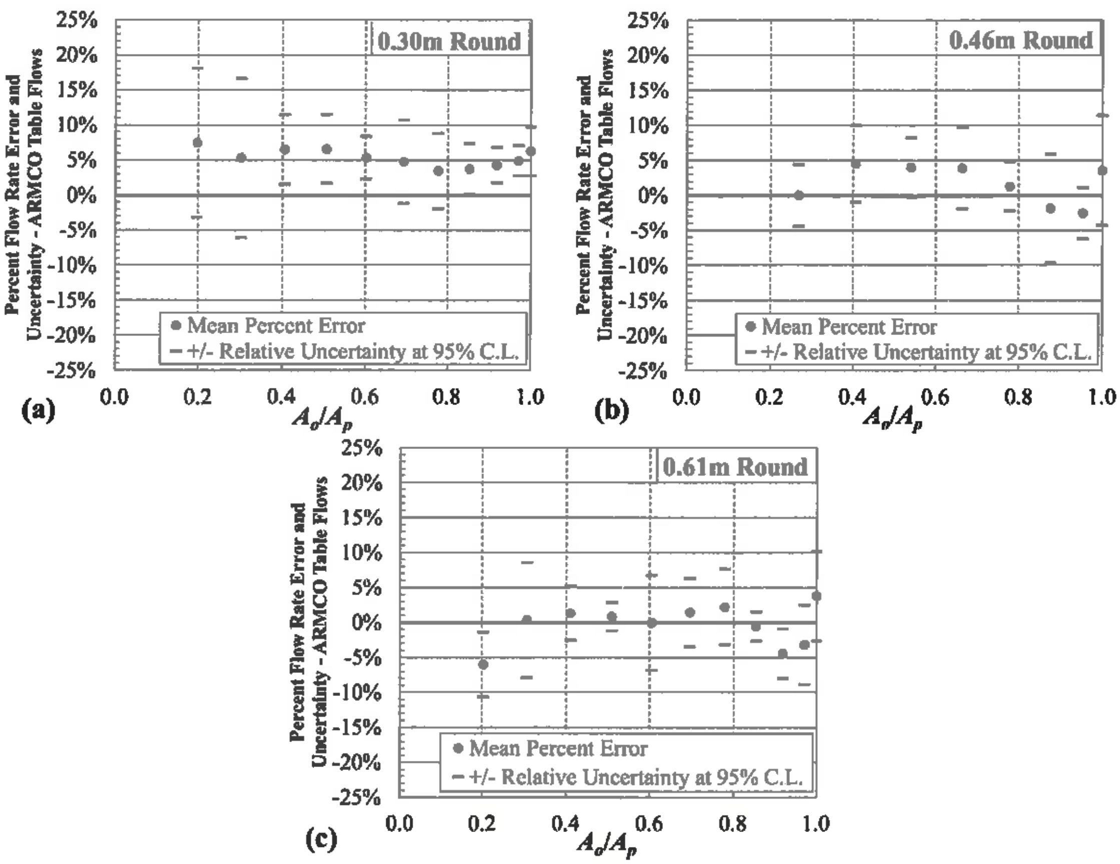

Figure 11. Comparison of percent error and uncertainty of discharge (Q) derived from the original Armco Meter Gate Rated Table to those measured in this study (low supply channel velocity tests).

As expected, the 0.30 m gate showed a high level of uncertainty at fractions of gate opening areas (A_o/A_p) of less than 40% (gate opening of 0.10 m or 4"). This high variability in C_d values shown in Figure 6 indicates that there was significant variability in the measurements at these low gate openings. At A_o/A_p of greater than 40% for the 0.30 m gate the average relative error was within 7%. The Armco flow tables tended to over-estimate the flow rate for the 0.30 m and 0.46 m gates. This could be caused by the gate arrangement perpendicular to the supply channel flow instead of straight on as they were for the original tests used for the Armco tables. The biased error combined with the expanded uncertainty for the 0.30 m gate exceeds +10% for A_o/A_i of 50% and lower. It should be noted that the actual relative errors for A_o/A_i at 41% and 51% did not exceed ± 10%.

Armco table flow uncertainties ranged from -9% to +10% for A_o/A_p greater than 0.25 for the 0.46 m and 0.61 m gates. This is a good indication that these original Armco tables have been providing and will continue to provide good accuracy if the net gate opening area fractions remain greater than 0.25 – 0.35 and less than 1.0 (100% open). In most applications this is the case. No evaluation of other round meter gate tables has been conducted.

Figure 12 shows the percent discharge measurement error and expanded uncertainty from rectangular gates if the discharged was computed based the discharge coefficients from *Figure 9-10* in the USBR Water Measurement Manual (USBR, 1997). For these figures, the downstream head for the ΔH in Eq. 2 was taken at D/3 (1/3rd of the pipe diameter downstream from the face of the gate) as recommended in the manual. There is significant error using the USBR Water Measurement Manual (WMM) C_d for rectangular gates. While the 18-inch (0.46 m) gate was better than the 24-inch (0.61 m) gate, we still do not recommend using the USBR (1997) C_d values.

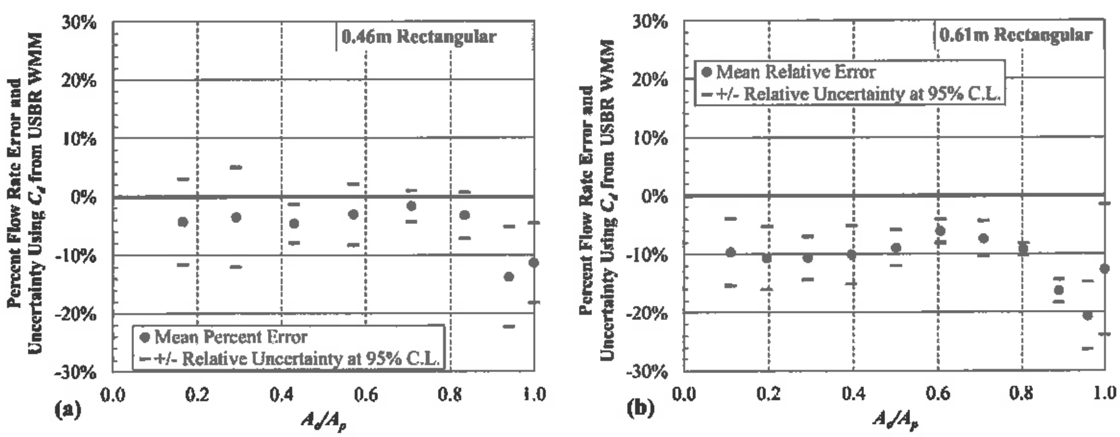

Figure 12. Rectangular gate percent error and uncertainty from using C_d values based on the USBR Water Measurement Manual Figure 9-10 to compute discharge compared to the actual flow measured in this study (low supply channel velocity tests)

The percent error is significantly reduced with the C_d values developed in this study (Table 4). This is to be expected since these C_d values were developed from this dataset. Of greater importance is the relative uncertainty, which remains within approximately ±7% for A_o/A_p above 0.4 for the 0.30 m gate and typically within a ±5% for A_o/A_p above 0.2 for other gates. It is recommended that users utilize the new C_d values developed in this study for the gates tested. For gates that have not been tested by ITRC, users should utilize the original Armco tables for all round gates on round pipes. For rectangular gates on round pipes, if gate sizes have not been tested by ITRC, onsite calibration or alternative flow measurement may be needed.

Downstream Pressure Tap Location Influence

Some impact of downstream pressure tap placement will be discussed since improper placement of the tap relative to the face of the gate is a common occurrence. Figure 5 shows the downstream pressure tap locations that were investigated. It is common for pressure taps to be placed closer than the recommended 0.305 m location. Figure 13 shows the C_d computed based on the 0.15 m (6 inches) and 0.20 m (8 inches) locations compared to the C_d computed from the recommended 0.30 m (12 inches) pressure tap location from Figure 10 for the five gates. It is interesting that for the 0.46 m and 0.61 m gates (both types) the C_d values are similar for relative fractions of net gate openings less than 0.75. For the 0.46 m and 0.61 m gates, improper placement should not cause a significant error unless gates are open more than 75%.

In contrast, the C_d values vary significantly for A_o/A_p greater than 0.4 for the 12-inch (0.30 m) round gate. The significantly lower C_d values are a result of greater ΔH measured at the 0.15 m and 0.2 m wells. If a rating table based on the 0.305 m stilling well location were used with a tap location at 0.15 m or 0.2 m, the resulting flow rate would be overestimated. This indicates that if C_d values or Armco tables are used for the 0.30 m gate, the pressure tap location should be moved or a correction factor should be applied to correct for the difference. For the 12-inch (0.30 m) round gate ONLY; if stilling wells are located closer than 0.2 m to the face of the gate, the flow rates from tables should be multiplied by a correction factor (F_{tap}) of 0.95 for gates openings less than or equal to 0.13 m (5 inches), by F_{tap} = 0.89 for gate openings between 0.13 m and 0.23 m (9 inches), and F_{tap} = 0.86 for gate openings greater than 0.23 m (although openings more than 75% are not recommended).

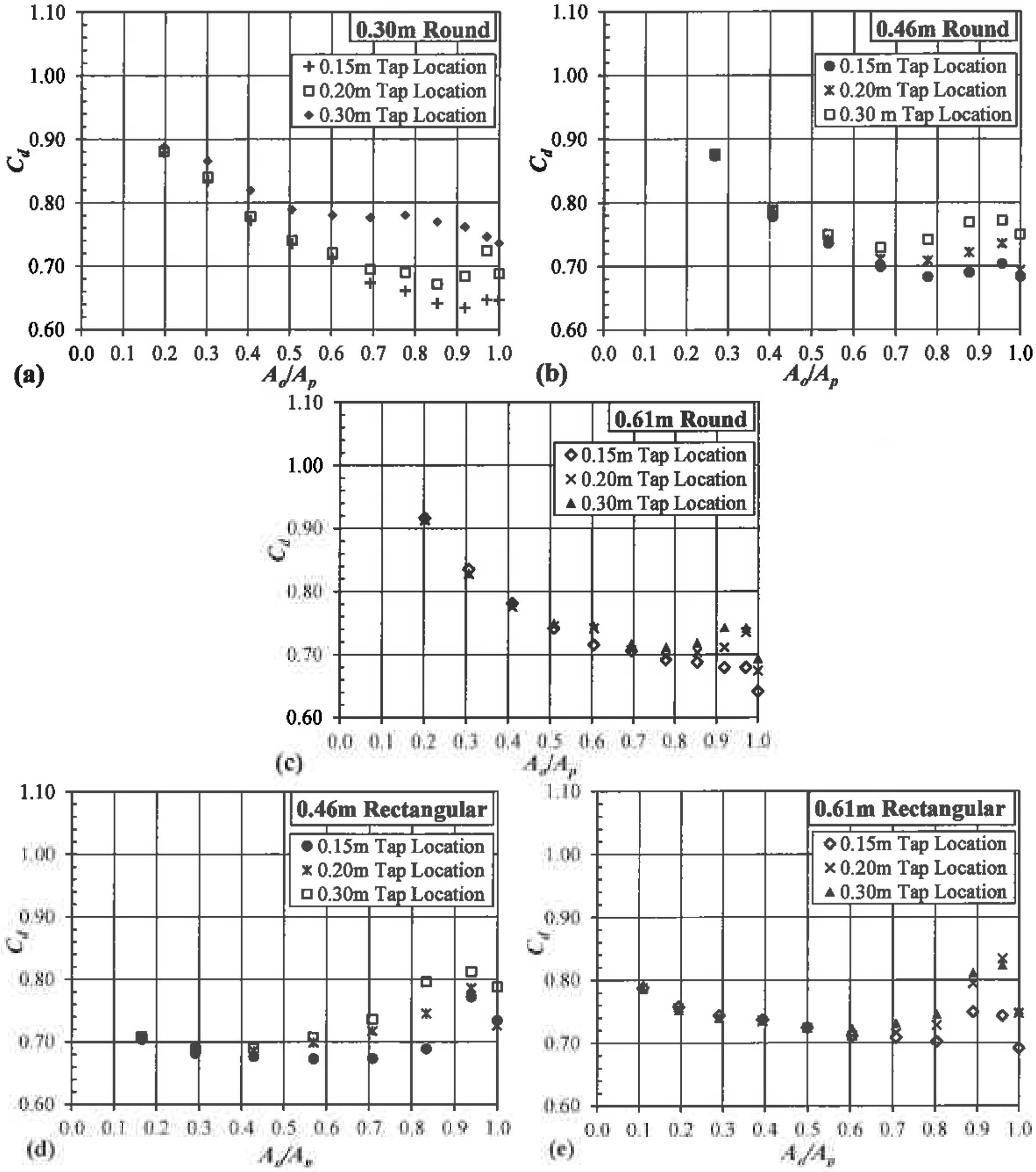

Figure 13. Influence of pressure tap location (6-inches (0.15 m) and 8 inches (0.20 m) downstream from the back face of the gate) on C_d, compared to the C_d computed using the standard 12 inches (0.30 m) pressure tap location.

Supply Channel Velocity Influence

Results from the multiple regression analysis indicated that supply channel Froude number did not seem have a significant influence on meter gate flow for the velocities tested (Table 3). To investigate how these additional tests and variable supply channel velocities influenced the uncertainty, the additional tests at the higher channel velocities were combined with the original low channel velocity tests shown previously.

The percent error was computed by comparing the computed flow through the meter gate using C_d values from Figure 10 to the measured flow through the meter gates with different supply channel velocities. Figure 14 (a-e) shows the results of this evaluation. The uncertainty is similar to those for recommended meter gate operation (within a ±5% with gate openings typically between 25% and 75%). However, the uncertainty increased for the 0.46 m and 0.61 m round and rectangular gates at gate openings above 75%. In general the relative error also increased slightly at these gate openings, indicating that the recommended C_d values resulted in a slight overestimation of the flow rate (0-2%). Although, overall, the higher supply channel velocity did not have a significant influence, at larger gate openings (above 75%) there may be greater impacts. This could be a result of increased variability in measurements due to hydraulics at the entrance of the pipe (which is why it is recommended to design meter gates to operate between 25% and 75% open).

Overall, we do not believe that any adjustments or corrections are needed based on supply channel velocity (up to say 3 ft/s).

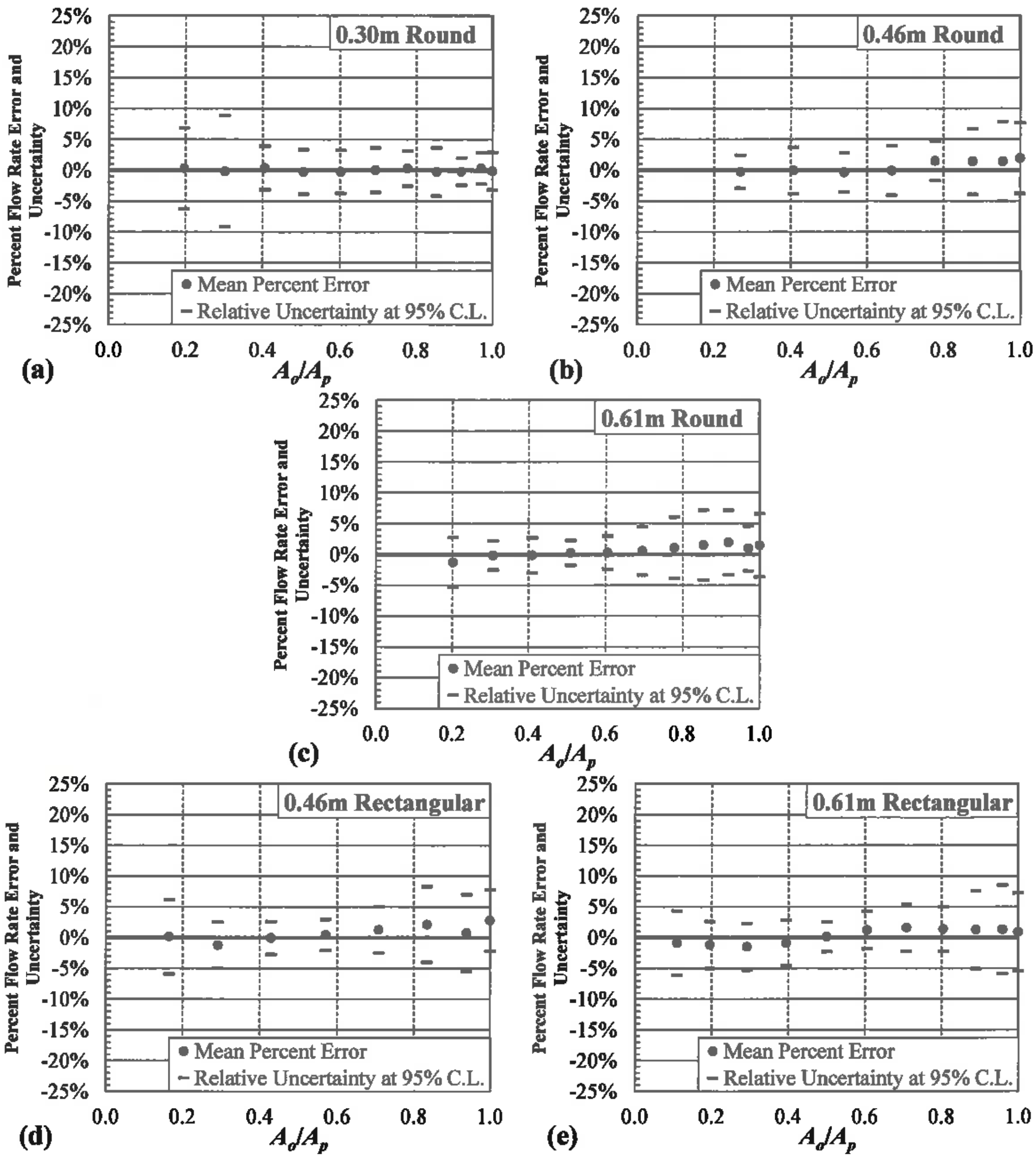

Figure 14. Percent flow rate error and uncertainty using C_d values from the low channel velocity tests for all supply channel velocities.

CONCLUSION

The meter gate can be an accurate flow measurement device if installed and operated correctly. If the recommendations in the *Recommendations* section and *Attachment B* are followed, users of improved rating tables (*Attachment C*) for the 0.30 m (12-inch), 0.46 m (18-inch), and 0.61 m (24-inch) gates can expect the relative uncertainty (U_{Q_new}) to be better than ±5 to ±7% at the 95% confidence level. For other gate sizes the continued use of the Armco Flow Measurement Tables (Armco Steel Corporation 1975) is recommended with an uncertainty (U_{Q_Armco}) of better than ±10% at a 95% confidence level if recommendations are followed. Uncertainties are lower than the required 10.7% instantaneous flow rate uncertainty required for SBx7-7.

The uncertainty is significantly less using the C_d values from this study compared to the original Armco tables. Therefore, new rating tables from C_d values developed in this study will be provided to users in digital format by the Irrigation Training and Research Center at California Polytechnic State University, San Luis Obispo (www.itrc.org). Until the remaining gates can be tested and improved C_d values developed, Armco Flow Measurement Tables will be made available in digital format, and will be replaced as gates are tested in the future and new tables are developed.

Future evaluations are necessary to develop C_d values and expanded tables for other Armco-type gates and gate sizes. Since the Waterman C-10 and XCAD X-Gate have very similar designs as the Fresno Valves and Casting, Inc. 101C gate, it is anticipated that the same rating tables can be used for these gates as well. Additional work is needed to confirm this. The Cal Poly ITRC meter gate testing facility is currently capable of testing gates up to 0.762 m (30 inches) in size.

Additionally, research is needed to investigate other uncertainties used to develop the overall volumetric uncertainty. Namely, the change in backpressure or downstream water level variations (U_{Hd}) and potential uncertainty related to durations (U_T) should be examined.

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ATTACHMENT A
Photos of Meter Gate Testing Facility Construction

Attachment A

Photos of Meter Gate Testing Facility Construction

Modifications were made to the Cal Poly Water Resources Facility Irrigation Training and Research Facility flume to test and calibrate the meter gates with perpendicular side flow. The facilities include:

- A new pipeline connection from the upstream reservoir to increase the inlet capacity (Figure A-1)
- A drain connection box to the drain pipe that returns the flow to the recirculation facility so that water can be recirculated at high flow (Figure A-1).
- A main spill box where water flows out of the pipe downstream of the meter gate. Water levels in this box will be varied as part of the study so that we can test different downstream conditions (Figure A-2).
- One 24-inch pipeline and one 18-inch pipeline have been constructed and installed with calibrated magnetic meters between the main spill box and the drain connection box to provide accurate flow measurement readings for gate calibration (Figure A-2).
- Manifold connection from the two magmeter pipelines into a 30-inch steel pipe that connects to the drain pipe connection box (Figure A-2).

Figure A-1. Adding a 30" pipe to the head of the flume to increase the capacity into the flume (left)

Figure A-2. Construction of the drain pipe connection box (right). Students in BRAE 433 (Fall Quarter) helped design and construct the bottom concrete slab shown in the top photo.

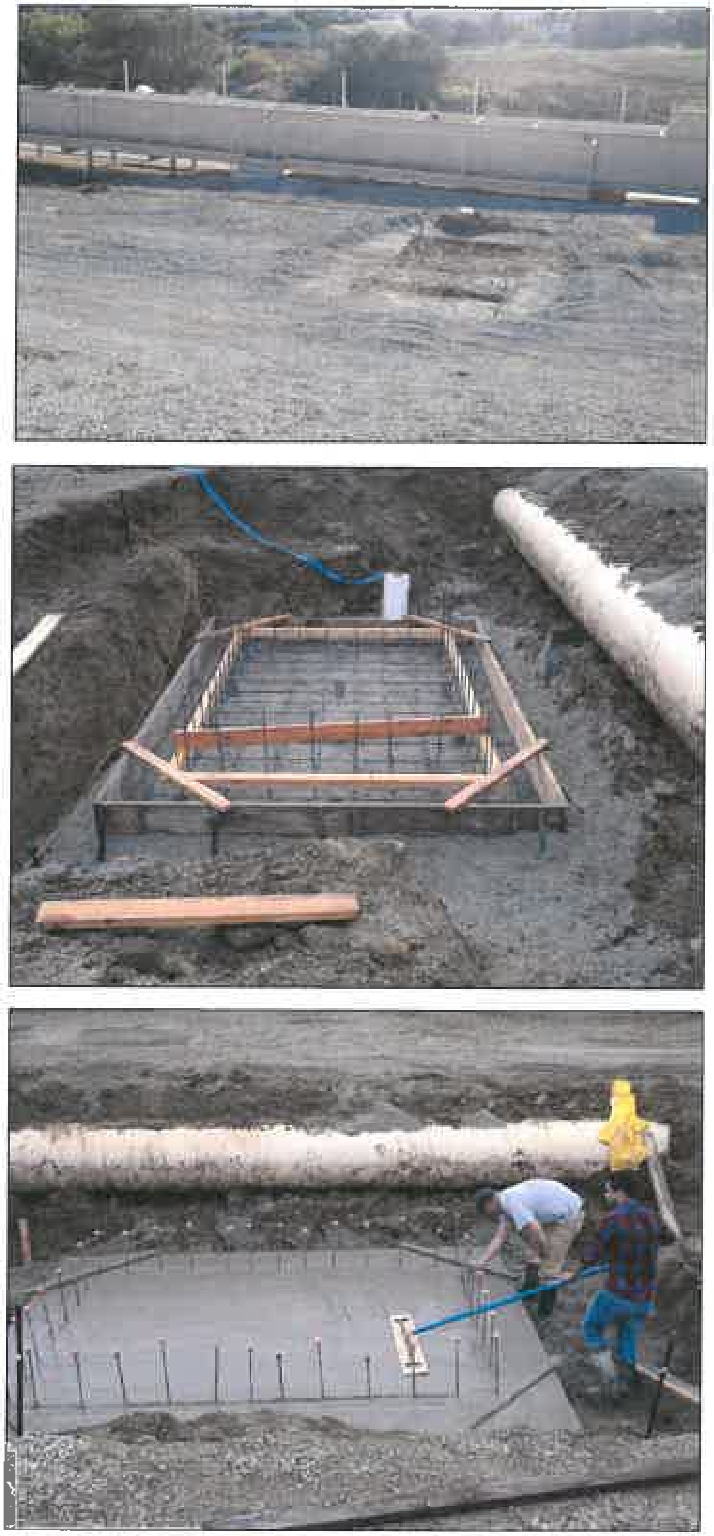

Figure A-3. Initial construction of main spill box that the meter gate pipeline drains into.

Figure A-4. Construction of the main spill box and 24" and 18" pipelines with magmeters

Figure A-5. Weir in flume to maintain the water level upstream of the gate. The photos show a longer weir than was actually used. Only the two bays on the downstream end were used in the actual testing.

Figure A-6. Completed testing setup after construction.

ATTACHMENT B
Practical Guide for Meter Gates

Attachment B

moving water in new directions

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Practical Guide for Meter Gates

by
Dr. Charles Burt and Dr. Daniel Howes
Rev June 30, 2015

Background

This document contains brief instructions on the use of special round canal gates called "meter gates" for flow measurement. A meter gate differs from a traditional canal gate turnout because it has a hole in the top of the pipe attached to a stilling well downstream of the gate so that the downstream water level can be measured.

Meter gates have been used since the early 1900's for flow measurement in addition to on-off control. Recent research conducted by the authors at the Irrigation Training and Research Center has shown that the existing tables for "Armco"-type meter gates, published after the 1950's, provide good accuracy for flow measurement (if measurements are made correctly).

Armco-type meter gates include round gates from Fresno Valve and Casting (101), Waterman (C-10), and X-CAD (model unknown) gates. In order to properly use these gates, a hole (5/8 to 3/4 inch in diameter) must be drilled in the pipe 12 inches downstream of the back face of the gate (or at the top of a corrugation as close to 12 inches as possible). This hole must be attached to a stilling well at least 6 inches in diameter that protrudes up to the elevation of the top of the gate frame.

Figure B-1 shows a common meter gate design drawing.

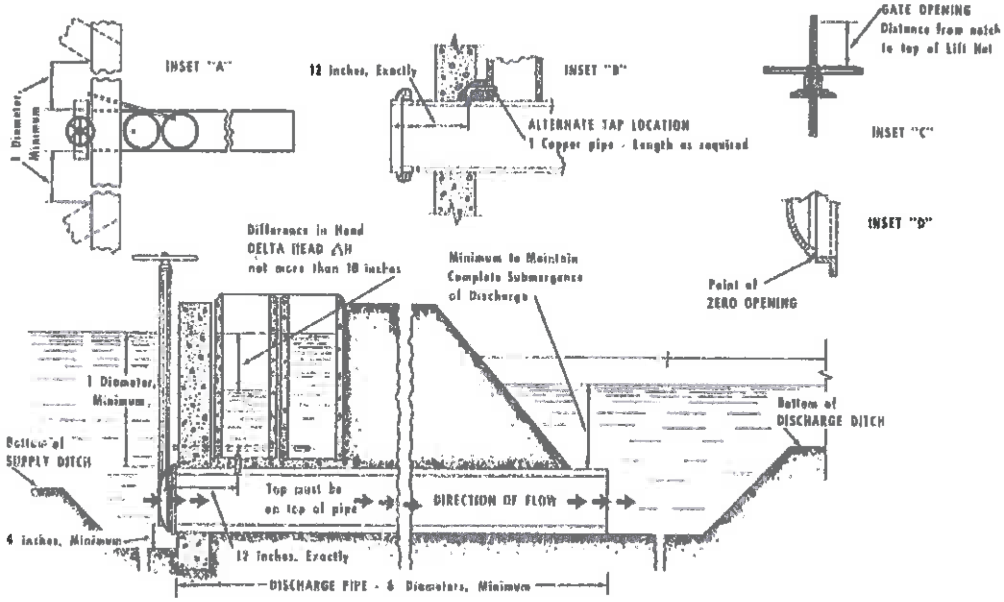

Figure B-1. Meter gate drawing used by various manufacturers, USBR, etc.

ITRC Research

ITRC evaluated the calibration of a variety of Armco-type round and square gates to determine if published "meter gate" calibration tables are accurate. These gates were installed at the ITRC gate calibration facility (**Figure B-2**). The gate calibration facility is set up so that the turnout gate is perpendicular to the main supply channel flow, which is typical in field installations.

Figure B-2. ITRC gate calibration facility

Summary of ITRC Research Results

1) A high level of accuracy (+/-5%) was found if all of the following conditions are met:
    a. Gate opening range: 20% < Gate Opening < 75%
    b. Upstream submergence > 0.5D (where D is the gate diameter)
    c. Stilling well location was 4" to 12" downstream of the face of the gate
2) The distance downstream of the gate at which the stilling well is located (as long as it is within the 4" to 12" range) does not have a significant effect on the flow rate obtained using the tables **unless** the gate is **open** more than 70-75% (percent of fully open).

3) The preliminary evaluation of tangential supply channel flow velocity did not seem to have a significant impact on the flow through the turnout gates. Supply channel velocities up to 1.9 feet per second (fps) were examined in this evaluation.
4) Higher uncertainty (error) occurred at smaller gate openings.
5) Optimum range of operation for the highest accuracy was an opening between 20% and 75% under most conditions. Smaller gate openings seemed to be more problematic than larger gate openings.
6) One issue that is not discussed here but was apparent was the submergence (water level) in the supply canal above the turnout pipeline. Care should be taken to ensure that the water level upstream of the top of the turnout pipe remains above (0.5 × gate diameter). The USBR standard is (1 × gate diameter).

Correction for Stilling Well 4" from Gate

Standard flow tables are based on a stilling well located 12" downstream of the back of the gate. Stilling well measurements were made at multiple locations downstream of the gate to analyze the effects of stilling well location. It was found that, at gate openings less than 70% open, there was **minimal** impact on the change in head from any stilling well closer than 12" to the gate. Once the gate reached an opening of 70% or greater, the ΔH measurement measured at the closer stilling wells (e.g., at 4") began to vary depending on gate size resulting in more significant error.

On average, at gate openings above 75%, the flow rate for a 4" stilling well was 8%-10% greater than the value shown on a 12" stilling well-based table. This adjustment could be applied in the case where gates must be opened more than 75%.

Practical Details

Figure B-3 shows one recommended configuration for a meter gate. There are some significant differences between **Figures B-1** and **B-3**. With meter gates, "the devil is in the details". These are discussed on the next few pages.

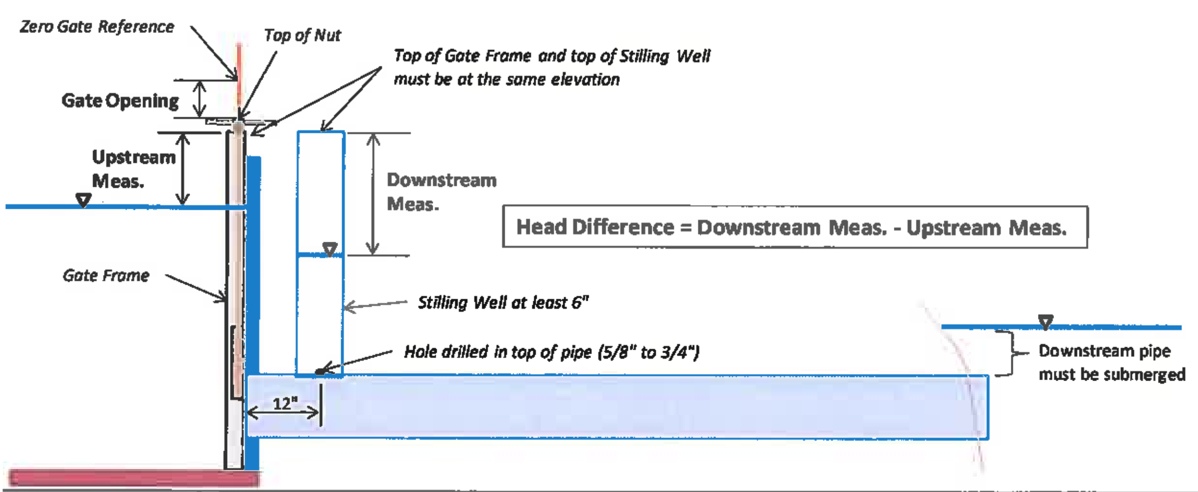

Figure B-3. ITRC recommendation for proper meter gate installation. These have been improved by Glenn Colusa ID with pre-cast concrete structures.

Practical Detail #1 – The pipe downstream of the meter gate needs to be full. The water level needs to rise to some measurable level in the downstream stilling well.

Practical Detail #2 – Sufficient upstream submergence is needed. The required water level in the canal, above the top of the pipe, must be at least ½ of the gate (or pipe) diameter. In other words, if there is a 12" pipe, the water level in the supply canal needs to be at least 6" above the top of the pipe.

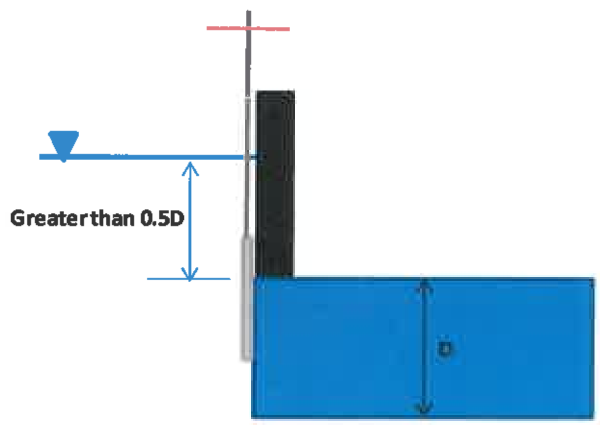

Figure B-4. Recommended upstream submergence above the gate to ensure accurate flow measurement

Practical Detail #3 – All of the calibration charts require knowledge of the **gate opening**, as measured by the shaft opening. The "zero" gate opening must be properly determined and marked on the gate shaft. This is not a trivial detail. Specific points are:

1. All measurements of gate opening, as well as the initial marking, must be made after the gate stem has been lifted (opened). This is because there is some "slop" or movement between the shaft and the gate itself.
2. The gate stem will move up some distance before the gate plate itself reaches the bottom of the pipe. The charts depend on knowing the gate opening, not the movement from the gate seating position. The gate must be closed beyond the bottom of the pipe to seal off completely. That sealed position is not the "zero" position.
3. There must be some specific way to measure the shaft position when the bottom of the gate just barely clears the bottom of the pipe – in other words, when there is a "zero opening". This is fairly easy to set and measure if the canal is full. The gate is opened until a narrow strip of paper can be inserted into the crack. **Figure B-5** shows photos taken at San Luis Canal Company of a customized tool that is used to detect the actual gate opening, but a similar device can be used to detect the initial "cracking (zero) open" position..

Figure B-5. Special tool to detect actual gate opening.

4. The shaft needs to be marked in a clear manner so that operators know where the "zero" opening is for the gate when they open the gate. **Figure B-6** shows a properly cut notch. It has a sharp bottom edge that was cut with a grinding wheel so that the bottom of the cut is at the same elevation as the top of the bushing. Notice from the color on the shaft that the shaft can be lowered from this position to properly seat the gate.

   The operator will measure from the bottom of cut to the top of the bushing, when the gate is open, to determine the gate opening. This is always measured after an "uplift" action.

Practical Detail #4 – The stilling well needs to have sufficient diameter to dampen the turbulence, and so that operators can see into it. ITRC recommends a stilling well of 6" – 8" diameter, with an access hole of about 5/8" or 3/4" diameter.

Figure B-6. Proper cut in shaft to mark the "zero" opening

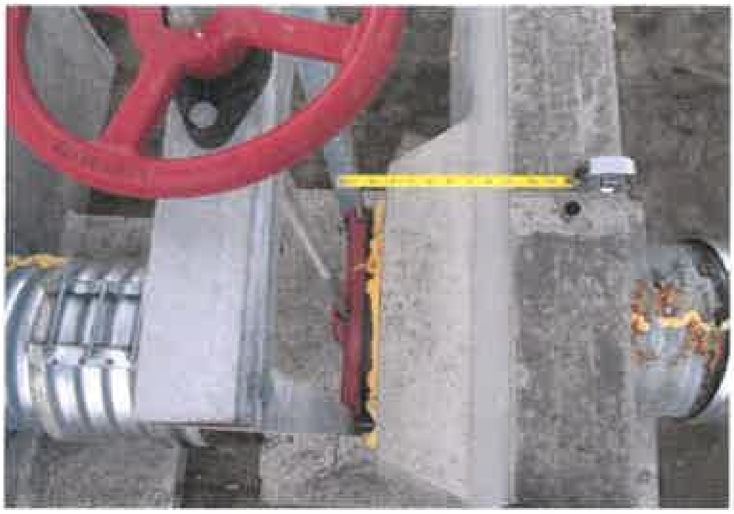

Figure B-7. Stilling well is located the correct distance downstream of the gate, but is so small that there will be tremendous surging (up/down movement), and operators cannot see the water surface

Practical Detail #5 – The stilling well does not need to be centered over the access hole in the top of the discharge pipe. In general, it is good to have the stilling well close to the gate frame/bulkhead, so that it can be supported.

Practical Detail #6 – Make it easy to measure the difference in head (between the water level in the canal, and the water level in the stilling well). In other words, use the same datum (elevation) for both measurements. **Figure B-8** shows a stilling well with the top correctly placed at the same elevation as the gate frame, and with a proper diameter. **The top of the stilling well should be at the same elevation as the top of the gate frame (where the bottom of the nut rests), or have the same elevation as another reference point.** Then the upstream measurement should be taken from the top of the gate frame to the water level. The downstream measurement should be taken from the top of the stilling well to the water level. The head difference is the difference between the upstream and downstream water levels.

Figure B-8. Stilling well installed on an existing discharge pipe. It is constructed of PVC pipe that is too thin for long life, but it serves as an example of the correct diameter, position, and height.

Figure B-9. An old type of dual-stilling well commonly found in Central California irrigation districts. One stilling well was connected to the canal, and the second was directly over the discharge pipe. The idea of measuring down into both stilling wells from the same center point was good, but the top of the stilling well was so close to the ground surface that road maintenance quickly filled these stilling wells with dirt. Also, the side connection between the canal stilling well and the canal itself was too difficult to clean.

Figure B-10. This stilling well is properly located, but it has too small a diameter. The operator also needs to know the elevation difference between the top of the stilling well and the gate frame, which requires an extra computation to determine the difference in head across the gate.

Figure B-11. Correct height of stilling well to match top of gate frame. However, the diameter is too small. Steel pipe material is good

Figure B-12. Large diameter stilling well, with cover to minimize having it fill with dirt from the road. Strong concrete, with the rim of the stilling well at the same elevation as the bulkhead top.

The tables on the next few pages show the key measurements needed to properly use a meter gate. The gate opening should be measured from the top of the gate opening nut to a zero gate opening reference. **As mentioned previously, the zero gate opening reference should be marked with a grinder at the gate opening nut on the shaft when the gate is just open enough to breach the bottom of the pipe.**

The Glenn-Colusa ID Configuration

Glenn-Colusa ID (GCID) worked with Briggs (a local pre-cast concrete structure company near Willows, CA) to incorporate the ITRC recommendations into a pre-cast structure. The following figures illustrate their solution, which appears to be excellent.

Figure B-13. GCID meter gate at Briggs

Figure B-14. Pre-cast metergate ready for transport

Figure B-15. Installation of GCID meter gate

Figure B-16. Final concrete for GCID meter gate, showing downstream pre-cast outlet box.

Table B-1. Approximate cost for GCID meter gate installation

18" X 6' H-Metergate with precast concrete tailbox

1). MATERIAL COST		QUANTITY			UNIT	COST/UNIT	COST
STILLING WELL 12" X 6' H W/ LID		1			EA	$340	$340
PRE/FAB 6' H BRIGG'S (metergate box)		1			EA	$470	$470
PLYWOOD					EA	$1	$0
SNAP TIES					YD	$1	$0
PIPE (18"PLASTIC)		25			Ft.	$11	$278
GATE 18" 5' FRAME		1			EA	$1,270	$1,270
CONCRETE		3			YD	$105	$315
METER BOX 5' H (tailbox)		1			EA	$550	$550
						TOTAL COST =	$3,223

2). LABOR COST		QUANTITY	HRS/JOB	COST/HR	UNIT	COST/UNIT	COST
						TOTAL COST =	$650

3). EQUIPMENT COST		QUANTITY	HRS/JOB	COST/HR*	UNIT	COST/UNIT	COST
BACKHOE				$25.00	P/H		$0
EXCAVATOR		1	$1.00	$50.00	P/H		$50
LONG REACH				$50.00	P/H		$0
TRUCK		1	$12.00	$25.00	P/H		$300
TRANSPORT		1	$1.00	$44.00	P/H		$44
CRANE				$50.00	P/H		$0
PICKUPS		1	$4.00	$5.50	P/H		$22
D-6 DOZER				$35.00	P/H		$0
D-4 DOZER				$25.00	P/H		$0
MISC.(WELDERS,PUMPS,GENERATORS)		1	$4.00	$8.00	P/H		$32
						TOTAL COST =	$448
						TOTAL HOURS =	**22**
						TOTAL =	**$4,321**

ATTACHMENT C
ITRC Water Measurement Tables

ITRC Water Measurement Tables for **ROUND (Armco-Type) Gates on Round Pipes**

Discharge Values in CFS

ITRC Water Measurement Tables – 12" Armco-Type Gate, Stilling Well Located 12" d/s of Back of Gate [Blue center represents best accuracy range]

ΔH	Net Gate Opening (feet)																
(feet)	0.042	0.08	0.13	0.17	0.21	0.25	0.29	0.33	0.38	0.42	0.46	0.50	0.58	0.67	0.75	0.83	0.92	1.00
0.08	0.07	0.16	0.25	0.34	0.42	0.48	0.55	0.61	0.67	0.73	0.79	0.85	0.97	1.10	1.20	1.27	1.32	1.34
0.10	0.08	0.18	0.28	0.38	0.47	0.54	0.61	0.68	0.75	0.81	0.89	0.96	1.09	1.23	1.34	1.42	1.47	1.50
0.13	0.09	0.20	0.31	0.42	0.51	0.59	0.67	0.74	0.82	0.89	0.97	1.05	1.19	1.35	1.46	1.56	1.61	1.64
0.15	0.09	0.21	0.33	0.45	0.55	0.64	0.72	0.80	0.88	0.96	1.05	1.13	1.28	1.46	1.58	1.68	1.74	1.77
0.17	0.10	0.23	0.36	0.49	0.59	0.68	0.77	0.86	0.94	1.03	1.12	1.21	1.37	1.56	1.69	1.80	1.86	1.89
0.19	0.10	0.24	0.38	0.52	0.63	0.72	0.82	0.91	1.00	1.09	1.19	1.28	1.46	1.66	1.79	1.91	1.98	2.01
0.21	0.11	0.25	0.40	0.54	0.66	0.76	0.87	0.96	1.06	1.15	1.25	1.35	1.53	1.74	1.89	2.01	2.08	2.12
0.23	0.12	0.26	0.42	0.57	0.69	0.80	0.91	1.00	1.11	1.20	1.31	1.42	1.61	1.83	1.98	2.11	2.19	2.22
0.25	0.12	0.28	0.44	0.60	0.72	0.84	0.95	1.05	1.16	1.26	1.37	1.48	1.68	1.91	2.07	2.21	2.28	2.32
0.27	0.13	0.29	0.45	0.62	0.75	0.87	0.99	1.09	1.20	1.31	1.43	1.54	1.75	1.99	2.16	2.30	2.38	2.41
0.29	0.13	0.30	0.47	0.64	0.78	0.90	1.02	1.13	1.25	1.36	1.48	1.60	1.82	2.06	2.24	2.38	2.47	2.50
0.31	0.14	0.31	0.49	0.67	0.81	0.94	1.06	1.17	1.29	1.41	1.53	1.66	1.88	2.14	2.32	2.47	2.55	2.59
0.33	0.14	0.32	0.50	0.69	0.84	0.97	1.09	1.21	1.34	1.45	1.58	1.71	1.94	2.21	2.39	2.55	2.64	2.68
0.35	0.14	0.33	0.52	0.71	0.86	1.00	1.13	1.25	1.38	1.50	1.63	1.76	2.00	2.27	2.46	2.63	2.72	2.76
0.38	0.15	0.34	0.53	0.73	0.89	1.03	1.16	1.28	1.42	1.54	1.68	1.81	2.06	2.34	2.54	2.70	2.80	2.84
0.40	0.15	0.35	0.55	0.75	0.91	1.05	1.19	1.32	1.46	1.58	1.73	1.86	2.12	2.40	2.61	2.78	2.87	2.92
0.42	0.16	0.36	0.56	0.77	0.93	1.08	1.22	1.35	1.49	1.62	1.77	1.91	2.17	2.47	2.67	2.85	2.95	2.99
0.46	0.16	0.37	0.59	0.81	0.98	1.13	1.28	1.42	1.57	1.70	1.86	2.00	2.28	2.59	2.80	2.99	3.09	3.14
0.50	0.17	0.39	0.62	0.84	1.02	1.18	1.34	1.48	1.64	1.78	1.94	2.09	2.38	2.70	2.93	3.12	3.23	3.28
0.54	0.18	0.41	0.64	0.88	1.06	1.23	1.40	1.54	1.70	1.85	2.02	2.18	2.47	2.81	3.05	3.25	3.36	3.41
0.58	0.19	0.42	0.66	0.91	1.10	1.28	1.45	1.60	1.77	1.92	2.10	2.26	2.57	2.92	3.16	3.37	3.49	3.54
0.63	0.19	0.44	0.69	0.94	1.14	1.32	1.50	1.66	1.83	1.99	2.17	2.34	2.66	3.02	3.27	3.49	3.61	3.67
0.67	0.20	0.45	0.71	0.97	1.18	1.37	1.55	1.71	1.89	2.06	2.24	2.42	2.75	3.12	3.38	3.60	3.73	3.79
0.71	0.20	0.46	0.73	1.00	1.22	1.41	1.60	1.76	1.95	2.12	2.31	2.49	2.83	3.22	3.49	3.71	3.84	3.90
0.75	0.21	0.48	0.75	1.03	1.25	1.45	1.64	1.82	2.00	2.18	2.38	2.56	2.91	3.31	3.59	3.82	3.96	4.02
0.79	0.22	0.49	0.77	1.06	1.29	1.49	1.69	1.87	2.06	2.24	2.44	2.63	2.99	3.40	3.68	3.93	4.06	4.13
0.83	0.22	0.50	0.79	1.09	1.32	1.53	1.73	1.91	2.11	2.30	2.50	2.70	3.07	3.49	3.78	4.03	4.17	4.23
0.92	0.23	0.53	0.83	1.14	1.39	1.60	1.82	2.01	2.22	2.41	2.63	2.83	3.22	3.66	3.97	4.22	4.37	4.44
1.00	0.24	0.55	0.87	1.19	1.45	1.67	1.90	2.10	2.31	2.52	2.74	2.96	3.36	3.82	4.14	4.41	4.57	4.64
1.08	0.25	0.57	0.91	1.24	1.51	1.74	1.97	2.18	2.41	2.62	2.86	3.08	3.50	3.98	4.31	4.59	4.75	4.83
1.17	0.26	0.60	0.94	1.29	1.56	1.81	2.05	2.26	2.50	2.72	2.96	3.20	3.63	4.13	4.47	4.77	4.93	5.01
1.25	0.27	0.62	0.97	1.33	1.62	1.87	2.12	2.34	2.59	2.81	3.07	3.31	3.76	4.27	4.63	4.93	5.11	5.19
1.33	0.28	0.64	1.00	1.37	1.67	1.93	2.19	2.42	2.67	2.91	3.17	3.42	3.88	4.41	4.78	5.09	5.27	5.36
1.42	0.29	0.66	1.04	1.42	1.72	1.99	2.26	2.50	2.75	3.00	3.27	3.52	4.00	4.55	4.93	5.25	5.44	5.52
1.50	0.30	0.68	1.07	1.46	1.77	2.05	2.32	2.57	2.83	3.08	3.36	3.63	4.12	4.68	5.07	5.40	5.59	5.68
1.58	0.30	0.69	1.09	1.50	1.82	2.11	2.39	2.64	2.91	3.17	3.45	3.73	4.23	4.81	5.21	5.55	5.75	5.84
1.67	0.31	0.71	1.12	1.54	1.87	2.16	2.45	2.71	2.99	3.25	3.54	3.82	4.34	4.93	5.35	5.70	5.90	5.99
1.75	0.32	0.73	1.15	1.57	1.91	2.21	2.51	2.77	3.06	3.33	3.63	3.92	4.45	5.06	5.48	5.84	6.04	6.14
1.83	0.33	0.75	1.18	1.61	1.96	2.27	2.57	2.84	3.13	3.41	3.71	4.01	4.55	5.18	5.61	5.97	6.18	6.28
1.92	0.34	0.76	1.20	1.65	2.00	2.32	2.63	2.90	3.20	3.48	3.80	4.10	4.66	5.29	5.73	6.11	6.32	6.42
2.00	0.34	0.78	1.23	1.68	2.05	2.37	2.68	2.96	3.27	3.56	3.88	4.19	4.76	5.41	5.86	6.24	6.46	6.56
2.08	0.35	0.80	1.26	1.72	2.09	2.42	2.74	3.03	3.34	3.63	3.96	4.27	4.85	5.52	5.98	6.37	6.59	6.69
2.17	0.36	0.81	1.28	1.75	2.13	2.46	2.79	3.09	3.41	3.70	4.04	4.36	4.95	5.63	6.10	6.49	6.72	6.83
2.25	0.36	0.83	1.31	1.79	2.17	2.51	2.84	3.14	3.47	3.78	4.11	4.44	5.04	5.73	6.21	6.62	6.85	6.96
2.33	0.37	0.84	1.33	1.82	2.21	2.56	2.90	3.20	3.53	3.84	4.19	4.52	5.14	5.84	6.33	6.74	6.98	7.09
2.42	0.38	0.86	1.35	1.85	2.25	2.60	2.95	3.26	3.60	3.91	4.26	4.60	5.23	5.94	6.44	6.86	7.10	7.21
2.50	0.38	0.87	1.38	1.88	2.29	2.65	3.00	3.31	3.66	3.98	4.34	4.68	5.32	6.04	6.55	6.98	7.22	7.33
2.58	0.39	0.89	1.40	1.91	2.33	2.69	3.05	3.37	3.72	4.05	4.41	4.76	5.40	6.14	6.66	7.09	7.34	7.45
2.67	0.40	0.90	1.42	1.94	2.36	2.73	3.10	3.42	3.78	4.11	4.48	4.84	5.49	6.24	6.76	7.20	7.46	7.57
2.75	0.40	0.91	1.44	1.97	2.40	2.78	3.15	3.48	3.84	4.17	4.55	4.91	5.58	6.34	6.87	7.32	7.57	7.69
2.83	0.41	0.93	1.46	2.00	2.44	2.82	3.19	3.53	3.89	4.24	4.62	4.98	5.66	6.43	6.97	7.43	7.69	7.81

ITRC Water Measurement Tables – 18" Armco-Type Gate, Stilling Well Located 12" d/s of Back of Gate [Blue center represents best accuracy range]

ΔH (feet)	Net Gate Opening (feet) 0.042	0.08	0.13	0.17	0.21	0.25	0.29	0.33	0.38	0.42	0.46	0.50	0.58	0.67	0.75	0.83	0.92	1.00	1.08	1.17	1.25	1.33	1.42	1.50
0.04	0.07	0.16	0.25	0.35	0.44	0.52	0.61	0.68	0.75	0.81	0.87	0.93	1.05	1.17	1.29	1.40	1.54	1.67	1.81	1.95	2.05	2.14	2.17	2.17
0.06	0.08	0.20	0.31	0.43	0.54	0.64	0.74	0.84	0.92	1.00	1.07	1.14	1.29	1.43	1.58	1.72	1.88	2.05	2.22	2.39	2.51	2.62	2.66	2.66
0.08	0.10	0.23	0.36	0.50	0.62	0.74	0.86	0.96	1.06	1.15	1.24	1.31	1.49	1.65	1.82	1.98	2.18	2.36	2.57	2.76	2.90	3.02	3.07	3.07
0.10	0.11	0.25	0.40	0.56	0.70	0.83	0.96	1.08	1.19	1.29	1.38	1.47	1.67	1.85	2.04	2.22	2.43	2.64	2.87	3.09	3.24	3.38	3.43	3.43
0.13	0.12	0.28	0.44	0.61	0.76	0.91	1.05	1.18	1.30	1.41	1.51	1.61	1.83	2.03	2.23	2.43	2.66	2.89	3.14	3.38	3.55	3.70	3.76	3.76
0.15	0.13	0.30	0.48	0.66	0.82	0.98	1.13	1.28	1.40	1.52	1.63	1.73	1.97	2.19	2.41	2.62	2.88	3.12	3.39	3.65	3.84	4.00	4.06	4.06
0.17	0.14	0.32	0.51	0.70	0.88	1.05	1.21	1.36	1.50	1.63	1.75	1.85	2.11	2.34	2.58	2.80	3.08	3.34	3.63	3.90	4.10	4.27	4.34	4.34
0.19	0.15	0.34	0.54	0.75	0.93	1.11	1.28	1.45	1.59	1.73	1.85	1.97	2.24	2.48	2.74	2.97	3.26	3.54	3.85	4.14	4.35	4.53	4.60	4.61
0.21	0.15	0.36	0.57	0.79	0.98	1.17	1.35	1.52	1.68	1.82	1.95	2.07	2.36	2.62	2.88	3.13	3.44	3.74	4.06	4.36	4.58	4.78	4.85	4.85
0.23	0.16	0.37	0.60	0.82	1.03	1.23	1.42	1.60	1.76	1.91	2.05	2.17	2.47	2.74	3.02	3.29	3.61	3.92	4.25	4.58	4.81	5.01	5.08	5.09
0.25	0.17	0.39	0.62	0.86	1.08	1.28	1.48	1.67	1.84	2.00	2.14	2.27	2.58	2.87	3.16	3.43	3.77	4.09	4.44	4.78	5.02	5.23	5.31	5.32
0.27	0.17	0.41	0.65	0.90	1.12	1.34	1.54	1.74	1.91	2.08	2.23	2.36	2.69	2.98	3.29	3.57	3.92	4.26	4.62	4.98	5.23	5.44	5.53	5.54
0.29	0.18	0.42	0.67	0.93	1.16	1.39	1.60	1.80	1.99	2.16	2.31	2.45	2.79	3.10	3.41	3.71	4.07	4.42	4.80	5.16	5.42	5.65	5.74	5.74
0.31	0.19	0.44	0.70	0.96	1.20	1.44	1.66	1.87	2.06	2.23	2.39	2.54	2.89	3.20	3.53	3.84	4.21	4.57	4.97	5.35	5.62	5.85	5.94	5.95
0.33	0.19	0.45	0.72	0.99	1.24	1.48	1.71	1.93	2.12	2.30	2.47	2.62	2.98	3.31	3.65	3.96	4.35	4.72	5.13	5.52	5.80	6.04	6.13	6.14
0.35	0.20	0.46	0.74	1.02	1.28	1.53	1.76	1.99	2.19	2.38	2.55	2.70	3.07	3.41	3.76	4.09	4.48	4.87	5.29	5.69	5.98	6.23	6.32	6.33
0.38	0.21	0.48	0.76	1.05	1.32	1.57	1.82	2.05	2.25	2.44	2.62	2.78	3.16	3.51	3.87	4.20	4.61	5.01	5.44	5.86	6.15	6.41	6.50	6.51
0.40	0.21	0.49	0.78	1.08	1.36	1.62	1.87	2.10	2.31	2.51	2.69	2.86	3.25	3.61	3.98	4.32	4.74	5.15	5.59	6.02	6.32	6.58	6.68	6.69
0.42	0.22	0.50	0.81	1.11	1.39	1.66	1.91	2.16	2.37	2.58	2.76	2.93	3.33	3.70	4.08	4.43	4.86	5.28	5.74	6.17	6.48	6.75	6.86	6.87
0.46	0.23	0.53	0.84	1.17	1.46	1.74	2.01	2.26	2.49	2.70	2.90	3.08	3.50	3.88	4.28	4.65	5.10	5.54	6.02	6.47	6.80	7.08	7.19	7.20
0.50	0.24	0.55	0.88	1.22	1.52	1.82	2.10	2.36	2.60	2.82	3.03	3.21	3.65	4.05	4.47	4.85	5.33	5.79	6.28	6.76	7.10	7.40	7.51	7.52
0.54	0.25	0.57	0.92	1.27	1.59	1.89	2.18	2.46	2.71	2.94	3.15	3.34	3.80	4.22	4.65	5.05	5.55	6.02	6.54	7.04	7.39	7.70	7.82	7.83
0.58	0.26	0.60	0.95	1.31	1.65	1.96	2.26	2.55	2.81	3.05	3.27	3.47	3.94	4.38	4.83	5.24	5.75	6.25	6.79	7.30	7.67	7.99	8.11	8.12
0.63	0.26	0.62	0.99	1.36	1.70	2.03	2.34	2.64	2.91	3.16	3.38	3.59	4.08	4.53	5.00	5.43	5.96	6.47	7.02	7.56	7.94	8.27	8.40	8.41
0.67	0.27	0.64	1.02	1.41	1.76	2.10	2.42	2.73	3.00	3.26	3.49	3.71	4.22	4.68	5.16	5.61	6.15	6.68	7.25	7.81	8.20	8.54	8.67	8.68
0.71	0.28	0.66	1.05	1.45	1.81	2.16	2.50	2.81	3.10	3.36	3.60	3.82	4.35	4.82	5.32	5.78	6.34	6.89	7.48	8.05	8.45	8.81	8.94	8.95
0.75	0.29	0.68	1.08	1.49	1.87	2.23	2.57	2.89	3.19	3.46	3.71	3.93	4.47	4.96	5.47	5.95	6.53	7.09	7.70	8.28	8.70	9.06	9.20	9.21
0.79	0.30	0.69	1.11	1.53	1.92	2.29	2.64	2.97	3.27	3.55	3.81	4.04	4.59	5.10	5.62	6.11	6.70	7.28	7.91	8.51	8.94	9.31	9.45	9.46
0.83	0.31	0.71	1.14	1.57	1.97	2.35	2.71	3.05	3.36	3.64	3.91	4.15	4.71	5.23	5.77	6.27	6.88	7.47	8.11	8.73	9.17	9.55	9.70	9.71
0.92	0.32	0.75	1.19	1.65	2.06	2.46	2.84	3.20	3.52	3.82	4.10	4.35	4.94	5.49	6.05	6.57	7.21	7.83	8.51	9.15	9.62	10.02	10.17	10.18
1.00	0.34	0.78	1.25	1.72	2.15	2.57	2.97	3.34	3.68	3.99	4.28	4.54	5.16	5.73	6.32	6.86	7.53	8.18	8.89	9.56	10.04	10.46	10.62	10.64
1.08	0.35	0.81	1.30	1.79	2.24	2.67	3.09	3.48	3.83	4.15	4.45	4.73	5.37	5.96	6.58	7.15	7.84	8.52	9.25	9.95	10.45	10.89	11.05	11.07
1.17	0.36	0.84	1.35	1.86	2.33	2.78	3.20	3.61	3.97	4.31	4.62	4.91	5.58	6.19	6.83	7.41	8.14	8.84	9.60	10.33	10.85	11.30	11.47	11.49
1.25	0.37	0.87	1.39	1.92	2.41	2.87	3.32	3.73	4.11	4.46	4.78	5.08	5.77	6.41	7.06	7.68	8.42	9.15	9.93	10.69	11.23	11.70	11.87	11.89
1.33	0.39	0.90	1.44	1.99	2.49	2.97	3.42	3.86	4.25	4.61	4.94	5.25	5.96	6.62	7.30	7.93	8.70	9.45	10.26	11.04	11.60	12.08	12.26	12.28
1.42	0.40	0.93	1.49	2.05	2.56	3.06	3.53	3.98	4.38	4.75	5.09	5.41	6.15	6.82	7.52	8.17	8.97	9.74	10.58	11.38	11.96	12.45	12.64	12.66
1.50	0.41	0.96	1.53	2.11	2.64	3.15	3.63	4.09	4.51	4.89	5.24	5.56	6.32	7.02	7.74	8.41	9.23	10.02	10.88	11.71	12.30	12.81	13.01	13.03
1.58	0.42	0.98	1.57	2.17	2.71	3.23	3.73	4.20	4.63	5.02	5.39	5.72	6.50	7.21	7.95	8.64	9.48	10.30	11.18	12.03	12.64	13.17	13.36	13.38
1.67	0.43	1.01	1.61	2.22	2.78	3.32	3.83	4.31	4.75	5.15	5.53	5.86	6.67	7.40	8.16	8.86	9.73	10.56	11.47	12.34	12.97	13.51	13.71	13.73
1.75	0.44	1.03	1.65	2.28	2.85	3.40	3.92	4.42	4.87	5.28	5.66	6.01	6.83	7.58	8.36	9.08	9.97	10.83	11.75	12.65	13.29	13.84	14.05	14.07
1.83	0.45	1.06	1.69	2.33	2.92	3.48	4.01	4.52	4.98	5.40	5.79	6.15	6.99	7.76	8.56	9.29	10.20	11.08	12.03	12.95	13.60	14.17	14.38	14.40
1.92	0.46	1.08	1.73	2.38	2.98	3.56	4.11	4.62	5.09	5.53	5.93	6.29	7.15	7.93	8.75	9.50	10.43	11.33	12.30	13.24	13.91	14.48	14.70	14.72
2.00	0.47	1.10	1.76	2.43	3.05	3.63	4.19	4.72	5.20	5.64	6.05	6.42	7.30	8.10	8.94	9.71	10.66	11.57	12.57	13.52	14.20	14.80	15.02	15.04
2.08	0.48	1.13	1.80	2.48	3.11	3.71	4.28	4.82	5.31	5.76	6.18	6.56	7.45	8.27	9.12	9.91	10.88	11.81	12.83	13.80	14.50	15.10	15.33	15.35
2.17	0.49	1.15	1.84	2.53	3.17	3.78	4.36	4.92	5.41	5.88	6.30	6.69	7.60	8.44	9.30	10.10	11.09	12.05	13.08	14.07	14.79	15.40	15.63	15.66
2.25	0.50	1.17	1.87	2.58	3.23	3.85	4.45	5.01	5.52	5.99	6.42	6.81	7.75	8.60	9.48	10.30	11.30	12.27	13.33	14.34	15.07	15.69	15.93	15.95
2.33	0.51	1.19	1.91	2.63	3.29	3.93	4.53	5.10	5.62	6.10	6.54	6.94	7.89	8.75	9.65	10.49	11.51	12.50	13.57	14.61	15.34	15.98	16.22	16.25
2.42	0.52	1.21	1.94	2.68	3.35	3.99	4.61	5.19	5.72	6.21	6.65	7.06	8.03	8.91	9.82	10.67	11.71	12.72	13.81	14.86	15.61	16.26	16.51	16.53
2.50	0.53	1.23	1.97	2.72	3.41	4.06	4.69	5.28	5.82	6.31	6.77	7.18	8.16	9.06	9.99	10.85	11.91	12.94	14.05	15.12	15.88	16.54	16.79	16.82
2.58	0.54	1.26	2.01	2.77	3.46	4.13	4.77	5.37	5.91	6.42	6.88	7.30	8.30	9.21	10.16	11.03	12.11	13.15	14.28	15.37	16.14	16.82	17.07	17.09
2.67	0.55	1.28	2.04	2.81	3.52	4.20	4.84	5.45	6.01	6.52	6.99	7.42	8.43	9.36	10.32	11.21	12.30	13.36	14.51	15.61	16.40	17.09	17.34	17.37
2.75	0.56	1.30	2.07	2.85	3.57	4.26	4.92	5.54	6.10	6.62	7.10	7.53	8.56	9.50	10.48	11.38	12.50	13.57	14.73	15.86	16.66	17.35	17.61	17.64
2.83	0.56	1.31	2.10	2.90	3.63	4.33	4.99	5.62	6.19	6.72	7.20	7.65	8.69	9.65	10.64	11.56	12.68	13.77	14.96	16.09	16.91	17.61	17.88	17.90

ITRC Water Measurement Tables – 24" Armco-Type Gate, Stilling Well Located 12" d/s of Back of Gate [Blue center represents best accuracy range]

Net Gate Opening (feet)

ΔH (feet)	0.042	0.08	0.13	0.17	0.21	0.25	0.29	0.33	0.38	0.42	0.46	0.50	0.58	0.67	0.75	0.83	0.92	1.00	1.08	1.17	1.25	1.33	1.42	1.50	1.58	1.67	1.75	1.83	1.92	2.00
0.04	0.10	0.22	0.35	0.49	0.61	0.73	0.84	0.95	1.05	1.14	1.23	1.31	1.49	1.65	1.81	1.96	2.14	2.32	2.45	2.57	2.71	2.85	3.01	3.16	3.30	3.51	3.68	3.71	3.77	3.57
0.06	0.12	0.27	0.43	0.60	0.75	0.89	1.03	1.17	1.29	1.40	1.51	1.61	1.82	2.02	2.22	2.40	2.63	2.84	3.00	3.14	3.32	3.49	3.68	3.87	4.04	4.30	4.51	4.54	4.62	4.37
0.08	0.14	0.31	0.50	0.69	0.86	1.03	1.19	1.35	1.49	1.62	1.74	1.85	2.10	2.33	2.56	2.78	3.03	3.28	3.46	3.63	3.84	4.03	4.25	4.47	4.67	4.97	5.20	5.24	5.34	5.04
0.10	0.15	0.35	0.56	0.77	0.96	1.15	1.33	1.51	1.66	1.81	1.95	2.07	2.35	2.61	2.87	3.10	3.39	3.67	3.87	4.06	4.29	4.51	4.76	4.99	5.22	5.56	5.82	5.86	5.97	5.64
0.13	0.17	0.39	0.61	0.84	1.06	1.26	1.46	1.65	1.82	1.98	2.13	2.27	2.58	2.86	3.14	3.40	3.71	4.02	4.24	4.44	4.70	4.94	5.21	5.47	5.72	6.09	6.37	6.42	6.54	6.18
0.15	0.18	0.42	0.66	0.91	1.14	1.36	1.58	1.78	1.97	2.14	2.30	2.45	2.78	3.09	3.39	3.67	4.01	4.34	4.58	4.80	5.07	5.33	5.63	5.91	6.17	6.57	6.88	6.93	7.06	6.67
0.17	0.19	0.44	0.71	0.97	1.22	1.46	1.69	1.91	2.10	2.29	2.46	2.62	2.98	3.30	3.63	3.93	4.29	4.64	4.90	5.13	5.43	5.70	6.02	6.32	6.60	7.03	7.36	7.41	7.55	7.13
0.19	0.20	0.47	0.75	1.03	1.29	1.55	1.79	2.02	2.23	2.43	2.61	2.78	3.16	3.50	3.85	4.17	4.55	4.92	5.20	5.44	5.75	6.05	6.38	6.70	7.00	7.45	7.81	7.86	8.01	7.56
0.21	0.22	0.50	0.79	1.09	1.36	1.63	1.89	2.13	2.35	2.56	2.75	2.93	3.33	3.69	4.05	4.39	4.80	5.19	5.48	5.74	6.07	6.38	6.73	7.06	7.38	7.86	8.23	8.29	8.44	7.97
0.23	0.23	0.52	0.83	1.14	1.43	1.71	1.98	2.23	2.47	2.68	2.89	3.07	3.49	3.87	4.25	4.61	5.03	5.44	5.74	6.02	6.36	6.69	7.05	7.41	7.74	8.24	8.63	8.69	8.85	8.36
0.25	0.24	0.54	0.87	1.19	1.49	1.78	2.07	2.33	2.58	2.80	3.02	3.21	3.65	4.04	4.44	4.81	5.25	5.68	6.00	6.28	6.64	6.98	7.37	7.74	8.08	8.61	9.01	9.08	9.24	8.74
0.27	0.25	0.57	0.90	1.24	1.55	1.86	2.15	2.43	2.68	2.92	3.14	3.34	3.79	4.21	4.62	5.01	5.47	5.92	6.24	6.54	6.92	7.27	7.67	8.05	8.41	8.96	9.38	9.45	9.62	9.09
0.29	0.26	0.59	0.94	1.29	1.61	1.93	2.23	2.52	2.78	3.03	3.26	3.47	3.94	4.37	4.80	5.20	5.67	6.14	6.48	6.79	7.18	7.54	7.96	8.36	8.73	9.30	9.74	9.80	9.98	9.43
0.31	0.26	0.61	0.97	1.33	1.67	2.00	2.31	2.61	2.88	3.13	3.37	3.59	4.08	4.52	4.96	5.38	5.87	6.36	6.71	7.03	7.43	7.81	8.24	8.65	9.04	9.62	10.08	10.15	10.33	9.77
0.33	0.27	0.63	1.00	1.38	1.72	2.06	2.38	2.69	2.97	3.24	3.48	3.71	4.21	4.67	5.13	5.55	6.07	6.56	6.93	7.26	7.67	8.06	8.51	8.93	9.33	9.94	10.41	10.48	10.67	10.09
0.35	0.28	0.65	1.03	1.42	1.78	2.12	2.46	2.78	3.07	3.34	3.59	3.82	4.34	4.81	5.29	5.72	6.25	6.77	7.14	7.48	7.91	8.31	8.77	9.21	9.62	10.25	10.73	10.80	11.00	10.40
0.38	0.29	0.67	1.06	1.46	1.83	2.19	2.53	2.86	3.16	3.43	3.69	3.93	4.46	4.95	5.44	5.89	6.43	6.96	7.35	7.70	8.14	8.55	9.02	9.47	9.90	10.54	11.04	11.12	11.32	10.70
0.40	0.30	0.69	1.09	1.50	1.88	2.25	2.60	2.94	3.24	3.53	3.79	4.04	4.59	5.09	5.59	6.05	6.61	7.15	7.55	7.91	8.36	8.79	9.27	9.73	10.17	10.83	11.34	11.42	11.63	10.99
0.42	0.31	0.70	1.12	1.54	1.93	2.30	2.67	3.01	3.33	3.62	3.89	4.15	4.71	5.22	5.73	6.21	6.78	7.34	7.75	8.11	8.58	9.02	9.51	9.99	10.44	11.11	11.64	11.72	11.93	11.28
0.46	0.32	0.74	1.17	1.61	2.02	2.42	2.80	3.16	3.49	3.80	4.08	4.35	4.94	5.47	6.01	6.51	7.11	7.70	8.12	8.51	9.00	9.46	9.98	10.47	10.94	11.66	12.20	12.29	12.52	11.83
0.50	0.33	0.77	1.22	1.69	2.11	2.52	2.92	3.30	3.64	3.96	4.26	4.54	5.16	5.72	6.28	6.80	7.43	8.04	8.48	8.89	9.40	9.88	10.42	10.94	11.43	12.17	12.75	12.84	13.07	12.35
0.54	0.35	0.80	1.27	1.75	2.20	2.63	3.04	3.44	3.79	4.13	4.44	4.73	5.37	5.95	6.54	7.08	7.73	8.37	8.83	9.25	9.78	10.28	10.85	11.39	11.90	12.67	13.27	13.36	13.61	12.86
0.58	0.36	0.83	1.32	1.82	2.28	2.73	3.15	3.56	3.94	4.28	4.61	4.91	5.57	6.17	6.78	7.35	8.03	8.68	9.16	9.60	10.15	10.67	11.26	11.82	12.35	13.15	13.77	13.87	14.12	13.34
0.63	0.37	0.86	1.37	1.88	2.36	2.82	3.27	3.69	4.07	4.43	4.77	5.08	5.76	6.39	7.02	7.61	8.31	8.99	9.49	9.94	10.51	11.04	11.65	12.23	12.78	13.61	14.25	14.35	14.62	13.81
0.67	0.39	0.89	1.41	1.95	2.44	2.91	3.37	3.81	4.21	4.58	4.92	5.24	5.95	6.60	7.25	7.85	8.58	9.28	9.80	10.26	10.85	11.41	12.03	12.63	13.20	14.06	14.72	14.82	15.10	14.26
0.71	0.40	0.92	1.46	2.01	2.51	3.00	3.48	3.93	4.34	4.72	5.08	5.41	6.14	6.80	7.47	8.10	8.84	9.57	10.10	10.58	11.18	11.76	12.40	13.02	13.61	14.49	15.17	15.28	15.56	14.70
0.75	0.41	0.94	1.50	2.06	2.59	3.09	3.58	4.04	4.46	4.86	5.22	5.56	6.31	7.00	7.69	8.33	9.10	9.85	10.39	10.89	11.51	12.10	12.76	13.40	14.00	14.91	15.61	15.72	16.01	15.13
0.79	0.42	0.97	1.54	2.12	2.66	3.18	3.67	4.15	4.58	4.99	5.37	5.71	6.49	7.19	7.90	8.56	9.35	10.12	10.68	11.18	11.82	12.43	13.11	13.77	14.38	15.32	16.04	16.15	16.45	15.54
0.83	0.43	0.99	1.58	2.18	2.73	3.26	3.77	4.26	4.70	5.12	5.50	5.86	6.66	7.38	8.11	8.78	9.59	10.38	10.95	11.47	12.13	12.75	13.45	14.12	14.76	15.72	16.46	16.57	16.88	15.95
0.92	0.45	1.04	1.66	2.28	2.86	3.42	3.95	4.47	4.93	5.37	5.77	6.15	6.98	7.74	8.50	9.21	10.06	10.88	11.49	12.03	12.72	13.37	14.11	14.81	15.48	16.48	17.26	17.38	17.70	16.73
1.00	0.47	1.09	1.73	2.38	2.99	3.57	4.13	4.67	5.15	5.61	6.03	6.42	7.29	8.08	8.88	9.62	10.51	11.37	12.00	12.57	13.29	13.97	14.74	15.47	16.17	17.22	18.03	18.15	18.49	17.47
1.08	0.49	1.13	1.80	2.48	3.11	3.72	4.30	4.86	5.36	5.84	6.28	6.69	7.59	8.41	9.24	10.01	10.94	11.83	12.49	13.08	13.83	14.54	15.34	16.10	16.83	17.92	18.76	18.90	19.24	18.18
1.17	0.51	1.18	1.87	2.57	3.23	3.86	4.46	5.04	5.57	6.06	6.51	6.94	7.87	8.73	9.59	10.39	11.35	12.28	12.96	13.58	14.35	15.09	15.92	16.71	17.46	18.60	19.47	19.61	19.97	18.87
1.25	0.53	1.22	1.94	2.66	3.34	3.99	4.62	5.22	5.76	6.27	6.74	7.18	8.15	9.04	9.93	10.76	11.75	12.71	13.41	14.05	14.86	15.62	16.48	17.30	18.07	19.25	20.15	20.30	20.67	19.53
1.33	0.55	1.26	2.00	2.75	3.45	4.12	4.77	5.39	5.95	6.47	6.96	7.42	8.42	9.33	10.26	11.11	12.13	13.13	13.85	14.51	15.34	16.13	17.02	17.87	18.67	19.88	20.81	20.96	21.35	20.17
1.42	0.56	1.30	2.06	2.84	3.56	4.25	4.92	5.56	6.13	6.67	7.18	7.64	8.68	9.62	10.57	11.45	12.51	13.53	14.28	14.96	15.82	16.63	17.54	18.42	19.24	20.49	21.46	21.61	22.00	20.79
1.50	0.58	1.33	2.12	2.92	3.66	4.37	5.06	5.72	6.31	6.87	7.39	7.87	8.93	9.90	10.88	11.78	12.87	13.92	14.70	15.40	16.28	17.11	18.05	18.95	19.80	21.09	22.08	22.24	22.64	21.40
1.58	0.59	1.37	2.18	3.00	3.76	4.49	5.20	5.87	6.48	7.06	7.59	8.08	9.17	10.17	11.18	12.10	13.22	14.31	15.10	15.82	16.72	17.58	18.54	19.47	20.34	21.66	22.68	22.84	23.26	21.98
1.67	0.61	1.41	2.24	3.08	3.86	4.61	5.33	6.03	6.65	7.24	7.79	8.29	9.41	10.44	11.47	12.42	13.56	14.68	15.49	16.23	17.16	18.03	19.03	19.97	20.87	22.23	23.27	23.44	23.87	22.55
1.75	0.63	1.44	2.29	3.15	3.95	4.72	5.46	6.17	6.82	7.42	7.98	8.50	9.64	10.69	11.75	12.73	13.90	15.04	15.87	16.63	17.58	18.48	19.50	20.47	21.39	22.77	23.85	24.02	24.46	23.11
1.83	0.64	1.48	2.35	3.23	4.04	4.83	5.59	6.32	6.98	7.59	8.17	8.70	9.87	10.95	12.03	13.03	14.23	15.39	16.25	17.02	17.99	18.91	19.95	20.95	21.89	23.31	24.41	24.58	25.03	23.65
1.92	0.65	1.51	2.40	3.30	4.14	4.94	5.72	6.46	7.13	7.76	8.35	8.89	10.09	11.19	12.30	13.32	14.55	15.74	16.61	17.40	18.40	19.34	20.40	21.42	22.38	23.83	24.96	25.13	25.60	24.19
2.00	0.67	1.54	2.45	3.37	4.22	5.05	5.84	6.60	7.29	7.93	8.53	9.08	10.31	11.43	12.56	13.60	14.86	16.08	16.97	17.78	18.79	19.75	20.84	21.88	22.86	24.35	25.49	25.67	26.15	24.71
2.08	0.68	1.57	2.50	3.44	4.31	5.15	5.96	6.74	7.44	8.09	8.70	9.27	10.52	11.67	12.82	13.88	15.17	16.41	17.32	18.14	19.18	20.16	21.27	22.33	23.33	24.85	26.02	26.20	26.68	25.22
2.17	0.70	1.60	2.55	3.51	4.40	5.25	6.08	6.87	7.58	8.25	8.88	9.45	10.73	11.90	13.07	14.16	15.47	16.73	17.66	18.50	19.56	20.56	21.69	22.77	23.80	25.34	26.53	26.72	27.21	25.72
2.25	0.71	1.63	2.60	3.58	4.48	5.35	6.20	7.00	7.73	8.41	9.05	9.63	10.94	12.13	13.32	14.43	15.76	17.05	18.00	18.85	19.93	20.95	22.11	23.21	24.25	25.82	27.04	27.23	27.73	26.21
2.33	0.72	1.66	2.65	3.64	4.56	5.45	6.31	7.13	7.87	8.56	9.21	9.81	11.14	12.35	13.57	14.69	16.05	17.37	18.33	19.20	20.30	21.34	22.51	23.63	24.69	26.30	27.54	27.73	28.24	26.69
2.42	0.73	1.69	2.69	3.71	4.64	5.55	6.42	7.26	8.01	8.72	9.37	9.98	11.33	12.57	13.81	14.95	16.33	17.67	18.65	19.54	20.66	21.71	22.91	24.05	25.13	26.76	28.02	28.22	28.74	27.16
2.50	0.75	1.72	2.74	3.77	4.72	5.64	6.53	7.38	8.15	8.87	9.53	10.16	11.53	12.78	14.04	15.21	16.61	17.98	18.97	19.87	21.01	22.09	23.30	24.46	25.56	27.22	28.50	28.71	29.23	27.62
2.58	0.76	1.75	2.78	3.83	4.80	5.74	6.64	7.50	8.28	9.01	9.69	10.32	11.72	12.99	14.28	15.46	16.89	18.27	19.29	20.20	21.36	22.45	23.69	24.87	25.98	27.67	28.97	29.18	29.71	28.08
2.67	0.77	1.78	2.83	3.89	4.88	5.83	6.74	7.62	8.41	9.16	9.85	10.49	11.91	13.20	14.50	15.71	17.16	18.56	19.59	20.53	21.70	22.81	24.07	25.27	26.40	28.11	29.44	29.65	30.19	28.53
2.75	0.78	1.81	2.87	3.95	4.95	5.92	6.85	7.74	8.54	9.30	10.00	10.65	12.09	13.41	14.73	15.95	17.42	18.85	19.90	20.84	22.04	23.16	24.44	25.66	26.81	28.55	29.89	30.11	30.66	28.97
2.83	0.80	1.83	2.92	4.01	5.03	6.01	6.95	7.86	8.67	9.44	10.15	10.81	12.27	13.61	14.95	16.19	17.69	19.14	20.20	21.16	22.37	23.51	24.81	26.04	27.21	28.98	30.34	30.56	31.12	29.41

Preliminary Tables for

Round Gates on Round Pipes

Discharge Values in CFS

These tables are from the original ARMCO Flow Measurement Tables and will be replaced as these gate sizes are tested by ITRC

Armco-Type Meter Gate Tables - Preliminary

8-Inch Round Gate

Head Difference (feet)	Net Gate Opening (feet)												
	0.17	0.21	0.25	0.29	0.33	0.38	0.42	0.46	0.50	0.54	0.58	0.63	0.67
	Discharge (cfs)												
0.08	0.27	0.32	0.38	0.42	0.46	0.51	0.55	0.57	0.59	0.61	0.62	0.63	0.64
0.10	0.30	0.36	0.42	0.46	0.51	0.56	0.60	0.63	0.65	0.68	0.70	0.71	0.71
0.13	0.32	0.39	0.46	0.50	0.56	0.61	0.67	0.69	0.72	0.75	0.77	0.78	0.78
0.15	0.35	0.42	0.49	0.54	0.60	0.66	0.72	0.75	0.78	0.81	0.83	0.84	0.85
0.17	0.37	0.44	0.52	0.58	0.64	0.70	0.76	0.80	0.83	0.86	0.89	0.90	0.91
0.19	0.39	0.46	0.54	0.61	0.67	0.74	0.80	0.84	0.88	0.92	0.94	0.96	0.97
0.21	0.41	0.49	0.57	0.64	0.70	0.77	0.85	0.89	0.93	0.96	1.00	1.01	1.02
0.23	0.42	0.51	0.60	0.66	0.74	0.81	0.88	0.93	0.97	1.01	1.04	1.06	1.07
0.25	0.44	0.53	0.62	0.70	0.76	0.84	0.92	0.97	1.02	1.06	1.09	1.11	1.12
0.27	0.46	0.55	0.64	0.72	0.79	0.87	0.95	1.01	1.06	1.10	1.13	1.15	1.16
0.29	0.47	0.57	0.67	0.74	0.82	0.90	0.99	1.05	1.10	1.14	1.18	1.20	1.21
0.31	0.49	0.59	0.69	0.77	0.85	0.93	1.02	1.08	1.14	1.18	1.22	1.24	1.26
0.33	0.50	0.60	0.71	0.79	0.88	0.96	1.05	1.12	10.18	1.22	1.26	1.28	1.30
0.35	0.52	0.62	0.73	0.82	0.90	0.99	1.08	1.15	1.22	1.26	1.30	1.33	1.34
0.38	0.53	0.64	0.75	0.84	0.92	1.02	1.11	1.19	1.25	1.30	1.34	1.37	1.38
0.40	0.54	0.65	0.76	0.86	0.95	1.04	1.14	1.22	1.29	1.34	1.38	1.41	1.42
0.42	0.56	0.67	0.78	0.88	0.97	1.07	1.17	1.25	1.32	1.37	1.42	1.44	1.46
0.46	0.58	0.70	0.81	0.91	1.01	1.12	1.22	1.31	1.38	1.44	1.49	1.52	1.54
0.50	0.60	0.72	0.84	0.95	1.06	1.17	1.27	1.36	1.44	1.50	1.55	1.58	1.60
0.54	0.62	0.75	0.87	0.99	1.10	1.22	1.32	1.42	1.50	1.56	1.61	1.65	1.67
0.58	0.64	0.77	0.90	1.03	1.15	1.26	1.37	1.47	1.55	1.62	1.67	1.71	1.74
0.63	0.66	0.80	0.94	1.06	1.19	1.31	1.42	1.53	1.61	1.68	1.73	1.77	1.80
0.67	0.68	0.82	0.96	1.10	1.22	1.35	1.47	1.58	1.66	1.73	1.79	1.83	1.86
0.71	0.70	0.85	1.00	1.13	1.26	1.39	1.52	1.62	1.71	1.78	1.84	1.88	1.92
0.75	0.72	0.87	1.02	1.16	1.30	1.43	1.56	14.67	1.76	1.84	1.89	1.94	1.97
0.79	0.74	0.90	1.05	1.19	1.33	1.47	1.60	1.72	1.81	1.89	1.94	1.99	2.02
0.83	0.76	0.92	1.08	1.22	1.37	1.51	1.64	1.76	1.85	1.94	1.99	2.04	2.08
0.92	0.79	0.96	1.13	1.28	1.44	1.58	1.72	1.85	1.94	2.03	2.09	2.14	2.18
1.00	0.83	1.01	1.18	1.34	1.50	1.66	1.80	1.93	2.03	2.12	2.18	2.24	2.27
1.08	0.86	1.05	1.23	1.40	1.56	1.72	1.87	2.01	2.12	2.21	2.29	2.33	2.37
1.17	0.89	1.09	1.28	1.45	1.62	1.79	1.94	2.08	2.20	2.29	2.36	2.42	2.46
1.25	0.92	1.13	1.32	1.50	1.68	1.85	2.01	2.16	2.27	2.37	2.44	2.50	2.54
1.33	0.95	1.16	1.37	1.55	1.73	1.91	2.08	2.23	2.35	2.45	2.52	2.58	2.62
1.42	0.98	1.20	1.41	1.60	1.78	1.97	2.14	2.30	2.42	2.52	2.60	2.66	2.71
1.50	1.01	1.23	1.45	1.64	1.84	2.03	2.20	2.36	2.49	2.60	2.68	2.74	2.79

Armco-Type Meter Gate Tables - Preliminary

15-inch Round Gate

Head Difference (feet)	Net Gate Opening (feet)																	
	0.17	0.21	0.25	0.29	0.33	0.38	0.42	0.46	0.50	0.58	0.67	0.75	0.83	0.92	1.00	1.08	1.17	1.25
	Discharge (cfs)																	
0.08	0.46	0.57	0.66	0.75	0.83	0.91	0.98	1.07	1.14	1.30	1.43	1.58	1.71	1.84	1.94	2.04	2.13	2.18
0.10	0.51	0.62	0.73	0.83	0.92	1.02	1.09	1.19	1.27	1.44	1.59	1.75	1.90	2.05	2.17	2.29	2.38	2.43
0.13	0.55	0.67	0.79	0.91	1.00	1.11	1.19	1.30	1.38	1.57	1.74	1.91	2.08	2.24	2.38	2.51	2.62	2.67
0.15	0.59	0.72	0.85	0.98	1.08	1.19	1.28	1.39	1.49	1.68	1.87	2.06	2.24	2.41	2.57	2.72	2.83	2.90
0.17	0.63	0.77	0.90	1.04	1.15	1.27	1.37	1.48	1.59	1.79	1.99	2.20	2.39	2.58	2.75	2.90	3.03	3.09
0.19	0.67	0.81	0.95	1.10	1.22	1.34	1.45	1.57	1.48	1.89	2.11	2.33	2.54	2.73	2.91	3.07	3.22	3.28
0.21	0.70	0.85	1.00	1.15	1.28	1.41	1.53	1.65	1.76	1.99	2.22	2.45	2.68	2.87	3.07	3.24	3.40	3.46
0.23	0.73	0.89	1.05	1.20	1.33	1.48	1.60	1.73	1.84	2.09	2.33	2.57	2.81	3.01	3.21	3.40	3.57	6.64
0.25	0.76	3.93	1.09	1.25	1.38	1.54	1.67	1.80	1.92	2.18	2.43	2.69	2.93	3.14	3.35	3.54	3.73	3.81
0.27	0.79	0.97	1.13	1.29	1.43	1.60	1.73	1.87	2.00	2.27	2.53	2.80	3.05	3.27	3.49	3.68	3.88	3.97
0.29	0.82	1.00	1.17	1.33	1.48	1.65	1.79	1.94	2.08	2.36	2.63	2.90	3.17	3.39	3.62	3.82	4.01	4.11
0.31	0.85	1.03	1.21	1.37	1.53	1.70	1.85	2.01	2.15	2.44	2.72	3.00	3.28	3.51	3.75	3.96	4.14	4.25
0.33	0.88	1.06	1.25	1.41	1.58	1.75	1.91	2.07	1.22	2.52	2.81	3.10	3.39	3.63	3.87	4.09	4.27	4.39
0.35	0.91	1.09	1.29	1.45	1.63	1.80	1.97	2.13	2.29	2.60	2.90	3.20	3.49	3.74	3.99	4.21	4.40	4.53
0.38	0.93	1.12	1.32	1.49	1.68	1.85	2.03	2.19	2.36	2.68	2.98	3.29	3.59	3.85	4.10	4.33	4.53	4.67
0.40	0.95	1.15	1.35	1.53	1.73	1.90	2.09	2.25	2.42	2.75	3.06	3.38	3.69	3.96	4.21	4.45	4.65	4.80
0.42	0.97	1.18	1.38	1.57	1.77	1.95	2.14	2.31	2.48	2.82	3.14	3.47	3.79	4.06	2.32	4.57	4.77	4.92
0.46	1.01	1.23	1.44	1.64	1.85	2.05	2.24	2.43	2.60	2.96	3.30	3.63	3.97	4.26	4.54	4.79	5.00	5.14
0.50	1.05	1.28	1.50	1.71	1.93	2.14	2.34	2.54	2.72	3.09	3.44	3.79	4.15	4.44	4.74	5.00	5.22	5.36
0.54	1.09	1.33	1.56	1.78	2.01	2.23	2.44	2.64	2.83	3.22	3.58	3.95	4.32	4.62	4.93	5.20	5.43	5.58
0.58	1.13	1.38	1.62	1.85	2.09	2.31	2.53	2.74	2.93	3.34	3.72	4.10	4.48	4.79	5.11	5.40	5.64	5.79
0.63	1.17	1.42	1.68	1.92	2.16	2.39	2.62	2.84	3.03	3.46	2.85	4.25	4.64	4.96	5.29	5.59	5.84	5.99
0.67	1.21	1.46	1.73	1.98	2.23	2.47	2.71	2.93	3.13	3.57	2.98	4.39	4.79	5.13	5.47	5.78	6.03	6.19
0.71	1.24	1.50	1.78	2.04	2.30	2.55	2.79	3.02	3.23	3.68	4.10	4.52	4.93	5.29	5.64	5.95	6.22	6.38
0.75	1.27	1.54	1.83	2.10	2.37	2.62	2.87	3.11	3.33	3.79	4.22	4.65	5.07	5.44	5.80	6.12	6.40	6.56
0.79	1.30	1.58	1.88	2.16	2.43	2.69	2.95	3.19	3.42	3.89	4.34	4.78	5.21	5.59	5.96	6.29	6.58	6.74
0.83	1.33	1.62	1.93	2.22	2.49	2.76	3.03	3.27	3.51	3.99	4.45	4.91	5.35	5.73	6.11	6.46	6.75	6.92
0.92	1.39	1.70	2.03	2.32	2.61	2.90	3.17	3.43	3.68	4.18	4.66	5.14	5.61	6.01	6.41	6.77	7.07	7.26
1.00	1.45	1.78	2.12	2.42	2.73	3.03	3.31	3.59	3.84	4.37	4.87	5.37	5.86	6.29	6.70	7.07	7.39	7.59
1.08	1.50	1.85	2.21	2.52	2.84	3.15	3.45	3.73	4.00	4.55	5.07	5.59	6.10	6.54	6.97	7.36	7.69	7.89
1.17	1.55	1.92	2.29	2.62	2.95	2.37	3.58	3.87	4.15	4.72	5.26	5.80	6.34	6.79	7.24	7.64	7.98	8.19
1.25	1.60	1.99	2.37	2.71	3.05	3.38	3.70	4.01	4.30	4.88	5.44	6.00	6.56	7.03	7.49	7.91	8.26	8.47
1.33	1.65	2.05	2.45	2.80	3.15	3.49	3.82	4.14	4.44	5.04	5.62	6.20	6.77	7.26	7.73	8.17	8.53	8.75
1.42	1.70	2.11	2.52	2.89	3.25	3.60	3.94	4.27	4.57	5.20	5.80	6.39	6.98	7.48	7.97	8.42	8.80	9.02
1.50	1.75	2.17	2.59	2.97	3.34	3.70	4.05	4.39	4.70	5.35	5.96	6.58	7.18	7.69	8.20	8.66	9.05	9.28

16-inch Round Gate

Head Difference (feet)	Net Gate Opening (feet)																		
	0.17	0.21	0.25	0.29	0.33	0.38	0.42	0.46	0.50	0.58	0.67	0.75	0.83	0.92	1.00	1.08	1.17	1.25	1.33
	Discharge (cfs)																		
0.08	0.49	0.59	0.70	0.79	0.89	0.97	1.05	1.14	1.22	1.37	1.53	1.68	1.83	1.96	2.10	2.24	2.35	2.43	2.47
0.10	0.55	0.66	0.77	0.88	0.98	1.08	1.16	1.27	1.36	1.52	1.70	1.87	2.04	2.19	2.34	2.50	2.63	2.72	2.78
0.13	0.59	0.72	0.84	0.96	1.07	1.18	1.27	1.39	1.48	1.66	1.86	2.04	2.22	2.39	2.56	2.74	2.89	2.98	3.05
0.15	0.63	0.77	0.90	1.03	1.15	1.27	1.37	1.49	1.59	1.79	1.99	2.20	2.40	2.57	2.76	2.96	3.12	3.23	3.31
0.17	0.67	0.82	0.96	1.10	1.23	1.35	1.46	1.59	1.69	1.91	2.12	2.34	2.56	2.74	2.94	3.16	3.31	3.46	3.54
0.19	0.71	0.86	1.02	1.16	1.30	1.43	1.54	1.68	1.79	2.02	2.25	2.48	2.71	2.91	3.11	3.33	3.50	3.66	3.75
0.21	0.75	0.90	1.07	1.21	1.36	1.50	1.62	1.76	1.89	2.13	2.37	2.61	2.85	3.08	3.28	3.50	3.68	3.85	3.95
0.23	0.78	0.94	1.12	1.26	1.42	1.57	1.69	1.84	1.98	2.23	2.49	2.74	2.99	3.23	3.44	3.67	3.86	4.03	4.14
0.25	0.81	0.98	1.16	1.31	1.48	1.64	1.76	1.92	2.06	2.33	2.60	2.86	3.12	3.37	3.59	3.83	4.04	4.20	4.33
0.27	0.84	1.02	1.20	1.36	1.54	1.70	1.84	2.00	2.14	2.43	2.71	2.98	3.25	3.51	3.74	3.99	4.20	4.37	4.51
0.29	0.87	1.06	1.24	1.41	1.59	1.75	1.91	2.08	2.22	2.52	2.81	3.09	3.37	3.64	3.88	4.14	4.36	4.53	4.69
0.31	0.90	1.09	1.28	1.46	1.64	1.81	1.98	2.15	2.30	2.61	2.91	3.20	3.49	3.77	4.02	4.28	4.52	4.69	4.86
0.33	0.93	1.12	1.32	1.51	1.69	1.87	2.05	2.22	2.38	2.69	3.00	3.31	3.61	3.89	4.15	4.42	4.67	4.85	5.02
0.35	0.96	1.15	1.36	1.56	1.74	1.93	2.11	2.29	2.45	2.77	3.09	3.41	3.72	4.01	4.28	4.56	4.81	5.00	5.18
0.38	0.99	1.18	1.40	1.61	1.79	1.99	2.17	2.36	2.52	2.85	3.18	3.51	3.83	4.13	4.40	4.69	4.95	5.15	5.32
0.40	1.02	1.21	1.44	1.65	1.84	2.04	2.23	2.42	2.59	2.93	3.27	3.61	3.94	4.24	4.52	4.82	5.09	5.29	5.46
0.42	1.04	1.24	1.48	1.69	1.89	2.09	2.29	2.48	2.66	3.01	3.36	3.70	4.04	4.35	4.64	4.95	5.22	5.43	5.59
0.46	1.08	1.30	1.55	1.76	1.98	2.19	2.40	2.60	2.79	3.16	3.52	3.88	4.24	4.56	4.87	5.19	5.47	5.69	5.85
0.50	1.12	1.36	1.61	1.83	2.07	2.28	2.50	2.71	2.91	3.30	3.68	4.05	4.42	4.76	5.08	5.42	5.71	5.94	6.10
0.54	1.16	1.41	1.67	1.90	2.15	2.37	2.60	2.82	3.03	3.43	3.83	4.21	4.60	4.96	5.29	5.64	5.95	6.18	6.35
0.58	1.20	1.46	1.73	1.97	2.23	2.46	2.70	2.93	3.14	3.56	3.97	4.37	4.77	5.15	5.49	5.85	6.18	6.41	6.59
0.63	1.24	1.51	1.79	2.04	2.31	2.55	2.80	3.04	3.25	3.69	4.11	4.53	4.94	5.33	5.68	6.06	6.39	6.64	6.82
0.67	1.28	1.56	1.85	2.11	2.39	2.63	2.89	3.14	3.36	3.81	4.25	4.68	5.11	5.50	5.87	6.26	6.60	6.86	7.05
0.71	1.31	1.60	1.90	2.18	2.46	2.71	2.98	3.24	3.46	3.93	4.38	4.82	5.26	5.67	6.05	6.45	6.81	7.07	7.27
0.75	1.34	1.64	1.95	2.24	2.53	2.79	3.07	3.33	3.56	4.04	4.51	4.96	5.41	5.83	6.23	6.64	7.01	7.27	7.48
0.79	1.37	1.68	2.00	2.30	2.60	2.87	3.15	3.42	3.66	4.15	4.63	5.10	5.56	5.99	6.40	6.83	7.20	7.47	7.68
0.83	1.40	1.72	2.05	2.36	2.67	2.95	3.23	3.51	3.75	4.26	4.75	5.23	5.71	6.15	6.56	7.00	7.39	7.67	7.88
0.92	1.46	1.80	2.15	2.48	2.80	3.09	3.39	3.68	3.93	4.46	4.98	5.48	5.98	6.45	6.88	7.34	7.74	8.04	8.26
1.00	1.52	1.88	2.25	2.59	2.92	3.23	3.54	3.84	4.11	4.66	5.20	5.73	6.25	6.74	7.19	7.66	8.09	8.40	8.63
1.08	1.58	1.96	2.34	2.69	3.04	3.36	3.68	4.00	4.28	4.85	5.41	5.96	6.50	7.01	7.48	7.98	8.41	8.74	8.98
1.17	1.64	2.04	2.43	2.79	3.15	3.49	3.82	4.15	4.44	5.03	5.61	6.19	6.75	7.28	7.76	8.27	8.73	9.07	9.32
1.25	1.70	2.11	2.51	2.89	3.26	3.61	3.96	4.29	4.60	5.21	5.81	6.40	6.99	7.54	8.04	8.56	9.04	9.39	9.65
1.33	1.76	2.18	2.59	2.99	3.37	3.73	4.09	4.43	4.75	5.38	6.00	6.61	7.22	7.79	8.30	8.85	9.34	9.70	9.96
1.42	1.81	2.25	2.67	3.08	3.48	3.84	4.22	4.57	4.90	5.55	6.19	6.82	7.44	8.03	8.56	9.13	9.63	10.00	10.27
1.50	1.86	2.31	2.75	3.16	3.58	3.95	4.34	4.70	5.04	5.71	6.37	7.01	7.65	8.25	8.80	9.39	9.90	10.28	10.56

20-inch Round Gate

Head Difference (feet)	Net Gate Opening (feet)																						
	0.17	0.21	0.25	0.29	0.33	0.38	0.42	0.46	0.50	0.58	0.67	0.75	0.83	0.92	1.00	1.08	1.17	1.25	1.33	1.42	1.50	1.58	1.67
	Discharge (cfs)																						
0.08	0.58	0.73	0.86	0.96	1.10	1.21	1.32	1.43	1.54	1.75	1.92	2.12	2.29	2.48	2.66	2.84	3.01	3.16	3.31	3.44	3.57	3.68	3.71
0.10	0.66	0.81	0.96	1.09	1.23	1.35	1.42	1.60	1.72	1.95	2.16	2.37	2.56	2.77	2.98	3.18	3.37	3.54	3.71	3.86	4.01	4.14	4.19
0.13	0.72	0.88	1.04	1.18	1.35	1.47	1.61	1.74	1.88	2.12	2.35	2.58	2.79	3.03	3.25	3.47	3.69	3.88	4.06	4.23	4.39	4.52	4.61
0.15	0.77	0.95	1.11	1.27	1.44	1.58	1.72	1.87	2.02	2.27	2.52	2.77	3.00	3.26	3.50	3.73	3.95	4.18	3.36	4.55	4.71	4.86	4.97
0.17	0.82	1.01	1.18	1.36	1.53	1.68	1.83	1.99	2.15	2.42	2.69	2.95	3.21	3.48	3.73	3.97	4.20	4.46	4.66	4.85	5.02	5.20	5.31
0.19	0.87	1.07	1.25	1.44	1.62	1.78	1.94	2.11	2.27	2.56	2.86	3.13	3.42	3.69	3.96	4.21	4.45	4.72	4.95	5.15	5.33	5.53	5.65
0.21	0.91	1.12	1.31	1.51	1.70	1.87	2.04	2.21	2.38	2.70	3.02	3.31	3.62	3.89	4.18	4.45	4.70	4.97	5.21	5.43	5.63	5.83	5.95
0.23	0.95	1.17	1.37	1.58	1.78	1.96	2.13	2.31	2.49	2.84	3.16	3.49	3.80	4.08	4.39	4.66	4.95	5.21	5.46	5.70	5.91	6.13	6.24
0.25	0.99	1.22	1.43	1.65	1.85	2.04	2.22	2.41	2.60	2.96	3.30	3.64	3.96	4.26	4.58	4.86	5.16	5.44	5.70	5.95	6.17	6.41	6.52
0.27	1.03	1.27	1.49	1.71	1.92	2.12	2.31	2.51	2.71	3.08	3.44	3.79	4.12	4.44	4.77	5.06	5.37	5.66	5.94	6.20	6.43	6.68	6.80
0.29	1.07	1.31	1.54	1.77	1.99	2.19	2.40	2.61	2.82	3.20	5.56	3.93	4.28	4.60	4.95	5.25	5.57	5.88	6.16	6.43	6.67	6.92	7.08
0.31	1.10	1.35	1.59	1.83	2.06	2.26	2.49	2.70	2.92	3.31	3.68	4.07	4.43	4.76	5.13	5.44	5.77	6.09	6.38	6.65	6.90	7.15	7.32
0.33	1.13	1.39	1.64	1.88	2.12	2.33	2.57	2.79	3.02	3.42	3.80	4.20	4.57	4.92	5.29	5.62	5.96	6.29	6.58	6.87	7.12	7.38	7.56
0.35	1.16	1.43	1.69	1.93	2.18	2.40	2.65	2.88	3.12	3.52	3.92	4.33	4.71	5.07	5.45	5.79	6.14	6.48	6.78	7.08	7.34	7.61	7.79
0.38	1.19	1.47	1.73	1.98	2.24	2.47	2.73	2.96	3.21	3.62	4.04	4.46	4.85	5.22	5.61	5.96	6.32	6.67	6.98	7.29	7.56	7.84	8.02
0.40	1.22	1.51	1.77	2.03	2.30	2.54	2.80	3.04	3.29	3.72	4.16	4.58	4.99	5.36	6.76	6.13	6.50	6.85	7.18	7.50	7.77	8.05	8.25
0.42	1.25	1.55	1.81	2.08	2.36	2.61	2.87	3.12	3.37	3.82	4.26	4.70	5.12	5.50	5.91	6.29	6.66	7.03	7.36	7.69	7.97	8.26	8.46
0.46	1.31	1.61	1.89	2.18	2.48	2.74	3.02	3.28	3.53	1.01	4.47	4.93	5.36	5.77	6.20	6.59	6.98	7.37	7.72	8.06	8.36	8.66	8.87
0.50	1.37	1.67	1.97	2.28	2.59	2.86	3.15	3.42	3.69	4.19	4.67	5.15	5.60	6.04	6.48	6.89	7.30	7.70	8.06	8.41	8.73	9.05	9.26
0.54	1.42	1.73	2.05	2.38	2.69	2.98	3.28	3.56	3.85	4.36	4.86	5.37	5.84	6.28	6.76	7.17	7.60	8.02	8.40	8.76	9.10	9.44	9.65
0.58	1.47	1.79	2.12	2.47	2.79	3.09	3.40	3.70	3.99	4.53	5.05	5.57	6.06	6.51	7.01	7.45	7.89	8.32	8.72	9.10	9.43	9.78	10.02
0.63	1.52	1.85	2.19	2.56	2.89	3.20	3.52	3.82	4.13	4.68	5.22	5.76	6.26	6.74	7.25	7.70	8.16	8.61	9.02	9.42	9.76	10.12	10.37
0.67	1.57	1.91	2.26	2.65	2.98	3.30	3.63	3.94	4.26	4.83	5.39	5.95	6.46	6.96	7.48	7.95	8.43	8.88	9.31	9.72	10.08	10.44	10.70
0.71	1.61	1.97	2.33	2.73	3.07	3.40	3.74	4.06	4.39	4.98	5.55	6.13	6.66	7.17	7.70	8.19	8.69	9.15	9.60	10.01	10.40	10.76	11.03
0.75	1.65	2.02	2.40	2.80	3.16	3.50	3.85	4.18	4.52	5.13	5.71	6.31	6.86	7.38	7.92	8.43	8.95	9.42	9.88	10.30	10.70	11.08	11.34
0.79	1.69	2.07	2.47	2.87	3.25	3.60	3.96	4.30	4.65	5.27	5.87	6.49	7.06	7.59	8.14	8.67	9.20	9.69	10.15	10.59	11.00	11.40	11.65
0.83	1.73	2.12	2.54	2.94	3.34	3.70	4.07	4.42	4.77	5.41	6.03	6.65	7.25	7.79	8.36	8.90	9.44	9.95	10.41	10.88	11.28	11.69	11.96
0.92	1.81	2.22	2.67	3.08	3.50	3.87	4.28	4.63	5.00	5.67	6.31	6.97	7.60	8.16	8.76	9.32	9.88	10.42	10.91	11.44	11.82	12.24	12.53
1.00	1.88	2.32	2.79	3.22	3.66	4.04	4.47	4.84	5.22	5.92	6.59	7.29	7.93	8.53	9.16	9.74	10.32	10.89	11.41	11.93	12.34	12.79	13.10
1.08	1.95	2.42	2.91	3.36	3.81	4.21	4.64	5.04	5.44	6.17	6.87	7.60	8.26	8.88	9.55	10.13	10.76	11.33	11.88	12.40	12.86	13.32	13.65
1.17	2.02	2.52	3.02	3.49	3.95	4.38	4.81	5.23	5.64	6.40	7.13	7.89	8.57	9.21	9.90	10.52	11.16	11.77	12.32	12.87	13.33	13.82	14.17
1.25	2.08	2.61	3.12	3.61	4.09	4.53	4.97	5.41	5.84	6.62	7.38	8.15	8.86	9.53	10.24	10.88	11.53	12.18	12.74	13.30	13.80	14.30	14.65
1.33	2.14	2.70	3.22	3.73	4.22	4.67	5.13	5.58	6.03	6.84	7.62	8.41	9.15	9.85	10.58	11.23	11.90	12.56	13.16	13.72	14.25	14.78	15.13
1.42	2.20	2.78	3.32	3.84	4.35	4.81	5.29	5.75	6.22	7.05	7.85	8.67	9.43	10.15	10.90	11.58	12.27	12.94	13.58	14.14	14.69	15.24	15.59
1.50	2.26	2.86	3.41	3.95	4.47	4.95	5.45	5.92	6.40	7.25	8.08	8.93	9.70	10.44	11.22	11.92	12.64	13.32	13.98	14.56	15.11	15.68	16.05

30-inch Round Gate

Head Difference (feet)	Net Gate Opening (feet)																								
	0.17	0.21	0.25	0.29	0.33	0.38	0.42	0.46	0.50	0.58	0.67	0.75	0.83	0.92	1.00	1.08	1.17	1.25	1.33	1.50	1.67	1.83	2.00	2.17	2.33	2.50
	Discharge (cfs)																									
0.08	0.84	1.05	1.25	1.45	1.63	1.84	2.00	2.20	2.34	2.69	3.03	3.35	3.64	3.92	4.20	4.48	4.75	5.03	5.28	5.84	6.34	6.76	7.10	7.46	7.70	7.86
0.10	0.93	1.17	1.39	1.62	1.82	2.04	2.23	2.45	2.61	2.99	3.36	3.71	4.04	4.36	4.67	4.99	5.30	5.61	5.89	6.49	7.04	7.51	7.90	8.31	8.58	8.77
0.13	1.01	1.27	1.52	1.76	1.97	2.22	2.43	2.66	2.85	3.25	3.63	4.05	4.41	4.75	5.11	5.46	5.80	6.12	6.46	7.08	7.67	8.19	8.65	9.07	9.40	9.59
0.15	1.08	1.37	1.63	1.89	2.12	2.39	2.62	2.87	3.06	3.50	3.88	4.37	4.73	5.11	5.49	5.86	6.22	6.57	6.94	7.60	8.25	8.81	9.29	9.72	10.15	10.32
0.17	1.16	1.46	1.74	2.02	2.27	2.54	2.80	3.05	3.27	3.73	4.13	4.64	5.03	5.45	5.86	6.26	6.63	7.02	7.41	8.11	8.78	9.40	9.91	10.34	10.88	11.04
0.19	1.23	1.55	1.85	2.14	2.40	2.69	2.96	3.22	3.46	3.95	4.38	4.90	5.33	5.78	6.21	6.64	7.04	7.45	7.86	8.61	9.31	9.94	10.48	10.94	11.56	11.74
0.21	1.30	1.63	1.94	2.25	2.52	2.84	3.11	3.38	3.63	4.15	4.63	5.15	5.61	6.09	6.55	7.00	7.41	7.85	8.29	9.07	9.81	10.48	11.03	11.52	12.16	12.40
0.23	1.36	1.70	2.03	2.35	2.64	2.98	3.25	3.53	3.80	4.34	4.86	5.40	5.89	6.39	6.87	7.34	7.78	8.23	8.69	9.51	10.28	19.98	11.56	12.08	12.68	13.00
0.25	1.41	1.77	2.11	2.45	2.75	3.11	3.38	3.67	3.95	4.53	5.08	5.64	6.16	6.68	7.17	7.67	8.13	8.60	9.08	9.94	10.75	11.47	12.07	12.62	13.18	13.55
0.27	1.46	1.84	2.19	2.55	2.86	3.22	3.50	3.81	4.10	4.71	5.29	5.87	6.41	6.95	7.46	7.98	8.46	8.95	9.45	10.34	11.20	11.95	12.57	13.15	13.68	14.05
0.29	1.51	1.90	2.27	2.64	2.96	3.33	3.62	3.94	4.25	4.88	5.49	6.09	6.65	7.21	7.75	8.28	8.78	9.29	9.81	10.74	11.62	12.40	13.06	13.65	14.18	14.52
0.31	1.56	1.96	2.35	2.72	3.06	3.43	3.74	4.07	4.40	5.05	5.68	6.30	6.88	7.47	8.02	8.57	9.09	9.62	10.14	11.12	12.03	12.83	13.50	14.12	14.67	14.98
0.33	1.61	2.02	2.42	2.80	3.15	3.53	3.85	4.20	4.54	5.21	5.86	6.51	7.10	7.71	8.28	8.85	9.38	9.93	10.47	11.48	12.42	13.25	13.94	15.58	15.15	15.44
0.35	1.65	2.08	2.49	2.88	3.24	3.63	3.96	4.33	4.68	5.38	6.04	6.71	7.32	7.95	8.54	9.12	9.67	10.23	10.80	11.83	12.80	13.66	14.37	15.03	15.61	15.90
0.38	1.69	2.14	2.56	2.96	3.33	3.73	4.07	4.45	4.82	5.54	6.22	6.91	7.54	8.18	8.79	9.39	9.95	10.53	11.12	12.17	13.17	14.06	14.80	15.47	16.07	16.36
0.40	1.73	2.20	2.62	3.04	3.42	3.82	4.18	4.57	4.95	5.69	6.39	7.10	7.75	8.40	9.03	9.65	13.23	10.82	11.43	12.51	13.54	14.45	15.20	15.90	16.52	16.82
0.42	1.77	2.25	2.68	3.11	3.50	3.91	4.29	4.69	5.08	5.84	6.56	7.29	7.95	8.62	9.26	9.90	10.50	11.11	11.73	12.84	13.90	14.83	15.60	16.32	16.95	17.26
0.46	1.85	2.35	2.80	3.25	3.66	4.09	4.50	4.92	5.33	6.12	6.88	7.64	8.34	9.05	9.72	10.38	11.02	11.65	12.30	13.47	14.57	15.56	16.36	17.10	17.77	18.10
0.50	1.93	2.45	2.92	3.39	3.82	4.27	4.70	5.14	5.56	6.39	7.19	7.98	8.70	9.45	10.14	10.84	11.50	12.16	12.83	14.06	15.20	16.23	17.08	17.85	18.55	18.90
0.54	2.01	2.55	3.04	3.53	3.97	4.44	4.89	5.35	5.79	6.65	7.48	8.31	9.06	9.84	10.56	11.29	11.96	12.66	13.36	14.63	15.83	16.90	17.77	18.58	19.30	19.65
0.58	2.09	2.64	3.15	3.64	4.13	4.61	5.07	5.55	6.01	6.90	7.76	8.62	9.40	10.20	10.96	11.72	12.42	13.14	13.87	15.19	16.43	17.53	18.45	19.30	20.04	20.40
0.63	2.16	2.72	3.25	3.76	4.27	4.77	5.25	5.75	6.21	7.15	8.03	8.92	9.74	10.56	11.35	12.13	12.85	13.60	14.36	15.72	17.00	18.15	19.10	19.97	20.74	21.12
0.67	2.23	2.80	3.34	3.88	4.41	4.92	5.42	5.94	6.42	7.38	8.30	9.21	10.06	10.90	11.72	12.52	13.27	14.04	14.83	16.23	17.56	18.73	19.72	20.62	21.42	21.82
0.71	2.30	2.88	3.43	3.99	4.54	5.07	5.59	6.12	6.61	7.60	8.55	9.49	10.36	11.23	12.08	12.91	13.68	14.47	15.29	16.73	18.10	19.30	20.32	21.26	22.08	22.52
0.75	2.36	2.96	3.52	4.10	4.67	5.22	5.75	6.30	6.81	7.82	8.80	9.76	10.66	11.56	12.44	13.28	14.07	14.90	15.74	17.21	18.62	19.87	20.91	21.87	22.72	23.17
0.79	2.42	3.04	3.61	4.21	4.80	5.36	5.91	6.47	7.00	8.04	9.04	10.03	10.95	11.89	19.79	13.64	14.46	15.30	16.15	17.68	19.14	20.41	21.49	22.47	23.34	23.80
0.83	2.48	3.12	3.70	4.32	4.93	5.50	6.06	6.64	7.18	8.26	9.28	10.30	11.24	12.20	13.12	14.00	14.85	15.70	16.60	18.15	19.65	20.95	22.06	23.06	23.95	24.40
0.92	2.59	3.27	3.88	4.53	5.17	5.78	6.36	6.96	7.53	8.66	9.73	10.80	11.78	12.79	13.74	14.69	15.57	16.47	17.40	19.03	20.50	21.96	23.13	24.20	25.12	25.58
1.00	2.70	3.40	4.05	4.74	5.4	6.04	6.64	7.27	7.86	9.04	10.16	11.28	12.31	13.36	14.35	15.33	16.26	17.20	18.16	19.88	21.50	22.95	24.15	25.25	26.23	26.72
1.08	2.81	3.52	4.21	4.93	5.62	6.28	6.91	7.57	8.19	9.40	10.57	11.74	12.82	13.90	14.94	15.96	16.93	17.90	18.90	20.70	22.40	23.90	25.15	26.28	27.30	27.80
1.17	2.91	3.64	4.37	5.11	5.84	6.51	7.17	7.86	8.49	9.76	10.97	12.18	13.30	14.43	15.50	15.56	17.56	18.57	19.60	21.48	23.23	24.80	26.10	27.28	28.32	28.85
1.25	3.01	3.76	4.52	5.29	6.04	6.74	7.42	8.13	8.79	10.10	11.37	12.62	13.76	14.93	16.04	17.14	18.18	19.23	20.30	22.23	24.05	25.66	27.00	28.23	29.32	29.86
1.33	3.11	3.88	4.67	5.47	6.24	6.96	7.66	8.40	9.08	10.43	11.74	13.03	14.22	15.42	16.57	17.70	18.77	19.86	20.97	22.95	24.84	26.50	27.87	29.15	30.30	30.84
1.42	3.20	3.99	4.81	5.64	6.43	7.18	7.90	8.66	9.36	10.76	12.10	13.43	14.65	15.90	17.08	18.26	19.36	20.48	21.62	23.66	25.60	27.32	28.73	30.06	31.25	31.80
1.50	3.28	4.10	4.95	5.79	6.61	7.39	8.13	8.91	9.63	11.06	12.43	13.81	15.08	16.36	17.57	18.78	19.90	21.05	22.25	24.34	26.34	28.10	29.56	30.92	32.15	32.70

Armco-Type Meter Gate Tables - Preliminary

36-inch Round Gate

Head Difference (feet)	Net Gate Opening (feet)																												
	0.17	0.21	0.25	0.29	0.33	0.38	0.42	0.46	0.50	0.58	0.67	0.75	0.83	0.92	1.00	1.08	1.17	1.25	1.33	1.50	1.67	1.83	2.00	2.17	2.33	2.50	2.67	2.83	3.00
	Discharge (cfs)																												
0.08	0.96	1.22	1.47	1.71	1.94	2.16	2.41	2.61	2.82	3.24	3.67	4.05	4.42	4.77	5.10	5.47	5.83	6.13	6.50	7.12	7.86	8.43	8.92	9.37	9.84	10.10	10.35	10.56	10.74
0.10	1.07	1.35	1.62	1.89	2.15	2.41	2.69	2.90	3.12	3.59	4.05	4.50	4.91	5.31	5.67	6.10	6.49	6.82	7.22	7.87	8.67	9.30	9.88	10.38	10.89	11.20	11.50	11.74	11.92
0.13	1.17	1.47	1.77	2.06	2.34	2.63	2.94	3.16	3.40	3.92	4.43	4.93	5.36	5.79	6.20	6.68	7.08	7.44	7.89	8.59	9.44	10.14	10.81	11.33	11.86	12.24	12.57	12.84	13.02
0.15	1.26	1.59	1.92	2.22	2.53	2.84	3.18	3.42	3.67	4.24	4.77	5.32	4.79	6.25	6.70	7.20	7.63	8.04	8.52	9.28	10.17	10.95	11.65	12.25	12.80	13.24	13.60	13.91	14.09
0.17	1.34	1.70	2.05	2.36	2.69	3.04	3.39	3.66	3.92	4.53	5.08	5.68	6.18	6.66	7.17	7.67	8.13	8.60	9.10	9.95	10.87	11.71	12.43	13.09	13.67	14.16	14.54	14.87	15.05
0.19	1.42	1.80	2.17	2.50	2.85	3.21	3.58	3.87	4.14	4.79	5.38	6.00	6.52	7.04	7.61	8.12	8.62	9.12	9.65	10.57	11.52	12.42	13.18	13.86	14.47	15.00	15.39	15.74	15.95
0.21	1.50	1.89	2.28	2.63	3.00	3.37	3.76	4.07	4.35	5.04	5.65	6.30	6.85	7.42	8.02	8.56	9.09	9.61	10.18	11.13	12.16	13.10	13.88	14.60	15.21	15.76	16.17	16.54	16.78
0.23	1.57	1.98	2.39	2.76	3.14	3.52	3.93	4.26	4.55	5.28	5.91	6.60	7.18	7.79	8.42	8.98	9.54	10.07	10.68	11.68	12.76	13.73	14.55	15.31	15.93	16.50	16.94	17.34	17.60
0.25	1.63	2.06	2.49	2.88	3.28	3.67	4.10	4.45	4.75	5.50	6.17	6.89	7.50	8.13	8.79	9.37	9.95	10.52	11.15	12.20	13.31	14.35	15.20	16.00	16.64	17.23	17.68	18.10	18.38
0.27	1.69	2.14	2.59	3.00	3.41	3.82	4.27	4.63	1.95	5.72	6.42	7.17	7.81	8.46	9.15	9.76	10.35	10.96	11.60	12.70	13.86	14.95	15.83	16.66	17.33	17.94	18.40	18.85	19.14
0.29	1.75	2.21	2.68	3.11	3.53	3.95	4.42	4.79	5.13	5.93	6.66	7.44	8.10	8.78	9.49	10.12	10.74	11.37	12.04	13.18	14.37	15.50	16.42	17.28	17.98	18.61	19.08	19.54	19.85
0.31	1.81	2.28	2.76	3.22	3.65	4.08	4.56	4.95	5.31	6.14	6.90	7.70	8.39	9.09	9.82	10.48	11.11	11.77	12.46	13.63	14.89	16.04	16.99	17.89	18.60	19.27	19.74	20.23	20.55
0.33	1.86	2.35	2.84	3.31	3.76	4.20	4.68	5.11	5.49	6.34	7.13	7.95	8.66	9.38	10.14	10.83	11.48	12.15	12.87	14.08	15.37	169.56	17.55	18.46	19.20	19.90	20.40	20.89	21.25
0.35	1.91	1.42	2.92	3.40	3.86	4.32	4.81	5.27	5.66	6.54	7.35	8.20	8.93	9.67	10.45	11.16	11.83	12.52	13.27	14.51	15.84	17.08	18.10	19.03	19.80	20.50	21.05	21.53	21.90
0.38	1.96	2.49	3.00	3.49	3.96	4.44	4.94	5.42	5.82	6.73	7.56	8.44	9.19	9.95	10.76	11.49	12.18	12.89	13.66	14.94	16.31	17.57	18.61	19.60	20.38	21.10	21.65	22.17	22.55
0.40	2.01	2.56	3.08	3.58	4.06	4.56	5.07	5.57	5.98	6.92	7.77	8.67	9.45	10.22	11.06	11.80	12.52	13.25	14.04	15.35	16.76	18.05	19.13	20.15	20.95	21.68	22.25	22.80	23.20
0.42	2.06	2.62	3.16	3.67	4.16	4.68	5.19	5.72	6.14	7.10	7.97	8.89	9.70	10.49	11.34	12.10	12.85	13.60	14.40	15.75	17.20	18.53	19.64	20.65	21.50	22.25	22.80	23.40	23.80
0.46	2.16	2.74	3.31	3.84	4.36	4.90	5.43	6.00	6.43	7.44	8.36	9.33	10.17	11.00	11.90	12.70	13.47	14.25	15.10	16.52	18.03	19.43	20.60	21.65	22.55	23.35	23.90	24.50	24.90
0.50	2.26	2.86	3.45	4.00	4.55	5.11	5.67	6.26	4.71	7.77	8.73	9.73	10.61	11.50	12.42	13.26	14.07	14.88	15.77	17.25	18.82	20.28	21.50	22.62	23.55	24.39	24.95	25.60	26.00
0.54	2.35	2.98	3.59	4.16	4.72	5.32	5.91	6.52	6.99	8.09	9.09	10.13	11.04	11.97	12.93	13.80	14.64	15.50	16.41	17.97	19.60	21.13	22.40	23.65	24.50	26.39	26.00	26.65	27.10
0.58	2.44	3.09	3.72	4.31	4.89	5.52	6.14	6.76	7.25	8.39	9.43	10.51	11.46	12.41	13.42	14.32	15.20	16.09	17.03	18.64	20.35	21.94	23.25	24.44	25.43	26.33	27.00	27.67	28.15
0.63	2.53	3.19	3.85	4.45	5.06	5.72	6.36	7.00	7.51	8.69	9.76	10.89	11.87	12.85	13.90	14.83	15.74	16.67	17.64	19.30	21.08	22.72	24.08	25.30	26.34	27.25	27.95	28.65	19.15
0.67	2.61	3.29	3.97	4.59	5.23	5.91	6.57	7.23	7.76	8.97	10.09	11.24	12.26	13.28	14.35	15.32	16.25	17.20	18.21	19.92	21.75	23.45	24.84	26.13	27.20	28.13	28.85	29.55	30.10
0.71	2.69	3.38	4.08	4.72	5.39	6.09	6.77	7.45	8.00	9.25	10.40	11.59	12.63	13.68	14.79	15.79	16.74	17.72	18.77	20.54	22.42	24.15	25.60	26.95	28.05	29.00	29.75	3.0.45	31.00
0.75	2.76	3.47	4.19	4.85	5.55	6.27	6.97	7.60	8.23	9.52	10.70	11.93	13.00	14.08	15.21	16.25	17.23	18.23	19.31	21.15	23.07	24.85	26.33	27.73	28.85	29.84	30.62	31.35	31.88
0.79	2.83	3.56	4.30	4.98	5.70	6.44	7.16	7.87	8.45	9.78	11.00	12.26	13.37	14.47	15.63	16.68	17.70	18.73	19.84	21.72	23.70	15.55	27.05	28.47	29.63	30.65	31.45	32.20	32.75
0.83	2.90	3.65	4.41	5.11	5.85	6.61	7.35	8.07	8.67	10.03	11.28	12.58	13.71	14.83	16.03	17.10	18.17	19.21	20.35	22.27	24.30	26.20	27.75	29.20	30.40	31.45	32.25	33.05	33.60
0.92	3.05	3.82	4.60	5.36	6.13	6.92	7.70	8.46	9.10	10.52	11.82	13.18	14.37	15.55	16.81	17.93	19.05	20.14	21.33	23.35	25.47	27.45	29.10	30.60	31.85	32.95	33.80	34.65	35.20
1.00	3.16	3.98	4.79	5.61	6.40	7.23	8.05	8.85	9.51	10.99	12.35	13.78	15.01	16.25	17.58	18.74	19.90	21.05	22.30	24.40	26.62	18.70	30.40	32.00	33.30	34.45	35.35	36.20	36.80
1.08	3.28	4.14	4.98	5.85	6.67	7.52	8.39	9.22	9.89	11.44	12.85	14.35	15.62	16.93	18.30	19.53	20.72	21.92	23.22	25.40	27.75	29.87	31.65	33.32	34.65	35.85	36.80	37.68	38.30
1.17	3.39	4.29	5.16	6.06	6.91	7.81	8.70	9.56	10.26	11.88	13.33	14.88	16.21	17.58	18.99	20.25	21.50	22.75	24.10	26.35	28.80	31.00	32.85	34.60	35.98	37.20	38.18	39.10	39.75
1.25	3.50	4.43	5.34	6.27	7.15	8.08	9.00	9.89	10.62	12.30	13.80	15.40	16.78	18.19	19.64	20.95	22.24	23.54	24.93	27.30	29.80	32.10	34.00	35.80	37.25	28.50	39.50	40.45	41.15
1.33	3.61	4.56	5.51	6.48	7.39	8.34	9.29	10.22	10.98	12.69	14.27	15.90	17.33	18.78	20.29	54.65	22.98	24.30	25.75	28.20	30.75	33.15	35.10	36.95	38.45	29.80	40.80	41.80	42.50
1.42	3.72	4.69	5.68	6.68	7.62	8.60	9.58	10.54	11.32	13.08	14.70	16.39	17.86	19.34	20.92	22.32	23.69	25.05	26.55	29.03	31.70	34.15	36.20	38.10	39.60	41.10	42.05	43.10	43.80
1.50	3.82	4.82	5.85	6.87	7.84	8.85	9.86	10.84	11.64	13.45	15.12	16.88	18.39	19.89	21.54	22.97	24.36	25.78	27.33	29.85	32.63	35.15	37.25	39.20	40.75	42.30	43.25	44.35	45.10

ITRC Water Measurement Tables for **RECTANGULAR Gates on Round Pipes**

Discharge Values in CFS

ITRC Water Measurement Tables – 18" Rectangular Gate, Stilling Well Located 12" d/s of Back of Gate [Blue center represents best accuracy range]

ΔH	Net Gate Opening (feet)																							
	0.042	0.08	0.13	0.17	0.21	0.25	0.29	0.33	0.38	0.42	0.46	0.50	0.58	0.67	0.75	0.83	0.92	1.00	1.08	1.17	1.25	1.33	1.42	1.50
(feet)	Discharge (cfs)																							
0.04	0.02	0.05	0.09	0.13	0.18	0.23	0.28	0.34	0.40	0.46	0.52	0.58	0.72	0.86	1.01	1.17	1.34	1.51	1.71	1.92	2.07	2.21	2.26	2.28
0.06	0.02	0.06	0.11	0.16	0.22	0.28	0.35	0.42	0.49	0.56	0.64	0.71	0.88	1.05	1.24	1.43	1.64	1.85	2.10	2.36	2.54	2.70	2.77	2.79
0.08	0.02	0.07	0.12	0.19	0.25	0.33	0.40	0.48	0.56	0.65	0.73	0.82	1.01	1.21	1.43	1.65	1.89	2.13	2.43	2.72	2.93	3.12	3.20	3.22
0.10	0.03	0.08	0.14	0.21	0.28	0.37	0.45	0.54	0.63	0.72	0.82	0.92	1.13	1.36	1.60	1.85	2.11	2.39	2.71	3.04	3.28	3.49	3.58	3.60
0.13	0.03	0.08	0.15	0.23	0.31	0.40	0.49	0.59	0.69	0.79	0.90	1.01	1.24	1.49	1.75	2.02	2.32	2.61	2.97	3.33	3.59	3.82	3.92	3.95
0.15	0.03	0.09	0.16	0.25	0.34	0.43	0.53	0.63	0.74	0.86	0.97	1.09	1.34	1.61	1.89	2.19	2.50	2.82	3.21	3.60	3.88	4.13	4.24	4.26
0.17	0.03	0.09	0.17	0.26	0.36	0.46	0.57	0.68	0.80	0.92	1.04	1.16	1.44	1.72	2.02	2.34	2.67	3.02	3.43	3.85	4.15	4.42	4.53	4.56
0.19	0.04	0.10	0.18	0.28	0.38	0.49	0.60	0.72	0.84	0.97	1.10	1.23	1.52	1.82	2.15	2.48	2.84	3.20	3.64	4.08	4.40	4.68	4.80	4.84
0.21	0.04	0.11	0.19	0.29	0.40	0.52	0.64	0.76	0.89	1.02	1.16	1.30	1.60	1.92	2.26	2.61	2.99	3.37	3.83	4.30	4.63	4.94	5.06	5.10
0.23	0.04	0.11	0.20	0.31	0.42	0.54	0.67	0.79	0.93	1.07	1.22	1.36	1.68	2.01	2.37	2.74	3.14	3.54	4.02	4.51	4.86	5.18	5.31	5.35
0.25	0.04	0.12	0.21	0.32	0.44	0.57	0.70	0.83	0.97	1.12	1.27	1.42	1.76	2.10	2.48	2.86	3.28	3.70	4.20	4.71	5.08	5.41	5.55	5.58
0.27	0.04	0.12	0.22	0.34	0.46	0.59	0.72	0.86	1.01	1.17	1.32	1.48	1.83	2.19	2.58	2.98	3.41	3.85	4.37	4.90	5.28	5.63	5.77	5.81
0.29	0.04	0.13	0.23	0.35	0.48	0.61	0.75	0.90	1.05	1.21	1.37	1.54	1.90	2.27	2.68	3.09	3.54	3.99	4.54	5.09	5.48	5.84	5.99	6.03
0.31	0.05	0.13	0.24	0.36	0.49	0.63	0.78	0.93	1.09	1.25	1.42	1.59	1.97	2.35	2.77	3.20	3.66	4.13	4.70	5.27	5.68	6.05	6.20	6.24
0.33	0.05	0.13	0.24	0.37	0.51	0.65	0.80	0.96	1.12	1.30	1.47	1.64	2.03	2.43	2.86	3.30	3.78	4.27	4.85	5.44	5.86	6.24	6.41	6.45
0.35	0.05	0.14	0.25	0.38	0.52	0.67	0.83	0.99	1.16	1.33	1.51	1.69	2.09	2.50	2.95	3.41	3.90	4.40	5.00	5.61	6.04	6.44	6.60	6.65
0.38	0.05	0.14	0.26	0.40	0.54	0.69	0.85	1.02	1.19	1.37	1.56	1.74	2.15	2.57	3.03	3.50	4.01	4.53	5.14	5.77	6.22	6.62	6.79	6.84
0.40	0.05	0.15	0.27	0.41	0.55	0.71	0.88	1.04	1.23	1.41	1.60	1.79	2.21	2.65	3.12	3.60	4.12	4.65	5.29	5.93	6.39	6.81	6.98	7.03
0.42	0.05	0.15	0.27	0.42	0.57	0.73	0.90	1.07	1.26	1.45	1.64	1.84	2.27	2.71	3.20	3.69	4.23	4.77	5.42	6.08	6.55	6.98	7.16	7.21
0.46	0.06	0.16	0.29	0.44	0.60	0.77	0.94	1.12	1.32	1.52	1.72	1.93	2.38	2.85	3.35	3.87	4.44	5.00	5.69	6.38	6.87	7.32	7.51	7.56
0.50	0.06	0.16	0.30	0.46	0.62	0.80	0.98	1.17	1.38	1.59	1.80	2.01	2.49	2.97	3.50	4.05	4.63	5.23	5.94	6.66	7.18	7.65	7.84	7.90
0.54	0.06	0.17	0.31	0.48	0.65	0.83	1.03	1.22	1.43	1.65	1.87	2.10	2.59	3.09	3.65	4.21	4.82	5.44	6.18	6.93	7.47	7.96	8.16	8.22
0.58	0.06	0.18	0.32	0.49	0.67	0.86	1.06	1.27	1.49	1.71	1.94	2.17	2.69	3.21	3.78	4.37	5.00	5.65	6.42	7.20	7.75	8.26	8.47	8.53
0.63	0.07	0.18	0.33	0.51	0.70	0.90	1.10	1.31	1.54	1.77	2.01	2.25	2.78	3.32	3.92	4.52	5.18	5.84	6.64	7.45	8.03	8.55	8.77	8.83
0.67	0.07	0.19	0.35	0.53	0.72	0.92	1.14	1.36	1.59	1.83	2.08	2.32	2.87	3.43	4.05	4.67	5.35	6.04	6.86	7.69	8.29	8.83	9.06	9.12
0.71	0.07	0.20	0.36	0.54	0.74	0.95	1.17	1.40	1.64	1.89	2.14	2.40	2.96	3.54	4.17	4.82	5.51	6.22	7.07	7.93	8.55	9.10	9.34	9.40
0.75	0.07	0.20	0.37	0.56	0.76	0.98	1.21	1.44	1.69	1.94	2.20	2.47	3.04	3.64	4.29	4.96	5.67	6.40	7.28	8.16	8.79	9.37	9.61	9.67
0.79	0.07	0.21	0.38	0.57	0.78	1.01	1.24	1.48	1.73	2.00	2.26	2.53	3.13	3.74	4.41	5.09	5.83	6.58	7.47	8.38	9.03	9.62	9.87	9.94
0.83	0.08	0.21	0.39	0.59	0.81	1.03	1.27	1.52	1.78	2.05	2.32	2.60	3.21	3.84	4.52	5.22	5.98	6.75	7.67	8.60	9.27	9.87	10.13	10.20
0.92	0.08	0.22	0.41	0.62	0.84	1.08	1.33	1.59	1.87	2.15	2.43	2.73	3.37	4.03	4.74	5.48	6.27	7.08	8.04	9.02	9.72	10.36	10.62	10.69
1.00	0.08	0.23	0.42	0.65	0.88	1.13	1.39	1.66	1.95	2.24	2.54	2.85	3.52	4.20	4.96	5.72	6.55	7.39	8.40	9.42	10.15	10.82	11.09	11.17
1.08	0.09	0.24	0.44	0.67	0.92	1.18	1.45	1.73	2.03	2.33	2.65	2.96	3.66	4.38	5.16	5.96	6.82	7.69	8.74	9.81	10.57	11.26	11.55	11.62
1.17	0.09	0.25	0.46	0.70	0.95	1.22	1.50	1.79	2.10	2.42	2.75	3.08	3.80	4.54	5.35	6.18	7.08	7.98	9.07	10.18	10.97	11.68	11.98	12.06
1.25	0.09	0.26	0.47	0.72	0.99	1.27	1.56	1.86	2.18	2.51	2.84	3.18	3.93	4.70	5.54	6.40	7.33	8.26	9.39	10.53	11.35	12.09	12.40	12.49
1.33	0.10	0.27	0.49	0.75	1.02	1.31	1.61	1.92	2.25	2.59	2.94	3.29	4.06	4.86	5.72	6.61	7.57	8.53	9.70	10.88	11.72	12.49	12.81	12.90
1.42	0.10	0.28	0.50	0.77	1.05	1.35	1.66	1.98	2.32	2.67	3.03	3.39	4.18	5.00	5.90	6.81	7.80	8.80	10.00	11.21	12.09	12.87	13.20	13.29
1.50	0.10	0.28	0.52	0.79	1.08	1.39	1.71	2.03	2.39	2.75	3.11	3.49	4.31	5.15	6.07	7.01	8.02	9.05	10.29	11.54	12.44	13.25	13.59	13.68
1.58	0.10	0.29	0.53	0.81	1.11	1.42	1.75	2.09	2.45	2.82	3.20	3.58	4.42	5.29	6.24	7.20	8.24	9.30	10.57	11.86	12.78	13.61	13.96	14.05
1.67	0.11	0.30	0.55	0.83	1.14	1.46	1.80	2.14	2.52	2.90	3.28	3.68	4.54	5.43	6.40	7.39	8.46	9.54	10.85	12.16	13.11	13.96	14.32	14.42
1.75	0.11	0.31	0.56	0.85	1.17	1.50	1.84	2.20	2.58	2.97	3.36	3.77	4.65	5.56	6.56	7.57	8.67	9.78	11.11	12.46	13.43	14.31	14.68	14.77
1.83	0.11	0.31	0.57	0.87	1.19	1.53	1.89	2.25	2.64	3.04	3.44	3.85	4.76	5.69	6.71	7.75	8.87	10.01	11.37	12.76	13.75	14.65	15.02	15.12
1.92	0.11	0.32	0.59	0.89	1.22	1.57	1.93	2.30	2.70	3.11	3.52	3.94	4.87	5.82	6.86	7.92	9.07	10.23	11.63	13.04	14.06	14.97	15.36	15.46
2.00	0.12	0.33	0.60	0.91	1.25	1.60	1.97	2.35	2.76	3.17	3.60	4.03	4.97	5.95	7.01	8.09	9.27	10.45	11.88	13.32	14.36	15.30	15.69	15.79
2.08	0.12	0.34	0.61	0.93	1.27	1.63	2.01	2.40	2.81	3.24	3.67	4.11	5.07	6.07	7.15	8.26	9.46	10.67	12.13	13.60	14.66	15.61	16.01	16.12
2.17	0.12	0.34	0.62	0.95	1.30	1.67	2.05	2.44	2.87	3.30	3.74	4.19	5.18	6.19	7.29	8.42	9.64	10.88	12.37	13.87	14.95	15.92	16.33	16.44
2.25	0.12	0.35	0.64	0.97	1.32	1.70	2.09	2.49	2.92	3.36	3.81	4.27	5.27	6.31	7.43	8.58	9.83	11.09	12.60	14.13	15.23	16.22	16.64	16.75
2.33	0.13	0.36	0.65	0.99	1.35	1.73	2.13	2.54	2.98	3.43	3.88	4.35	5.37	6.42	7.57	8.74	10.01	11.29	12.83	14.39	15.51	16.52	16.95	17.06
2.42	0.13	0.36	0.66	1.00	1.37	1.76	2.17	2.58	3.03	3.49	3.95	4.43	5.47	6.54	7.70	8.90	10.19	11.49	13.06	14.65	15.78	16.81	17.25	17.36
2.50	0.13	0.37	0.67	1.02	1.39	1.79	2.20	2.63	3.08	3.55	4.02	4.50	5.56	6.65	7.84	9.05	10.36	11.69	13.28	14.90	16.05	17.10	17.54	17.66
2.58	0.13	0.37	0.68	1.04	1.42	1.82	2.24	2.67	3.13	3.61	4.09	4.58	5.65	6.76	7.96	9.20	10.53	11.88	13.50	15.14	16.32	17.38	17.83	17.95
2.67	0.14	0.38	0.69	1.05	1.44	1.85	2.27	2.71	3.18	3.66	4.15	4.65	5.74	6.87	8.09	9.34	10.70	12.07	13.72	15.39	16.58	17.66	18.12	18.24
2.75	0.14	0.39	0.70	1.07	1.46	1.88	2.31	2.75	3.23	3.72	4.22	4.72	5.83	6.97	8.22	9.49	10.87	12.26	13.93	15.62	16.84	17.94	18.40	18.52
2.83	0.14	0.39	0.71	1.09	1.48	1.91	2.34	2.80	3.28	3.78	4.28	4.79	5.92	7.08	8.34	9.63	11.03	12.44	14.14	15.86	17.09	18.21	18.67	18.80

ITRC Water Measurement Tables – 24" Rectangular Gate, Stilling Well Located 12" d/s of Back of Gate [Blue center represents best accuracy range]

ΔH (feet)	Net Gate Opening (feet) / Discharge (cfs): 0.042	0.08	0.13	0.17	0.21	0.25	0.29	0.33	0.38	0.42	0.46	0.50	0.58	0.67	0.75	0.83	0.92	1.00	1.08	1.17	1.25	1.33	1.42	1.50	1.58	1.67	1.75	1.83	1.92	2.00
0.04	0.04	0.07	0.12	0.18	0.25	0.31	0.38	0.44	0.52	0.60	0.68	0.76	0.93	1.11	1.30	1.49	1.68	1.86	2.06	2.25	2.45	2.65	2.87	3.08	3.28	3.70	3.89	4.05	4.06	4.07
0.06	0.04	0.08	0.15	0.23	0.30	0.38	0.46	0.54	0.64	0.73	0.83	0.93	1.14	1.36	1.60	1.83	2.06	2.28	2.52	2.75	3.00	3.25	3.51	3.77	4.02	4.54	4.76	4.96	4.97	4.98
0.08	0.05	0.09	0.17	0.26	0.35	0.44	0.54	0.63	0.74	0.85	0.96	1.07	1.32	1.57	1.84	2.11	2.38	2.64	2.91	3.18	3.47	3.75	4.06	4.36	4.64	5.24	5.50	5.73	5.74	5.75
0.10	0.06	0.10	0.19	0.29	0.39	0.50	0.60	0.70	0.82	0.95	1.07	1.20	1.48	1.76	2.06	2.36	2.66	2.95	3.25	3.55	3.88	4.20	4.54	4.87	5.19	5.85	6.15	6.41	6.42	6.43
0.13	0.06	0.11	0.21	0.32	0.43	0.54	0.66	0.77	0.90	1.04	1.18	1.32	1.62	1.93	2.26	2.59	2.91	3.23	3.56	3.89	4.25	4.60	4.97	5.33	5.69	6.41	6.73	7.02	7.03	7.04
0.15	0.07	0.12	0.23	0.34	0.46	0.59	0.71	0.83	0.97	1.12	1.27	1.42	1.75	2.08	2.44	2.80	3.14	3.49	3.85	4.20	4.59	4.96	5.37	5.76	6.14	6.93	7.27	7.58	7.59	7.61
0.17	0.07	0.13	0.24	0.37	0.50	0.63	0.76	0.89	1.04	1.20	1.36	1.52	1.87	2.23	2.60	2.99	3.36	3.73	4.11	4.49	4.90	5.31	5.74	6.16	6.57	7.41	7.77	8.10	8.12	8.13
0.19	0.08	0.14	0.26	0.39	0.53	0.66	0.80	0.94	1.10	1.27	1.44	1.61	1.98	2.36	2.76	3.17	3.56	3.96	4.36	4.77	5.20	5.63	6.09	6.53	6.97	7.86	8.24	8.59	8.61	8.62
0.21	0.08	0.15	0.27	0.41	0.55	0.70	0.85	0.99	1.16	1.34	1.52	1.70	2.09	2.49	2.91	3.34	3.76	4.17	4.60	5.02	5.48	5.93	6.41	6.89	7.34	8.28	8.69	9.06	9.07	9.09
0.23	0.08	0.15	0.28	0.43	0.58	0.73	0.89	1.04	1.22	1.41	1.59	1.78	2.19	2.61	3.05	3.50	3.94	4.37	4.82	5.27	5.75	6.22	6.73	7.22	7.70	8.68	9.11	9.50	9.52	9.53
0.25	0.09	0.16	0.30	0.45	0.61	0.77	0.93	1.09	1.28	1.47	1.66	1.86	2.29	2.73	3.19	3.66	4.12	4.57	5.04	5.50	6.00	6.50	7.03	7.54	8.05	9.07	9.52	9.92	9.94	9.96
0.27	0.09	0.17	0.31	0.47	0.63	0.80	0.97	1.13	1.33	1.53	1.73	1.94	2.38	2.84	3.32	3.81	4.28	4.75	5.24	5.73	6.25	6.77	7.31	7.85	8.37	9.44	9.91	10.33	10.35	10.37
0.29	0.10	0.17	0.32	0.49	0.66	0.83	1.00	1.18	1.38	1.59	1.80	2.01	2.47	2.95	3.45	3.95	4.45	4.93	5.44	5.94	6.49	7.02	7.59	8.15	8.69	9.80	10.28	10.72	10.74	10.76
0.31	0.10	0.18	0.33	0.50	0.68	0.86	1.04	1.22	1.43	1.64	1.86	2.08	2.56	3.05	3.57	4.09	4.60	5.11	5.63	6.15	6.71	7.27	7.86	8.43	8.99	10.14	10.64	11.09	11.11	11.13
0.33	0.10	0.19	0.34	0.52	0.70	0.89	1.07	1.26	1.47	1.70	1.92	2.15	2.64	3.15	3.68	4.23	4.75	5.27	5.82	6.35	6.93	7.51	8.11	8.71	9.29	10.47	10.99	11.46	11.48	11.50
0.35	0.11	0.19	0.35	0.54	0.72	0.91	1.11	1.29	1.52	1.75	1.98	2.22	2.72	3.25	3.80	4.36	4.90	5.44	6.00	6.55	7.15	7.74	8.36	8.98	9.58	10.80	11.33	11.81	11.83	11.85
0.38	0.11	0.20	0.36	0.55	0.74	0.94	1.14	1.33	1.56	1.80	2.04	2.28	2.80	3.34	3.91	4.48	5.04	5.59	6.17	6.74	7.35	7.96	8.61	9.24	9.85	11.11	11.66	12.15	12.17	12.20
0.40	0.11	0.20	0.37	0.57	0.76	0.97	1.17	1.37	1.61	1.85	2.09	2.34	2.88	3.43	4.01	4.61	5.18	5.75	6.34	6.92	7.55	8.18	8.84	9.49	10.12	11.41	11.98	12.49	12.51	12.53
0.42	0.11	0.21	0.38	0.58	0.78	0.99	1.20	1.40	1.65	1.90	2.15	2.40	2.96	3.52	4.12	4.73	5.31	5.90	6.50	7.10	7.75	8.39	9.07	9.74	10.39	11.71	12.29	12.81	12.83	12.86
0.46	0.12	0.22	0.40	0.61	0.82	1.04	1.26	1.47	1.73	1.99	2.25	2.52	3.10	3.69	4.32	4.96	5.57	6.18	6.82	7.45	8.13	8.80	9.51	10.21	10.89	12.28	12.89	13.44	13.46	13.48
0.50	0.13	0.23	0.42	0.64	0.86	1.09	1.31	1.54	1.80	2.08	2.35	2.63	3.24	3.86	4.51	5.18	5.82	6.46	7.12	7.78	8.49	9.19	9.94	10.67	11.38	12.83	13.46	14.03	14.06	14.08
0.54	0.13	0.24	0.43	0.66	0.89	1.13	1.37	1.60	1.88	2.16	2.45	2.74	3.37	4.01	4.70	5.39	6.06	6.72	7.42	8.10	8.84	9.57	10.34	11.10	11.84	13.35	14.01	14.61	14.63	14.66
0.58	0.14	0.25	0.45	0.69	0.93	1.17	1.42	1.66	1.95	2.24	2.54	2.84	3.50	4.17	4.87	5.59	6.29	6.98	7.70	8.40	9.17	9.93	10.73	11.52	12.29	13.85	14.54	15.16	15.18	15.21
0.63	0.14	0.26	0.47	0.71	0.96	1.21	1.47	1.72	2.02	2.32	2.63	2.94	3.62	4.31	5.04	5.79	6.51	7.22	7.97	8.70	9.49	10.28	11.11	11.93	12.72	14.34	15.05	15.69	15.72	15.75
0.67	0.14	0.26	0.48	0.74	0.99	1.25	1.52	1.78	2.08	2.40	2.72	3.04	3.74	4.45	5.21	5.98	6.72	7.46	8.23	8.98	9.80	10.61	11.47	12.32	13.14	14.81	15.55	16.20	16.23	16.26
0.71	0.15	0.27	0.50	0.76	1.02	1.29	1.56	1.83	2.15	2.47	2.80	3.13	3.85	4.59	5.37	6.16	6.93	7.69	8.48	9.26	10.11	10.94	11.83	12.70	13.54	15.27	16.02	16.70	16.73	16.76
0.75	0.15	0.28	0.51	0.78	1.05	1.33	1.61	1.88	2.21	2.54	2.88	3.22	3.97	4.72	5.53	6.34	7.13	7.91	8.73	9.53	10.40	11.26	12.17	13.07	13.93	15.71	16.49	17.19	17.22	17.25
0.79	0.16	0.29	0.53	0.80	1.08	1.37	1.65	1.94	2.27	2.61	2.96	3.31	4.07	4.85	5.68	6.51	7.32	8.13	8.97	9.79	10.68	11.57	12.50	13.42	14.32	16.14	16.94	17.66	17.69	17.72
0.83	0.16	0.30	0.54	0.82	1.11	1.40	1.70	1.99	2.33	2.68	3.04	3.40	4.18	4.98	5.82	6.68	7.52	8.34	9.20	10.05	10.96	11.87	12.83	13.77	14.69	16.56	17.38	18.12	18.15	18.18
0.92	0.17	0.31	0.57	0.86	1.16	1.47	1.78	2.08	2.44	2.81	3.19	3.57	4.38	5.22	6.11	7.01	7.88	8.75	9.65	10.54	11.50	12.45	13.45	14.44	15.41	17.37	18.23	19.00	19.03	19.07
1.00	0.18	0.32	0.59	0.90	1.21	1.53	1.86	2.18	2.55	2.94	3.33	3.72	4.58	5.45	6.38	7.32	8.23	9.14	10.08	11.00	12.01	13.00	14.05	15.09	16.09	18.14	19.04	19.85	19.88	19.92
1.08	0.18	0.34	0.61	0.94	1.26	1.60	1.93	2.26	2.66	3.06	3.46	3.88	4.77	5.68	6.64	7.62	8.57	9.51	10.49	11.45	12.50	13.53	14.63	15.70	16.75	18.88	19.82	20.66	20.69	20.73
1.17	0.19	0.35	0.64	0.98	1.31	1.66	2.01	2.35	2.76	3.17	3.59	4.02	4.95	5.89	6.89	7.91	8.89	9.87	10.88	11.89	12.97	14.04	15.18	16.30	17.38	19.59	20.57	21.44	21.47	21.51
1.25	0.20	0.36	0.66	1.01	1.36	1.72	2.08	2.43	2.85	3.28	3.72	4.16	5.12	6.10	7.13	8.18	9.20	10.21	11.27	12.30	13.43	14.53	15.71	16.87	17.99	20.28	21.29	22.19	22.23	22.27
1.33	0.20	0.37	0.68	1.04	1.40	1.77	2.14	2.51	2.95	3.39	3.84	4.30	5.29	6.30	7.37	8.45	9.51	10.55	11.63	12.71	13.87	15.01	16.23	17.42	18.58	20.95	21.99	22.92	22.95	23.00
1.42	0.21	0.39	0.70	1.07	1.45	1.83	2.21	2.59	3.04	3.49	3.96	4.43	5.45	6.49	7.59	8.71	9.80	10.87	11.99	13.10	14.29	15.47	16.73	17.96	19.15	21.59	22.66	23.62	23.66	23.71
1.50	0.22	0.40	0.72	1.11	1.49	1.88	2.27	2.66	3.13	3.60	4.08	4.56	5.61	6.68	7.81	8.97	10.08	11.19	12.34	13.48	14.71	15.92	17.21	18.48	19.71	22.22	23.32	24.31	24.35	24.39
1.58	0.22	0.41	0.74	1.14	1.53	1.93	2.34	2.74	3.21	3.69	4.19	4.69	5.76	6.86	8.03	9.21	10.36	11.50	12.68	13.85	15.11	16.36	17.68	18.98	20.25	22.83	23.96	24.97	25.01	25.06
1.67	0.23	0.42	0.76	1.17	1.57	1.98	2.40	2.81	3.29	3.79	4.30	4.81	5.91	7.04	8.24	9.45	10.63	11.79	13.01	14.21	15.50	16.78	18.14	19.48	20.77	23.42	24.58	25.62	25.66	25.71
1.75	0.23	0.43	0.78	1.19	1.61	2.03	2.46	2.88	3.38	3.88	4.40	4.93	6.06	7.22	8.44	9.68	10.89	12.08	13.33	14.56	15.89	17.20	18.59	19.96	21.29	24.00	25.19	26.25	26.30	26.35
1.83	0.24	0.44	0.80	1.22	1.64	2.08	2.51	2.95	3.45	3.98	4.51	5.04	6.20	7.38	8.64	9.91	11.15	12.37	13.64	14.90	16.26	17.60	19.03	20.43	21.79	24.56	25.78	26.87	26.92	26.97
1.92	0.24	0.45	0.82	1.25	1.68	2.13	2.57	3.01	3.53	4.07	4.61	5.16	6.34	7.55	8.83	10.14	11.40	12.65	13.95	15.23	16.62	18.00	19.46	20.89	22.28	25.11	26.36	27.48	27.52	27.57
2.00	0.25	0.46	0.84	1.28	1.72	2.17	2.63	3.08	3.61	4.15	4.71	5.27	6.47	7.71	9.02	10.35	11.64	12.92	14.25	15.56	16.98	18.39	19.87	21.34	22.76	25.65	26.93	28.07	28.11	28.17
2.08	0.26	0.47	0.85	1.30	1.75	2.22	2.68	3.14	3.68	4.24	4.80	5.37	6.61	7.87	9.21	10.57	11.88	13.19	14.54	15.88	17.33	18.76	20.28	21.78	23.22	26.18	27.48	28.65	28.69	28.75
2.17	0.26	0.48	0.87	1.33	1.79	2.26	2.73	3.20	3.76	4.32	4.90	5.48	6.74	8.03	9.39	10.78	12.12	13.45	14.83	16.20	17.68	19.14	20.69	22.21	23.68	26.70	28.03	29.21	29.26	29.32
2.25	0.27	0.49	0.89	1.35	1.82	2.30	2.79	3.26	3.83	4.40	4.99	5.59	6.87	8.18	9.57	10.98	12.35	13.70	15.11	16.51	18.01	19.50	21.08	22.63	24.14	27.21	28.56	29.77	29.82	29.88
2.33	0.27	0.49	0.90	1.38	1.86	2.34	2.84	3.32	3.90	4.49	5.08	5.69	6.99	8.33	9.75	11.18	12.58	13.95	15.39	16.81	18.34	19.86	21.47	23.05	24.58	27.71	29.08	30.32	30.37	30.42
2.42	0.27	0.50	0.92	1.40	1.89	2.39	2.89	3.38	3.97	4.56	5.17	5.79	7.12	8.48	9.92	11.38	12.80	14.20	15.66	17.11	18.67	20.21	21.85	23.45	25.01	28.20	29.60	30.85	30.90	30.96
2.50	0.28	0.51	0.93	1.43	1.92	2.43	2.94	3.44	4.03	4.64	5.26	5.89	7.24	8.62	10.09	11.58	13.02	14.44	15.93	17.40	18.99	20.56	22.22	23.85	25.44	28.68	30.11	31.38	31.43	31.49
2.58	0.28	0.52	0.95	1.45	1.95	2.47	2.99	3.50	4.10	4.72	5.35	5.99	7.36	8.77	10.25	11.77	13.23	14.68	16.19	17.69	19.30	20.90	22.59	24.25	25.86	29.16	30.60	31.90	31.95	32.01
2.67	0.29	0.53	0.96	1.47	1.98	2.51	3.03	3.55	4.17	4.80	5.43	6.08	7.48	8.91	10.42	11.95	13.44	14.92	16.45	17.97	19.61	21.23	22.95	24.64	26.28	29.62	31.09	32.41	32.46	32.52
2.75	0.29	0.54	0.98	1.50	2.01	2.55	3.08	3.61	4.23	4.87	5.52	6.18	7.59	9.04	10.58	12.14	13.65	15.15	16.71	18.25	19.91	21.56	23.30	25.02	26.68	30.08	31.57	32.91	32.97	33.03
2.83	0.30	0.54	0.99	1.52	2.04	2.58	3.13	3.66	4.29	4.94	5.60	6.27	7.71	9.18	10.74	12.32	13.86	15.38	16.96	18.52	20.21	21.88	23.65	25.39	27.08	30.53	32.05	33.41	33.46	33.52

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FLOW MEASUREMENT OPTIONS FOR CANAL TURNOUTS

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ABSTRACT

Volumetric record-keeping, billing, and allocations at irrigation district delivery points (turnouts) are the norm, rather than the exception for most California irrigation districts. However, many older districts are just beginning these efforts, and other districts are trying to improve existing hardware and procedures. Volumetric accounting with high accuracy and a reasonable price presents unique engineering challenges for irrigation districts because of the variety of existing structures and configurations at irrigation delivery points. Because it is likely that irrigation districts will attempt to utilize existing devices, or slightly modify them, there is a need for standardized installation and/or calibration. This paper discusses three efforts to adapt, improve, and/or calibrate existing technologies for flow rate and volumetric metering of canal turnouts.

INTRODUCTION

In the most basic form, all irrigation turnouts, or delivery points, serve two purposes:

- Starting and stopping the flow of water
- Control of delivered flow rates – typically provided by a mechanism such as a valve or gate. In other cases, the turnout mechanism is adjusted wide open, and the turnout flow rate is determined by something such as the number of alfalfa valves or sprinklers open downstream.

Modern turnouts are also capable of:

- Flow measurement – an instantaneous quantification provided by various methods.
    - For some turnouts, a supplementary device measures the flow rate (with various levels of accuracy) and displays the result digitally or with an analog gauge.
    - More frequently, field measurements of the mechanism's opening, upstream and (sometimes) downstream water levels are applied to an equation or rating table. In these cases, the turnout structure itself is used as the flow measurement device, without auxiliary equipment.
- Volumetric totalizing – an accumulation of the flow measurement over time. The accumulation can be completed by either:
    - Automatically mechanical or electronic methods, or
    - Manually "averaging" multiple, discrete flow measurements over an irrigation event.

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Regulations now mandate that in the near future, many California agricultural irrigation turnouts must be configured to provide flow measurement and volumetric totalizing of delivered irrigation water. Furthermore, the measured quantities must also meet specific accuracy standards for new and existing flow measurement devices (CA SBX77 2009).

In most cases accurate flow measurement requires, among other things, satisfactory hydraulic conditions both upstream and downstream of the flow measurement location. For this reason, flumes are not recommended immediately downstream of a bend in the canal. Similarly, propeller meters are not recommended for installations immediately downstream of a partially closed butterfly valve. In these examples, it is unlikely that the instantaneous flow measurement would reflect the actual flow rate.

From an engineering perspective, achieving flow measurement and automatic volumetric totalizing within acceptable accuracy stipulations has become relatively straight-forward for most <u>pipeline</u> turnouts because:

- The hydraulic conditions upstream and downstream of the flow measurement device can be easily "standardized" with a length of straight pipe. The exact length of straight pipe required by each product is specified by the manufacturer. If there is too little room to fit straight pipe lengths or a skewed flow profile cannot be corrected with straight pipe, commercially available "straightening vanes" can be installed to correct poor upstream hydraulic conditions.
- The round pipe cross section provides a clean and an easily calculated flow area.
- There are numerous commercially available "flow meters" (utilizing various technologies) that provide flow measurement and *automatic* volumetric totalizing with more than acceptable accuracies. Many can also be delivered with factory calibration certificates traceable to the National Institute for Science and Technology (NIST).
- If the piping system is designed properly, the flow meter can be easily removed and re-calibrated by the manufacturer or other entities.
- Flow meters can be easily installed with standard, commercially available fittings.

For the reasons above, meeting flow measurement and volumetric totalizing regulations for new or existing pipeline turnouts has become more of an economic analysis than an engineering topic. A variety of irrigation districts simplify the challenge by requiring that farmers install accessible, properly installed magnetic or propeller meters downstream of their filter systems when the farmers install a drip/micro system.

Conversely, meeting flow measurement mandates for <u>canal</u> turnouts is more complex. Although there are good solutions for new canal turnouts, there are very few new canal turnouts being constructed and it is prohibitively expensive to replace each non-conforming structure at the district level. As such, the remainder of this paper will focus on the options for utilizing existing structures for flow measurement as well as options for retrofitting existing canal turnout structures to meet flow measurement regulatory obligations.

A major constraint for canal turnout flow measurement is access to existing physical configurations. In general, most canal turnout structures and accompanying gate/valve mechanisms are installed in the canal. The structure discharges into a buried pipe under a canal access road. The buried pipe may or may not daylight on the farm side of the access road with various arrangements. This physical configuration limits flow measurement options to one side of the buried pipe or the other, and many districts have limited (or no) jurisdiction to install devices on the farm side of the turnout.

The size and placement of a flow measurement device is also constrained by other factors. The device cannot obstruct normal canal maintenance operations, or be vulnerable to damage from access road traffic (Burt 2010). In addition to these factors, flow measurement devices are also susceptible to typical problems experienced in most open channel applications such as sedimentation, trash and biological debris, and vandalism. Despite these challenges, canal turnout flow measurement has been successful at various levels.

Most existing canal turnouts fit into one of the following categories:

- Simple canal gate that was never designed to provide a means of flow measurement or volume totalizing.
- A “rated” gate to which a prescribed formula or rating table is used in conjunction with field measurements such as the upstream and downstream water levels, and the gate opening. Examples include:
    - ARMCO metergate
    - IID jack gate
    - Constant head orifice
- A simple canal gate, combined with an auxiliary and dedicated flow measurement device including:
    - Open propeller meters
    - Portable or permanent Acoustic Doppler Velocity Meters (ADVMs) and similar electric devices
- Relatively new, complete gate and flow measurement packages (e.g., the Rubicon SlipMeter)
- Pumps, which for the purposes of this paper are considered pipeline turnouts

This paper discusses three specific efforts to work with existing structures to improve accuracy. The three examples are:

1. Verifications of ARMCO meter gate rating tables for standard and non-standard installations
2. A calibration system and procedure for IID jack gates
3. Pilot installations of an adjustable, flow measurement orifice for non-standard canal turnouts

METERGATE CALIBRATIONS

Overview

Metergates are the most common canal turnout structure in California irrigation districts (ITRC 2002), although many (if not most) do not have a proper downstream stilling well. Since the early 1900's metergates have been commercially available from various manufacturers as an integrated canal turnout package, functioning as both a flow control and flow measurement device. Metergates are standard round canal gates with a specific configuration, as shown in Figure 1, which serves to "standardize" the downstream hydraulic conditions for field measurements.

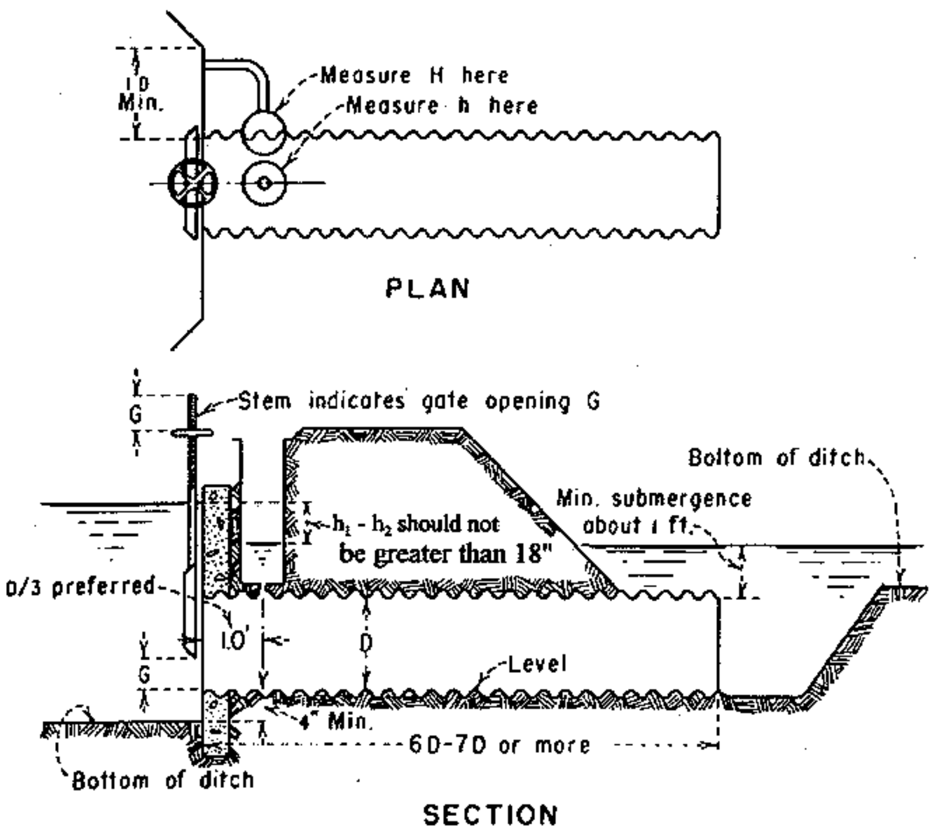

Figure 1. Metergate installation requirements (USBR 1997). Recommended modifications are noted in Burt and Howes (2014).

Flow Measurement. The difference in head pressure between the upstream and downstream sides of the gate mechanism and the gate opening are determined during an irrigation event and applied to manufacturer-provided rating tables (USBR 1997).

Volumetric Totalizing. The irrigation water volume delivered during an irrigation event can be calculated with the following equation:

$$V = \sum_{i=1}^{n}(Q_i \times t) \times \frac{3600}{43560} \qquad \text{Equation (1)}$$

Where,
V = volume delivered (Acre-feet)
Q_i = instantaneous flow measurements (ft^3/sec)
n = number of observations made
t = times between measurements, (hours)
3600/43560 = conversion factor

Calibration Evaluation

Many existing metergate installations do not meet the prescribed installation requirements; for example, the downstream water level measurement connection is often not installed 12" downstream of the gate face. For these and other non-standard metergate installations, applying the standard rating tables provides an unknown flow measurement uncertainty.

ITRC evaluated standard metergate rating tables for both standard and non-standard installations (Howes and Fulton 2013). Round and square gates of various sizes were included in the evaluation.

Results. A summary of the results from the evaluation is provided below (Burt and Howes 2014):

1. A high level of flow measurement accuracy (+/-5%) was found if all of the following conditions are met:
    a. The gate opening is between 20% and 75%
    b. The top of the gate is submerged by a minimum of one-half the gate opening
    c. The location of the downstream water level measurement is between 4" to 12" downstream of the face of the gate
2. A downstream water level measurement location between 4" and 12" downstream of the gate face does not have a significant effect on the flow rate obtained using the existing rating tables unless the gate is open more than 70-75% (percent of fully open).
3. Supply canal (tangential) water velocities did not seem to have a significant impact on the flow through the turnout gates. Supply channel velocities up to 1.9 feet per second (fps) were examined.
4. Higher flow measurement uncertainty (error) occurred at gate openings less than 20%.
5. Optimum range of operation for the highest accuracy was an opening between 20% and 75% under most conditions. Smaller gate openings seemed to be more problematic than larger gate openings.
6. Increased flow measurement uncertainty occurs if the upstream gate face is not submerged by at least one-half the gate height (or diameter). USBR recommends upstream gate submergence of at least a full gate height (or diameter).

During the evaluation, practical installation and operational recommendations were developed for metergates:

1. The buried pipe downstream of any metergate needs to remain full to enable downstream water level measurements.
2. Upstream submergence of at least one-half the gate height (or diameter) is required.
3. The true gate opening needs to be known. This is typically different than simply measuring the vertical gate movement from the seating position because of:
    a. Tolerances between the gate stem and the gate face. There is almost always measurable “slop” (0.25” or more) in the stem-gate connection.
    b. Overlap of the gate face to the actual opening. To fully seated (closed) position, most round and square canal gate faces must overlap the flow area opening.
4. The true gate zero should be marked by a grinder or other permanent means other than a marker or paint.
5. A stilling well should be installed on the downstream water level measurement location. The stilling well provides dampening of water level fluctuations due to turbulence. The stilling well should be:
    a. At least 6”-8” in diameter with a small access hole to the buried pipe of approximately ¾” diameter. Not only does this combination of sizes provide for adequate dampening, but also:
        i. The larger diameter allows easier measurements. The operator can actually see the water level and use a standard tape to measure down.
        ii. The larger diameter allows for cleaning the stilling well, such as removing sediment, trash, leaves, and other debris.
    b. The top of the stilling well should be equal in elevation to the top of the gate frame. This ensures that a single reference plane is available to the operator to measure the upstream water level (down from the gate frame) and the downstream water level (down from the top of the stilling well).

<u>Discussion</u>. The results of the evaluation indicated that with the proper installation, preparation and operation techniques, metergates could achieve acceptable accuracies for both flow measurement and volumetric totalizing.

- The delivered <u>flow rate</u> can be measured within acceptable accuracies using rating tables as long as various key conditions are met. The ITRC rating tables also provide flow measurements with improved uncertainties for less-than-ideal gate openings (less than 25% or greater than 75%).
- Delivered <u>volumes</u> of water can meet required accuracy standards with sufficient periodic flow measurements. The minimum frequency of those periodic measurements must be determined by local conditions, such as the variability in the water level of the supply canal.

IID GATE CALIBRATION SYSTEM

The typical canal turnout for Imperial Irrigation District (IID) is a jack gate. The name is derived from the lifting mechanism. A typical IID jack gate is shown in Figure 2.

Figure 2. A typical IID jack gate

For flow measurement, the difference in head pressure between the upstream and downstream sides of the gate mechanism and the gate opening are measured during an irrigation event and applied to gate discharge equations. It is difficult to determine the validity of the equation and its coefficients without verification. Furthermore, different equations and sets of measurements are required for submerged and free flow conditions.

Various theoretical and analytical methods have been proposed to determine the correct coefficients based on field-measured ratios such as the relative opening using momentum or energy conservation approaches (Belaud et al 2009); however, these are likely too complex for utilization in the field. Rather, it was proposed that the general submerged and free flow gate discharge equations could be used (or rating tables) to provide sufficiently accurate flow measurement if the discharge coefficient was determined empirically. The general gate discharge equation for a submerged flow condition is shown as (USBR 1997):

$$Q = CA\sqrt{2g\Delta H} \qquad \text{Equation (2)}$$

Where,
C = discharge coefficient
A = open flow area (ft^2)
g = acceleration of gravity, (ft/sec^2)
ΔH = head differential across the gate (ft)

For gates that operate in free-flow conditions, the following general equation is used:

$$Q = CA\sqrt{2gH} \qquad \text{Equation (3)}$$

Where,
C = discharge coefficient
A = open flow area (ft^2)
G = acceleration of gravity, (ft/sec^2)
ΔH = upstream head (ft)

Through in-situ field testing, the discharge coefficient could be determined. It was thought that such an approach would not only simplify the flow measurement process compared to other methods, but also provide verified field data as an improvement over theoretical equations.

Characterization Overview

Transitioning flow conditions and the variety of (i) side contractions, (ii) bottom contractions, and (iii) hydraulic entrance conditions further complicate the use of theoretical equations and coefficients. Because it would also be economically infeasible to standardize all IID jack gates through replacement, it was determined that characterizing jack gates could be a possible solution to meet district-level flow measurement obligations.

In cooperation with Sawtelle and Rosprim, a Corcoran, CA fabrication firm, ITRC modified a “moon-buggy” pumping system that would be used to calibrate individual IID jack gates. The pumping system is shown in Figure 3.

Figure 3. Pumping system for IID jack gate characterization

Fundamentally, the pumping system can be used to characterize canal turnouts by delivering water through the gate, and pumping the water back to the supply canal while measuring the flow rate with redundant, certified flow meters.

More specifically, the characterization process was conducted as follows:
1. The supply canal would be configured to provide relatively good water level control via weir flow, and the water level was manually adjusted to be close to the high water mark. Therefore, slight fluctuations in the canal water level would be a smaller percent of the total submergence of the gate.
2. A removable dam was installed in the farm ditch approximately 60 feet downstream of the turnout gate.

3. The suction piping of the pumping system was set approximately 20-40 feet downstream of the turnout gate.
4. The discharge piping of the pumping system was set to return into the supply canal.
5. The true gate zero was determined.
6. The gate was slowly opened to deliver a historic maximum flow, and the pumping system flow rate was adjusted via hydraulic Vernier controls.
7. The pumping system flow rate was adjusted so that the farm ditch had little freeboard, but a consistent depth.
8. Once the farm ditch water level had stabilized at the maximum flow rate, multiple flow meter readings and gate water level measurements were recorded over a period of 10 minutes.
9. The gate position was adjusted to lower the flow rate, and the process was repeated.
10. The field data was recorded at a total of three flow rates: a historical maximum, a medium flow rate, and the historical minimum flow rate.

The field measurements were entered into a spreadsheet that was set up to automatically calculate a discharge coefficient at the particular flow rate and gate opening. Equation (4) is rearranged from Equation (2) for a submerged flow condition:

$$C_d = \frac{Q}{A\sqrt{2g\Delta H}} \qquad \text{Equation (4)}$$

Results

To train IID staff on the characterization operations, a full gate characterization was completed. A jack gate was characterized at three different flow rates. Using Equation (4) the results from the completed characterization are shown in Table 1.

Table 1. Results of completed jack gate characterization

	High Flow	Medium Flow	Low Flow
Submerged (Y/N)	Y	Y	Y
Measured Flow Rate (CFS)	11.09	7.25	3.96
Δ H (ft)	0.26	0.34	0.48
Flow Area (sq. ft)	3.81	1.90	0.78
Discharge Coefficient, Cd	**0.715**	**0.815**	**0.912**

The three discharge coefficients can then be plotted to develop an equation to solve for interpolated discharge coefficients for any expected flow rate. The plot is shown in Figure 4. A linear trendline was developed so that discharge coefficients can be interpolated with a reasonable level of accuracy (R^2 = 0.9988), for flow rates typical of the specific canal turnout.

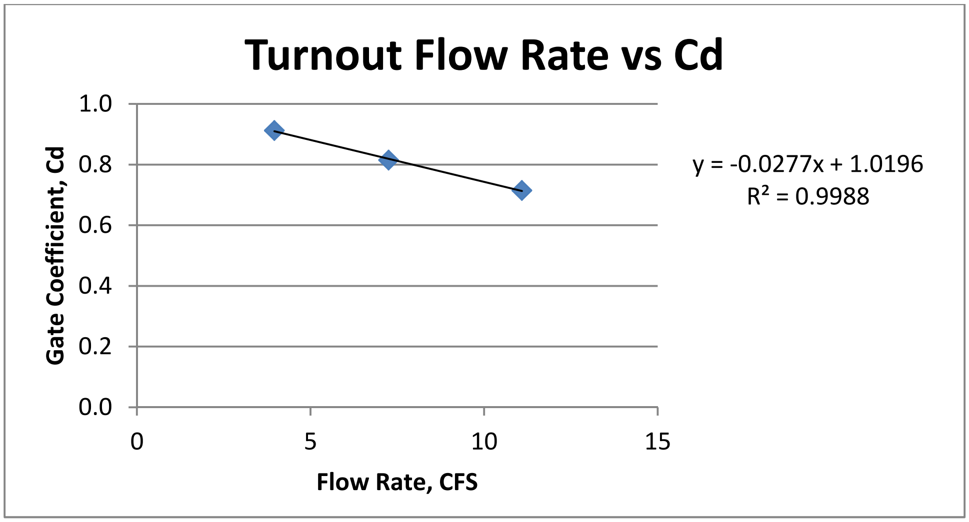

Figure 4. IID jack gate – flow rate versus discharge coefficient

Discussion

Some jack gates transition between free flow and submerged flow conditions. The transition between flow conditions can occur between low and high flow rates, or be caused by fluctuating downstream conditions throughout irrigation events.

For these transitional flow condition turnouts, it can also be difficult to properly identify the flow condition, and can be confusing to operators. For these sites, it would be recommended that a hydraulic "bump" be installed downstream of the jack gate to raise the water level downstream of the gate for a short distance. This would ensure the gate operates under submerged flow conditions for typical delivered flow rates.

Flow Measurement. The pumping system was successful in developing individual discharge coefficients, which could be used in conjunction with the appropriate gate discharge equation and field measurements. It is expected this method would provide flow measurement within the stipulated accuracies for existing gates.

However, many of the same practical and operational recommendations developed by ITRC from the metergate evaluation also apply to the use of gate discharge equations for jack gate flow measurement, including:

1. Determining a true gate zero opening position
2. Permanently marking that position
3. Providing a single reference plane for water level measurements for submerged flow gates

In addition, ITRC recommended that jack gate turnouts could be categorized by similar hydraulic conditions such as:

- Submerged, free-flow, or transitioning conditions
- Suppression or contraction on the gate sides
- Suppression or contraction on the gate bottom

By categorizing gates, the total number of characterizations could be significantly decreased. A second gate characterization was started as part of the training, but was not completed with ITRC support.

Volumetric Totalizing. Similar to the metergate, operators must take one or more instantaneous flow measurements and apply those to Equation (1) to determine the delivered irrigation water volume per irrigation event.

Challenges. A complete turnout characterization took approximately 6 hours; however, much of that was focused on IID staff training on the transportation, operation and data analysis. It is likely that after a few iterations, two complete characterizations could be completed in less than 8 hours with a team of 2-3 operators/engineers, if the two turnouts were somewhat close together along the same channel.

Safe transportation along a canal access road was possible with a standard 1-ton truck; however, over-the-road transport required a semi-truck and trailer with “oversize” flags.

Cost. The complete pumping system, parts and accessories cost approximately $110,000. Although the initial capital investment is relatively large, the cost per turnout is much lower in such a large district. Furthermore, the pumping system can be, and probably will be, used for other district operations such as dewatering canals.

ADJUSTABLE ORIFICE PLATE

There are many existing California canal turnouts that were never designed to provide flow measurement, or never installed properly to meet certain conditions. For these installations, districts will need to either replace the structure or install an auxiliary device to provide accurate flow measurement and volumetric totalizing.

For these structures, ITRC examined the applicability of an adjustable orifice plate with a key feature – a datalogger with single pressure transducer that measured the differential head across the orifice. There is nothing new about using orifice plates upstream of a flow control gate – this application was designed for the case of frequently varying flow rates into a turnout that would not be properly measured by the district operators. The plate can be installed without replacing the existing structure, keeping everything on the irrigation district side of the access road. The orifice plates can be installed vertically or parallel with a canal’s side slope, upstream of an existing canal turnout, as shown in Figure 5.

Figure 5. Orifice plate configuration with an existing non-standard metergate

Orifice Plate Overview

The orifice plate approach combines a standard USBR submerged orifice discharge equation with the physical configuration of a constant head orifice (CHO). The discharge equation is the same as Equation (4), for a submerged flow gate, with the exception of the discharge coefficient. Provided the following conditions are met, a C_d of 0.61 can be used (USBR 1997):

- The upstream edges of the orifice should be straight, sharp, and smooth.
- The upstream face and the sides of the orifice opening need to be vertical.
- The top and bottom edges of the orifice opening need to be level.
- Any fasteners present on the upstream side of the orifice plate and the bulkhead must be countersunk.
- The face of the orifice plate must be clean of grease and oil.
- The thickness of the orifice plate perimeter should be between 0.03 and 0.08 inches. Thicker plates would need to have the downstream side edge chamfered at an angle of at least 45 degrees.
- Flow edges of the plate require machining or filing perpendicular to the upstream face to remove burrs or scratches and should not be smoothed off with abrasives.
- For submerged flow, the differential in head should be at least 0.2 feet.
- Using the dimensions depicted in Figure 6, P > 2Y, Z > 2Y, and M > 2Y.

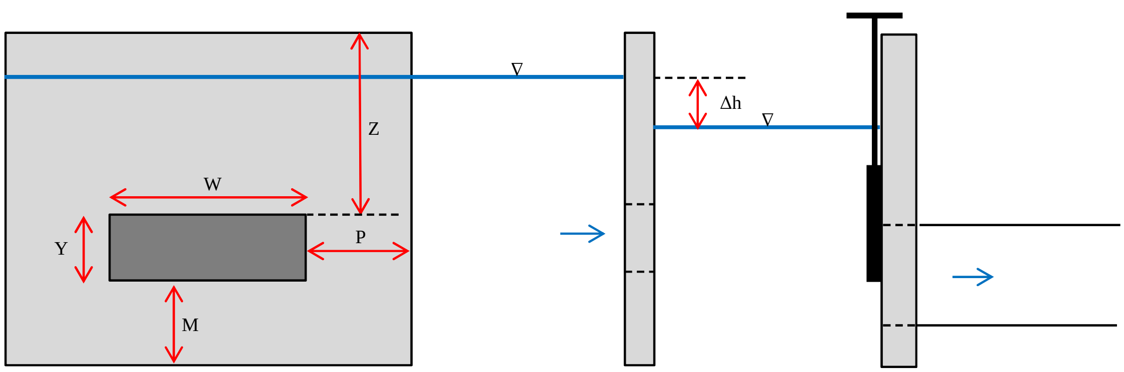

Figure 6. Submerged orifice dimensional requirements

It was proposed that the orifice area be made adjustable so that a range of flows could be delivered, while maintaining a measurable head differential across the orifice (0.2' minimum).

Operators could then use a rating table to choose an appropriate orifice opening to meet the irrigation demand, such as the one as shown in Table 2.

Table 2. Orifice plate rating table

	Width of Orifice Opening, ft											
	2.5											
	Height of Orifice Opening, ft											
	0.5	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.5
Flow Rate, CFS	Change in Head, ft											
30.0											1.04	0.96
25.0									1.04	0.86	0.72	0.67
20.0							1.04	0.82	0.67	0.55	0.46	0.43
15.0					1.04	0.77	0.59	0.46	0.38	0.31	0.26	0.24
10.0			1.04	0.67	0.46	0.34	0.26	0.21	0.17	0.14	0.12	0.11
9.0			0.85	0.54	0.38	0.28	0.21	0.17	0.14	0.11		
8.0		1.19	0.67	0.43	0.30	0.22	0.17	0.13	0.11			
7.0		0.91	0.51	0.33	0.23	0.17	0.13	0.10				
6.0	0.96	0.67	0.38	0.24	0.17	0.12						
5.0	0.67	0.46	0.26	0.17	0.12							
4.5	0.54	0.38	0.21	0.14								
4.0	0.43	0.30	0.17	0.11								
3.5	0.33	0.23	0.13									
3.0	0.24	0.17										
2.5	0.17	0.12										
2.0	0.11											
1.5												
1.0												

The orifice can be adjusted and locked in place with pins at discrete orifice opening intervals (0.1'), as shown in Figure 7.

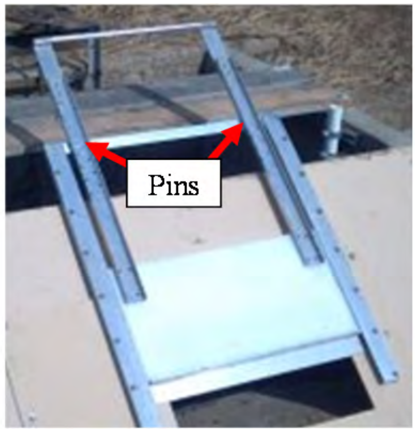

Figure 7. Adjustable orifice

Flow Measurement. The existing canal gate would then be used to start and adjust the delivered flow. The flow rate can be manually measured by using an incorporated stilling well, as shown in Figure 8.

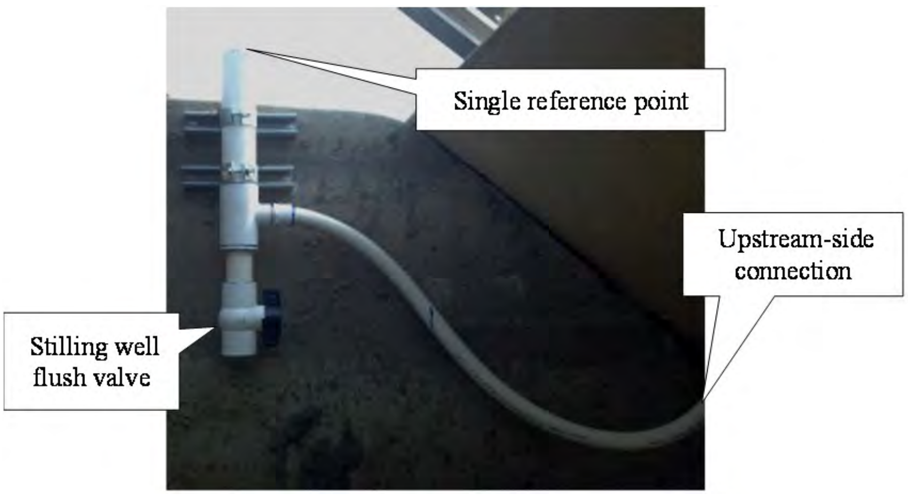

Figure 8. Stilling well configuration, installed downstream of the orifice plate

With the orifice width fixed and the orifice height known, the head differential is measured by two methods. Manual head differential measurements are taken at the top of the stilling well. The upstream water level is measured from the top of the stilling well to the water level inside. The downstream water level is also measured from the top of the stilling well to the surrounding water level. In addition, a differential pressure transducer and data logger is installed to record the head differential measurement over time.

Volume Totalizing. Manual flow measurements could be averaged and the volume totalized using Equation (1). The data logger provides a redundant record of instantaneous flow measurements at 2.5 minute intervals. The spreadsheet data can then be manipulated using a computer program such as Microsoft Excel® to calculate delivered volumes.

Results

Flow Measurement. ITRC installed two orifice plates with single pressure transducers: one at Patterson Irrigation District (PID) and a second in Merced Irrigation District (MID). During the first season, problems with the differential pressure transducer were found. However, the PID installation has continued to operate over two complete irrigation seasons. The PID data was retrieved and plotted. The PID flow measurement results using Equation (2) and a discharge coefficient of 0.61 are shown in Figure 9.

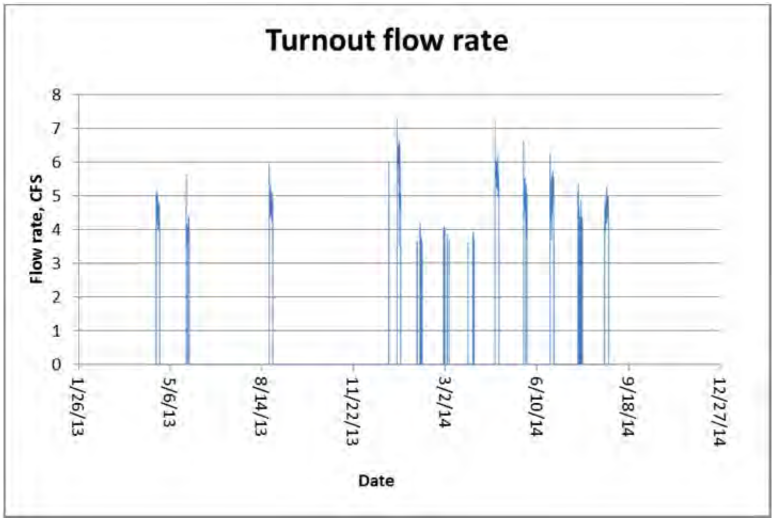

Figure 9. PID orifice plate flow measurement data

Volume totalizing. Using the same spreadsheet, the delivered volumes were calculated and accumulated over two irrigation seasons. The volumetric results are shown in Figure 10.

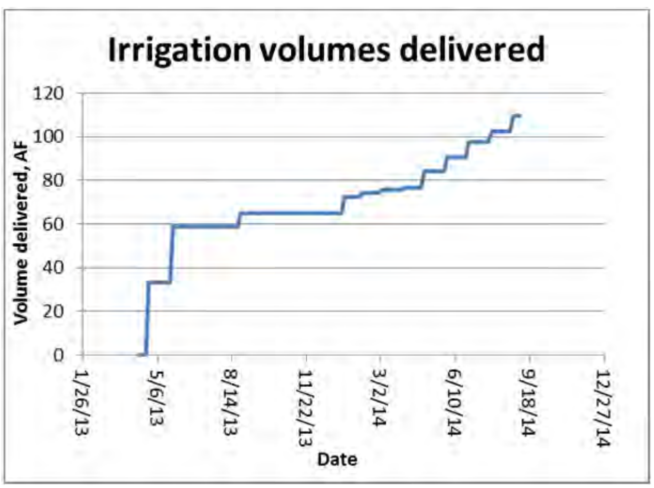

Figure 10. PID orifice plate volumetric data

The turnout delivered roughly 65 acre-feet during the 2013 irrigation season and 55 acre-feet during the 2014 irrigation season.

Discussion

Although the orifice plates were not calibrated at a flow measurement facility, their configuration provided a method of applying standard discharge equations to non-standard canal turnouts. Further evaluation may be conducted in the future regarding the discharge coefficient in both the vertical orifice and slanted orifice orientations.

Challenges. The Telog data logger utilized for these and other trials has proven to be a rugged and dependable tool for research. However, data retrieval requires a field visit, as well as a proprietary cable and program installed on a laptop. Recent technological advances have become readily available for these applications such as wireless communication, cloud-based databases, and automated reporting. However, that advanced technology would do little to resolve most of the challenges experienced during this experiment.

The most challenging aspect to the expanded implementation of the orifice plate trials was finding adequate sensing products. There are very few manufacturers of submersible, differential pressure transducers of the type used in this experiment. Even fewer of these available products are sufficiently rugged for the application. One of the two GE Druck pressure transducers experienced significant drift over the first season. It has since been removed until another solution can be found. Future testing of orifice plates for flow measurement will likely include various other sensing technologies.

Cost. Each orifice plate cost roughly $6,000 to fabricate and install in the field. The cost of construction could likely be decreased with less expensive materials and local fabrication shops.

CONCLUSION

Various methods are available to irrigation districts that can provide canal turnout flow measurement and volumetric totalizing that conform to regulatory standards. However, the variety of existing canal turnout structures, their hydraulic conditions, and specific local considerations will likely result in an equally varied implementation of flow measurement and volumetric totalizing across California.

Regardless of the method used for flow measurement and volumetric totalizing, there will likely be further challenges in the future for irrigation districts to aggregate and organize the large amounts of volumetric data.

ACKNOWLEDGEMENTS

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SBx7 Flow Rate Measurement Compliance for Agricultural Irrigation Districts

SBx7 Compliance

Aug 26, 2012

SBx7 Compliance for Agricultural Irrigation Districts

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GROUPED DELIVERIES

Senate Bill x7-7 (SBx7-7) requires documented volumetric accounting to individual turnouts for water deliveries. Section 597.3 of the bill lists two very different requirements for devices (***bold, underlined, italics*** have been added for emphasis):

- Section 597.3(a) discusses measurement devices that must be used at points where there is a reasonable degree of flow rate control.
- Section 597.3(b) states that "An agricultural water supplier may measure water delivered at a location upstream of the delivery points or farm-gates of multiple customers using one of the measurement options described in §597.3(a) if the downstream individual customer's delivery points meet ***either*** of the following conditions:

  A. The agricultural water supplier does not have legal access to the delivery points of individual customers or group of customers to install, measure, maintain, operate, and monitor a measurement device.

     Or,

  B. An engineer determines that due to small differentials in water level ***or*** large fluctuations in flow rate or velocity that occur during the delivery ***season*** at a single farm-gate, accuracy standards of the measurement options in §597.3(a) cannot be met by installing a measurement device or devices (manufactured or on site built or in-house built devices) with or without additional components (such as gauging rod, water level control structure at the farm-gate, etc.).

This last section (B) in essence defines the most downstream point of measurement to be located at the "hand-off point".

The "hand-off point" can be defined as the location, moving downstream in the branching hydraulic network, below which the irrigation district no longer has good control over the flow rates that go to individual farm-gates.

For example, one might consider using a ditch or pipeline with a rotation delivery schedule, with one "head" or delivery at a time. That single "head" or flow rate is rotated among users, one at a time. There is no control over flow rates at individual turnouts (along that ditch or pipeline); the flow rate is controlled at the head of the ditch or pipeline.

This is also true of ditches or pipelines with a rotation delivery schedule, with two or three "heads" or deliveries. These systems typically have little or no precise flow control downstream of the heading. In some districts, the delivery points are not even to a field; the distribution pipelines have alfalfa valves for each border strip that is irrigated. When there is an internal splitting of two "heads", it is done without the benefit of the structures that provide good water level or pressure control.

While it may be possible in many cases to install flow measurement devices within these pipelines or canals, the measurement would be of uncontrolled flows unless the pipelines or canals were substantially modified. In other words, "additional components" besides the flow measurement devices would be required.

Rice systems are a special category, as good water management of rice irrigation is premised on maintaining a target water level in the fields, rather than on delivering a specific volume to a specific field.

That said, with traditional rice laterals, or with traditional rotation laterals, it is entirely reasonable to require farmers with new pressurized systems on such ditches/pipelines to install magnetic meters or propeller meters on their systems. Such flow measurement installations are rather typical and do not represent technical or fiscal challenges for implementation.

Conclusions

1. The wording of SBx7 appears to clearly indicate that the proper, most downstream flow measurement location would be at the head of any "community ditches". "Community ditches" (sometimes called "improvement districts") are defined as privately owned distribution systems that receive water from the irrigation district. The distribution, partitioning, and scheduling of water deliveries within the "community ditch" is not done by irrigation district personnel.
2. Irrigation district ditches and pipelines that are operated on a rotation schedule need an accurate flow measurement device at the head of the ditch or pipeline, but not at individual delivery points within/along the ditch or pipeline that receives water on a rotation schedule. This pertains to ditches and pipelines that are owned either by improvement districts or by irrigation districts.
3. Individual delivery points with pressurized irrigation systems that receive water from an irrigation district ditch or pipeline that is primarily a "rotation" system must be individually metered.

Note: The phrase "irrigation district" encompasses a wide range of district types including reclamation districts (e.g., RD108), water districts (e.g., Coachella WD), irrigation districts (e.g., Modesto ID), and Water Storage Districts (e.g., Buena Vista WSD).

FLOW RATE VS. VOLUMETRIC ACCURACY

SBx7 requires the verification of the accuracy of annual volumes provided at delivery points.

- For devices **with** totalizers, it can be assumed that:

  Flow rate accuracy = Volumetric accuracy

- For devices such as meter gates and orifice plates that do **not** have totalizers, the flow rate accuracy may only be part of the total desired 12% volumetric accuracy. The annual volumetric accuracy of any such single turnout depends upon errors due to:
  - IFR – Instantaneous flow rate error
  - CWLF – Canal water level fluctuations, or pipeline pressure fluctuations over time. The impact of these fluctuations are mostly self-canceling over the course of an irrigation season. This is discussed later in this report.
  - CBP – Changes in "backpressure". Backpressure is the pressure on the downstream side of the flow measurement device.
  - ARD – Accuracy of the recording of durations. For example, if an actual delivery lasts for a total of 25 hours but it is recorded and billed as a 24-hour delivery, this would be an error of one hour, or 4.2%

These inaccuracies must be mathematically combined to determine the total volumetric accuracy.

$$Volumetric\ accuracy = 100\ \times \left[1 - \sqrt{(IFR)^2 + (CWLF)^2 + (CBP)^2 + (ARD)^2}\right]$$

For example, assume the following errors expressed as decimals rather than as percentages. These are plus/minus errors ("within 5%" means "within +/- 5%"):

IFR is within 5% (IFR =.05) CBP = .03
CWLF = .02 ARD = .04

Then,

$$Volumetric\ accuracy\ (VA) = 100\ \times \left[1 - \sqrt{(.05)^2 + (.02)^2 + (.03)^2 + (.04)^2}\right]$$

$$VA = 92.7 = 93\%$$

The errors are independent of each other. Therefore, the total error does ***not*** equal the sum of the errors (14%), which would incorrectly indicate an 86% accuracy.

The maximum acceptable flow rate measurement error (expressed as a decimal) equals:

$$\text{Max. acceptable device flow rate error} = \sqrt{(1 - \frac{VA}{100})^2\ -\ ARD^2 - CBP^2 - CWLF^2}$$

For example, if the required volumetric accuracy (VA) = 88% (88) (i.e., within 12%) and:
ARD = .04 CBP = .03 CWLF = .02

Then, the maximum acceptable device flow rate accuracy error = 0.107 = 10.7%

That is, this specific device, when tested at a specific representative flow rate, must be within 89.3% accuracy.

Impact of Canal Water Level Changes on Annual Volumetric Accuracy

Background

The volume delivered through flow measurement devices without totalizers is computed as:

$$\text{Volume} = (\text{Flow Rate}) \times \text{Time}$$

The flow rate is typically checked once per day, and a new flow rate is either noted on the records, or the flow rate control device is re-adjusted to provide the target flow rate.

During any 24-hour period, the canal water levels will fluctuate, resulting in a delivery of more or less flow rate than was originally set.

The question addressed in this section is: Over the course of an irrigation season with ten, twenty, or thirty 24-hour irrigation events, do these minute-to-minute fluctuations cancel out? If they do, this will remove the "CWLF" (discussed in the previous section) from consideration.

To examine this, ITRC obtained water level data from multiple locations throughout San Luis Canal Company, over a time period from June 8 to July 11, 2012. Canal levels were recorded automatically on an hourly basis. The total change in water level across the turnout [(water surface in the canal) - (water surface in the downstream ditch)] was also recorded at the start of each datalogging session. The irrigation district has typical flashboard check structures to maintain water levels in the majority of its locations.

A series of 22 sites were analyzed for 48-72 hours. It is believed that these sites are representative of the range of conditions throughout the district. No special management of the check structures was involved; the canal operators were unaware that the levels were being recorded.

Error Analysis

Water Level Error Model

In order to assess the error of volumetric flow rate measurement in the canal system, first the fluctuations in water level must be computed. A model was constructed to measure the percent error of the water level over a 24-hour period from a given starting point in the sample set.

The raw data was normalized so that canal fluctuations would be represented as a percentage of the head difference. In this way, all the data points could be accumulated to create a contiguous set of hourly fluctuations for the model data set. The resulting model contains a total of 5500 hourly data points.

Sample Set

A sample set was generated from the model. The sample set contained three different blocks. Each block had 30 different seasons with varying numbers of irrigations events per season. Block 1 had 30 seasons of ten 24-hour irrigations, Block 2 had 30 seasons of twenty 24-hour irrigations, and block 3 had 30 seasons of thirty 24-hour irrigations.

The starting points for the irrigation events in each season were selected by a random number generator. The error was recorded for each hour from the starting point for a total 24 hours. Thus, each irrigation event consisted of 24 data points, resulting in a total of 21,600 data points sampled for all of the seasons in all 3 blocks.

Results

If the present water level for a moment during an irrigation event in the model is equal to the starting water level for that event, then the percent error at that moment is zero. The percent error at each recorded time during an irrigation is calculated by the following equation:

$$\%\ Error\ at\ a\ moment = \frac{Present\ Water\ Level - Initial\ Water\ Level}{Initial\ Change\ in\ Head} \times 100$$

Where "Initial Water Level" is the water level when the 24-hour irrigation began.

The characteristics of the population of "errors" in water level are shown in the figure below.

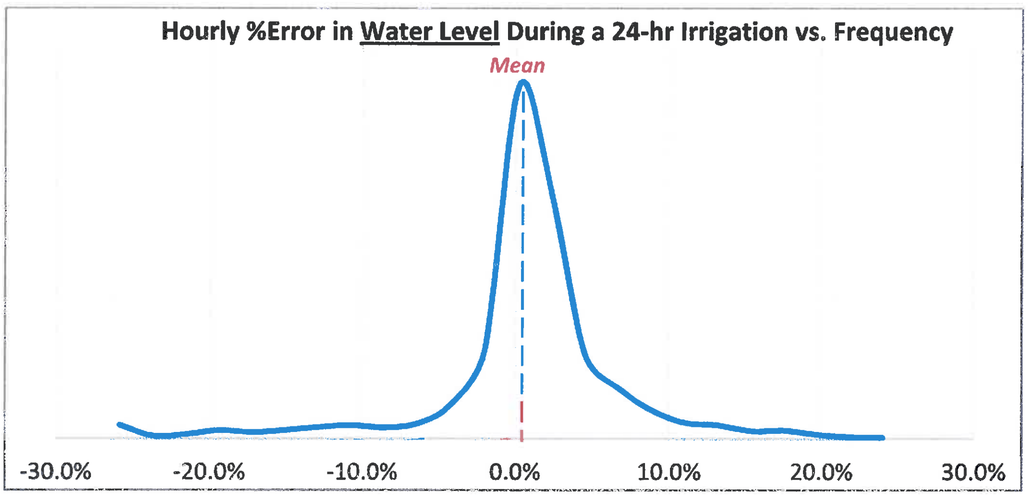


Figure 1. Sample distribution for hourly % error in water level vs. frequency

The variation in relative water levels over time is interesting, but of more interest is the impact on turnout flow rates. There are two possible situations, described below:

1. The flow measurement device is operated under "free flow". That is, the water jets out from it, and the flow rate through the orifice device is not affected by changing downstream water levels. The variation in flow rate over time can be computed, based solely on the upstream water level change. In this case, the sensitivity of the turnout flows to canal water levels is computed as:

$$Free\ Flow\ Error = (1 + Level\ Error)^{0.5} - 1$$

2. The flow measurement device operates under a "submerged" condition. In this case, what happens is that if the canal water level changes, the flow through the measurement device increases. But that also results in a rise in the downstream water level. This provides a "pressure compensating" effect. The total head change is less than the change in the canal water level. ITRC has examined a number of possible downstream channel conditions, and uses the following equation to estimate the effect of a change in canal water level:

$$Submerged\ Flow\ Error = (1 + Level\ Error)^{0.38} - 1$$

For each block (group of 30 randomly selected seasonal irrigation cycles), the mean and standard deviation of the error were computed. **Figure 2** shows the results of the analysis. The mean error is plotted for each block along with the standard deviations. The red bars are 1 standard deviation above the mean, and the green bars are 1 standard deviation below the mean.

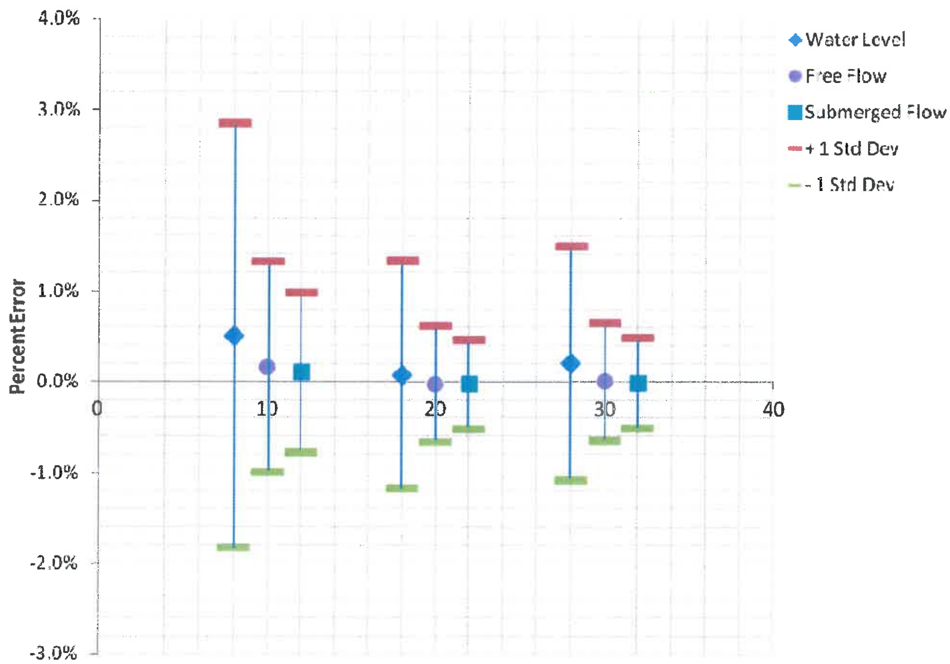


Figure 2. Means and standard deviations for each block

Conclusion

For the condition of 10 irrigations per season, the seasonal flow rate error due to fluctuating canal water levels averages less than 0.2%, regardless of whether the turnout is free flow or submerged flow. The average seasonal error for 20-30 irrigations per season is almost 0.0%.

Because most irrigation districts deliver more than 10 irrigations per season, it appears that a reasonable estimate of the annual volumetric error due to a fluctuating canal water level is about +/- 0.5%, when one considers one standard deviation from the mean.

While this data originated in a single district, ITRC believes that the conditions are representative of "typical" canal districts, based on experiences in about 150 irrigation districts in the western U.S. The exception would be the few irrigation districts that have a very extensive distribution of long-crested weirs or ITRC flap gates throughout the canals. An extreme example would be Modesto ID, in which case almost every check structure is a long-crested weir. In that case, the seasonal impact of fluctuating canal water levels is likely 0.0%, for all practical purposes.

SELECTION OF A REPRESENTATIVE SAMPLE FOR VERIFICATION OF ACCURACY

California Legislature SBx7 requires flow measurement devices to be within a required level of accuracy. For existing flow measurement devices, the acceptable error for volumetric flow measurement is ±12% as stated in §597.3(a)(1). Initial certification of existing devices requires a random and statistically representative sample set <u>or</u> an accepted statistical methodology as described in §597.4(a)(1) and §597.4(b)(1). This document defines a statistical methodology that can be used to provide good information that meets both the intent of SBx7 and the needs of the irrigation districts.

Background

Representative Sample

Irrigation districts have turnouts with flow measurement devices that supply water to areas with correspondingly varying annual delivered volumes. The selection process defined below is intended to define how to select a representative sample set of flow measurement devices for verification of volumetric measurement quality in the district as whole.

In an irrigation district with a wide range of acreages downstream of flow measurement devices, a simple random selection of measurement devices would statistically over-emphasize the importance of small delivery points. The sampling may only represent a very small percentage of all the water delivered in the district. The volume delivered through a turnout is related to the size of the area irrigated. Therefore, it is better to weigh the importance of each measurement device according to the area it services, rather than weighing all turnouts equally. Thus, the sample of flow measurement devices to be tested will be constructed using a ***probability-proportional-to-size (PPS)*** sampling method so that the likelihood of inspection for a given flow measurement device will be proportional to the acreage served by that device.

Considerations for Availability

Ideally, all the devices would be randomly selected by the PPS sampling process mentioned above, and then the selected devices would be evaluated for accuracy. However, only some percentage of the turnouts will be operating at a given time. Therefore, if a turnout is selected in a purely random manner, the customer served by that turnout may not be ready to irrigate, prohibiting evaluation of the flow measurement device at that turnout. It is also clear that even if farmers are scheduled to receive water from a turnout on a specific date/time, they do not always irrigate on that schedule; this makes advance and careful scheduling of field evaluations problematic.

A solution to this is to use ***opportunity sampling*** in combination with ***sampling quotas***. An opportunity sample is composed of samples taken as they are available or convenient. Since device availability will be an issue, devices should be inspected when they are available.

Point #1: To ensure that the data set is representative of the district's overall volumetric flow measurement, a minimum of 10% of the district's service area (or volume) should be represented by the combined service acreage for the turnouts in the sample set.

Point #2: To meet the SBx7 requirements, the minimum sample size of 5 and maximum of 100 for a particular device type should be evaluated.

Point #3: Two scenarios for sampling are described in this document:
- Advance Probability-Proportional-To-Size (PPS) Sampling
- Opportunity Sampling with a consideration of PPS

Scenario 1: Acreage-Based Sampling Using Probability-Proportional-to-Size (PPS)

Scenario 1 is the ideal situation, where at any given time all turnouts will be available for inspection.

Background

Representative Sample Selection

Flow measurement devices in a district will be assigned a number ***range*** based on the acreage (or known annual volume) that the devices serve (e.g., a turnout servicing 10 acres may be assigned 10 numbers such as 61-70). This numbering will have a logical sequencing that is appropriate for the given district. A random number generator will then be used to select a device from the developed sequence. In this way each device will be weighted in selection by the acreage it serves. Specifically, the sample will be skewed favoring devices that measure greater volumes of water. This will ensure that the random sample will be statistically representative of the overall accuracy of flow measurement within the district.

Random Selection Process

A random number generator will be used to select a device to be tested. If the number produced by the random number generator is within the range assigned to a device, then that device will be tested. Once a device has been tested, its range will no longer be considered in the selection process, and numbers randomly generated in its range will be ignored. This procedure will be improved from the example given in §597.4(b)(1), in that devices providing at least 10% of the district volume or acreage (rather 10% of the devices) will be tested, with a minimum of 5 devices, and not to exceed 100 individual devices of a certain type.

Device Types

It is important to take note of device types for this legislation. If 25% of existing devices (as estimated from the properly selected sample) of a particular type are not in compliance with ±12% accuracy requirements, the district must develop a plan to test another sample of measurement devices of this type as stated in §597.4(b)(2). This document interprets the intent of the legislation as applying to 25% of water delivered, rather than 25% of existing devices. For illustration, in the extreme case of a district with the following:

- 100 garden plots of 0.25 acres each, each with a measurement device (25 acres total)
- 50 larger fields of 80 acres each, each with a measurement device (4000 acres total)

Certainly, careful irrigation water management would not focus on the large number of very small plots that represent less than 1% of the total acreage. This document therefore assumes that the proper interpretation is to focus on reasonable measurement of at least 25% of sample water volume, rather than 25% of the sample devices.

Step 1: Assign Sequence Range Numbers to Each Turnout

Table 1 describes a sample scenario and shows a sequence range of number assignments for each turnout. The district in the sample scenario has one lateral with 10 turnouts serving a varying array of acreage.

Table 1. Example of assigning sequence range numbers

Turnout #	Acreage Served	Sequence Range From	Sequence Range To
1	10	1	10
2	10	11	20
3	15	21	35
4	15	36	50
5	2	51	52
6	2	53	54
7	5	55	59
8	5	60	64
9	50	65	114
10	50	115	164
Total	**164**		

Note that the final sequence number should be equal to the total acreage

Each turnout is assigned sequence range numbers based on their acreage. Turnout 1 is assigned the sequence range from 1 to 10 because it has 10 acres, and Turnout 2 is similarly assigned 11 to 20. Turnout 3 is assigned a longer sequence range, from 21 to 35, because it has 15 acres. Turnouts are continued to be assigned sequence range numbers in this fashion. As a result of this sequence range numbering, each turnout will represent a portion of the total 164 acres.

Step 2: Use a Random Number Generator to Select Turnouts

Use a random number generator to choose a number between 1 and the total acreage of the district. A random number generator can be a software program or simply pulling numbers out of a hat. In the example above the random number generator would pick a number between 1 and 164. If the number produced by the random number generator is between the sequence range numbers assigned to a device, then that device will be tested.

Repeat this process until devices representing 10% of the acreage served (or volume delivered) have been selected with a minimum of 5 and a maximum of 100 per device type.

Continuing with the example data set above, assume that the first numbers selected by the random number generator were: 17, 24, 157, 156, 53, 42, 41, 36, 2, 12, and 52.

Eliminate duplicate turnouts, starting from the first random number.

With this random selection of numbers, the following turnouts are selected:

2 (selected by number 17; 12 is a duplicate)
3 (selected by number 24)
10 (selected by number 157; 156 is a duplicate)
6 (selected by number 53)
4 (selected by number 41; 41 and 36 are duplicates)

This provides the minimum number of 5 turnouts. Now, the acreage must be checked to verify that the selection represents more than 10% of the acreage (or volume).

Table 2. Example of randomly selected sample set

Green rows indicate the selected devices for the sample set

Turnout #	Acreage Served: Acres	Acreage Served: % of Total	Sequence Range: From	Sequence Range: To
1	10	6%	1	10
2	10	6%	11	20
3	15	9%	21	35
4	15	9%	36	50
5	2	1%	51	52
6	2	1%	53	54
7	5	3%	55	59
8	5	3%	60	64
9	50	30%	65	114
10	50	30%	115	164
Total	**164**	**100%**		

The five turnout samples represent 55% of the total acreage.

Therefore, this sample set meets the criteria of:
- greater than or equal to 10% of the acreage, and
- a minimum of 5 turnouts of a particular type - assuming all are the same device.

Note: If there is more than one device, this process would be repeated ***by device***. The final criteria to be met are:

- Including all device sample sets, at least 10% of the district acreage (or volume) must be accounted for.
- A minimum of 5 turnouts of a particular device, for each device.
- No more than 100 of any particular device.

Step 3: Evaluate Selected Turnouts and Record Data

Once the turnouts have been selected, evaluate each flow measurement device for accuracy. Record gate type, total acreage serviced by the device, and measured accuracy. This data will need to be retained for ten years or two Agricultural Water Management Plan Cycles as per 597.4(c).

To continue the example, **Table 3** shows how data should be recorded for the example district. For simplicity, it is assumed that all devices are meter gates.

Table 3. Sample data collection for selected turnouts

Red rows indicate devices that do not meet the required standard

Turnout #	Device Type	Acreage Served	Flow Accuracy Error, %
2	Meter Gate	10	15%
3	Meter Gate	15	9%
4	Meter Gate	15	6%
6	Meter Gate	2	8%
10	Meter Gate	50	4%
	Total acreage sampled:	***92***	

Step 4: Determination of Compliance

SBx7 requires an annual volumetric accuracy of within 12% on existing devices. Table 3 addresses flow rate accuracy, not volumetric accuracy.

If 25% or more of the sampled area for a particular device type exceeds the 12% annual volumetric allowable error, then a second round of testing must be conducted. This second round of testing should be conducted in the same manner as the first, but only for the device type(s) that did not meet the required accuracy standard.

Compliance of this particular example. Table 3 is repeated below for illustration.

Table 3. Sample data collection for selected turnouts

Red rows indicate devices that do not meet the required standard

Turnout #	Device Type	Acreage Served	Flow Accuracy error, %
2	Meter Gate	10	15%
3	Meter Gate	15	9%
4	Meter Gate	15	6%
6	Meter Gate	2	8%
10	Meter Gate	50	4%
	Total acreage sampled:	***92***	

Assuming that the minimum required flow rate accuracy is 10.7% (using the example), then only one turnout measurement device does not meet the requirement. No re-testing is needed, because:

1. Ninety-two acres were tested out of the total 164 acres. This is much greater than the 10% sample size required.
2. Five devices were sampled, which meets the minimum because all devices are of the same basic design.
3. The one device with greater than 10.7% error only represents 10 acres, which is 11% of the acreage sampled. This is below the allowable 25%.

Scenario 2: Limited Availability of Turnouts and Opportunity Sampling

Turnouts may not be available for inspection due to fluctuations in irrigation scheduling. Therefore, opportunity sample can be used to select devices to be evaluated. As opposed to the PPS random sample set, this sample will be based on availability and service size rather than a weighted random sampling.

Background

Representative Sample Selection

To ensure the sample is representative of the district as a whole, evaluators need to ensure that the area serviced by the devices evaluated is at least 10% of the district's entire area. Furthermore, when given a choice between devices of equal convenience, devices servicing a larger acreage should be given priority for inspection. Additionally, a minimum of 5 devices must be inspected. In this way each device will be weighted in selection by the acreage it serves. Specifically, the sample will be skewed favoring devices that measure greater volumes of water. This will ensure that the opportunity sample will be statistically representative of the overall accuracy of flow measurement within the district.

Selection Process

Devices will be selected as they are available to be tested. Priority for evaluation will be given to devices that service greater acreage. Once a device has been tested, it will no longer be considered in the selection process. A minimum of 5 devices will be tested, and all evaluated devices (summation of all types) will service a combined 10% of the district's total area (or delivered volume), not to exceed 100 individual devices of a certain type.

Step 1: Choose a Currently Available Turnout

Select a turnout that is available for testing based on the size of the turnout, giving priority to turnouts that serve greater acreage. Do not test the same device more than once. **Table 4** shows an example of the selection process for two days. On the first day Turnout 10 serves the largest acreage out of the available turnouts. On day two, Turnout 5 is chosen because it serves the largest area and has not yet been tested. The district in this example has one canal lateral with 10 turnouts, and the turnouts have limited availability for testing.

Table 4. Device selection on two separate days

Green rows indicate the selected turnout. Grey rows indicate a turnout that has been tested.

Day 1

Turnout #	Currently Available	Acreage Served
1	yes	10
2	yes	10
3	no	9
4	yes	7
5	no	30
6	no	1
7	yes	1
8	yes	2
9	no	50
10	yes	50

Day 2

Turnout #	Currently Available	Acreage Served
1	no	10
2	yes	10
3	no	9
4	yes	7
5	yes	30
6	no	1
7	yes	1
8	yes	2
9	no	50
10	yes	50

Continue testing devices until the following criteria have been met:

- *At least 10% of the total district acreage is serviced by the devices tested*
- *At least 5 devices have been tested*
- *Test no more than 100 devices of a particular type*

Steps 2-4 : Follow the Previous Scenario Instructions

FLOW MEASUREMENT DEVICES

Background

This section is intended to provide useful information on several common flow measurement devices that might be considered for traditional, non-pressurized turnouts. Often, the problems with some of the devices (meter gates, orifice plates, and propeller meters) are largely associated with improper measurement, or improper installation or maintenance. If properly designed and maintained, all three of these measurement devices will generally fall well within required SBx7 requirements.

Meter Gates

Meter gates are one of the most common devices used in California irrigation districts to both measure and control flow rates. There is no doubt that many of these devices provide accurate results. However, as with all devices, certain rules must be followed. Typical physical inaccuracies associated with meter gates include:

1. *Incorrect "zero" measurement of gate opening*, as determined by the vertical movement of the threaded shaft.
   a. There are four primary reasons operators might measure the opening from an incorrect "zero" mark on the threaded shaft:
      i. The zero point is affected by "slop" in the connection between the shaft and the gate plate.
      ii. Wedges are used to force the plate against the gate frame during gate closure. These wedges are often adjusted in the field, so there is no standard stopping distance (vertically) for the plate.
      iii. When the plate begins to move, it may overlap the opening (by 0.5 - 2"). Although water may begin to leak as the plate moves out of the wedge constraint, the true zero is the opening at which the bottom of the plate is exactly at the bottom of the frame opening.
      iv. The "zero" point should always be determined while the gate is being raised.
   b. Once the zero point is known, a notch should be scribed into the shaft to note the location of the zero mark. Then the gate opening should always be measured as the gate is being opened, rather than being closed.

2. *Incorrect downstream water level measurement.*
   a. The stilling well must be placed over a full pipe, at a specific distance downstream of the meter gate.
   b. Many existing stilling wells were actually designed to be air vents, and have such a small diameter that there is constant surging. A large diameter stilling well, fed by a relatively small access hole at its bottom (about 1/6th the diameter of the stilling well), is needed to "still" the water surface so it can be measured downstream of the gate. The problem with a small access hole is that it can plug up easily. A good combination is a 2" access hole (connecting the stilling well to the top of the pipe) and a 12" stilling well.
   c. The pipe must be full at all flow rates. This may require the placement of a small obstruction downstream, in the pipe, similar to what is done with well pump discharges to keep propeller meters full. Various entities, including ITRC, have successfully designed side contractions in pipes to create "Replogle flumes" that have very little loss, and that pass bottom loads of silt. Something similar could be used downstream of the meter gates.

Figure 3. Side contractions rather than a traditional "Replogle Flume". Designed by USBR, Yuma. The rocks are not part of the design.

Another technique used in some districts to maintain a submerged condition on a gate is to install "bumps" in the bottom of a canal or ditch downstream of the turnout. These should be permanent "bumps" which, at low flows, will keep the water level high. The rule for building these "bumps" is:

> Build up the restriction from the bottom of the ditch/canal so that at high flow rates, the upstream water surface (relative to the bump) is only raised by about 0.1' or less. In other words, its presence will hardly be noticeable.

If farmers move downstream in their canal, setting siphons at a different place, this "bump" will keep the backpressure on the meter gate almost constant, and minimize the flow rate change that would normally occur.

3. *Incorrect gate opening geometry.* Since the plate has a larger outside diameter than the inside diameter of the pipe, the ratio of the open area between the two openings must be taken into account. Almost everyone uses tables that were developed decades ago. ITRC is not certain if the gate dimensions have changed since then, or if different manufacturers use different gate dimensions. ITRC is planning to verify this in the future.

4. *Non-standard entrance and exit conditions.* The flow rate is associated with a measured opening and head loss. The head loss will be different (at the same flow rate) with different entrance conditions. Various manuals, such as the USBR Flow Measurement Manual, provide recommended dimensions.

Orifice Plates

The following is an explanation of the characteristics of a submerged (on both sides) rectangular orifice plate.

According to the U.S. Bureau of Reclamation *Water Measurement Manual*, conditions for achieving accurate flow measurement of ± 2% for a fully contracted submerged rectangular orifice are:

- The upstream edges of the orifice should be straight, sharp, and smooth.
- The upstream face and the sides of the orifice opening need to be vertical.
- The top and bottom edges of the orifice opening need to be level.
- Any fasteners present on the upstream side of the orifice plate and the bulkhead must be countersunk.
- The face of the orifice plate must be clean of grease and oil.
- The thickness of the orifice plate perimeter should be between 0.03 and 0.08 inches. Thicker plates would need to have the downstream side edge chamfered at an angle of at least 45 degrees.
- Flow edges of the plate require machining or filing perpendicular to the upstream face to remove burrs or scratches and should not be smoothed off with abrasives.
- For submerged flow, the differential in head should be at least 0.2 feet.
- Using the dimensions depicted in **Figure 4** below, P > 2Y, Z > 2Y, and M > 2Y

The equation for determining the flow through a submerged orifice plate is:

$$Q = C_d A\sqrt{2g\Delta h}$$

Where:

Q = Flow Rate, CFS
C_d = Coefficient of Discharge, 0.61
A = Area of the orifice, ft^2
A = W x Y
W = Orifice opening width, ft
Y = Orifice opening height, ft
g = Acceleration due to gravity, 32.2 ft/s^2
Δh = Change in head, ft

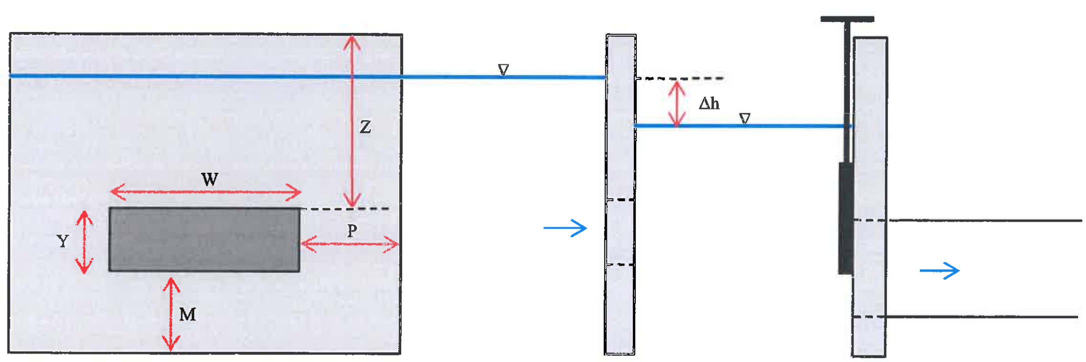


Figure 4. Flow through a submerged orifice plate

For a sharp-edged rectangular orifice where full contraction occurs from every side of the orifice, the coefficient of discharge is 0.61.

It is recommended that "Y" be smaller than "W", so that a good depth "Z" can be maintained. This helps keep the orifice entrance submerged all the time regardless of upstream water level fluctuations, and also provides for the proper entrance conditions.

It is assumed that the flow control gate will be located downstream of the orifice plate. The particular dimensions of that gate would rarely influence the performance of an orifice plate.

Typical problems include:

1. Inaccurate measurement of the difference in head.
   Solution:
   a. Careful relative calibration of pressure transducers, if used. They do not need to read a correct "elevation", but at zero flow rate must read the same "elevation".
   b. Install a horizontal reference steel plate on a bulkhead wall, so operators use the same reference elevation for both measurements if they manually measure the head difference.
2. The distances P, Z, or M are not greater than 2 times the smallest opening dimension (usually "Y"). In reality, it is rare that this "2 times" criteria is met in irrigation districts, except with very small flows.
   Solution:
   a. If only one side is suppressed (typically the bottom entrance, which might have no convergence), adjust the discharge coefficient, C_d as follows:

W/Y	1	2	4
Cd	0.63	0.64	0.65

   b. We do not know exactly how much to adjust the C_d if the distances P, Z, or M are less than two times the smallest opening dimension. Therefore, it is recommended that the orifice be installed in a plate that is wide enough and tall enough to approximately meet those required distances – even if the plate must be extended beyond the inlet to the turnout. See the figure below.

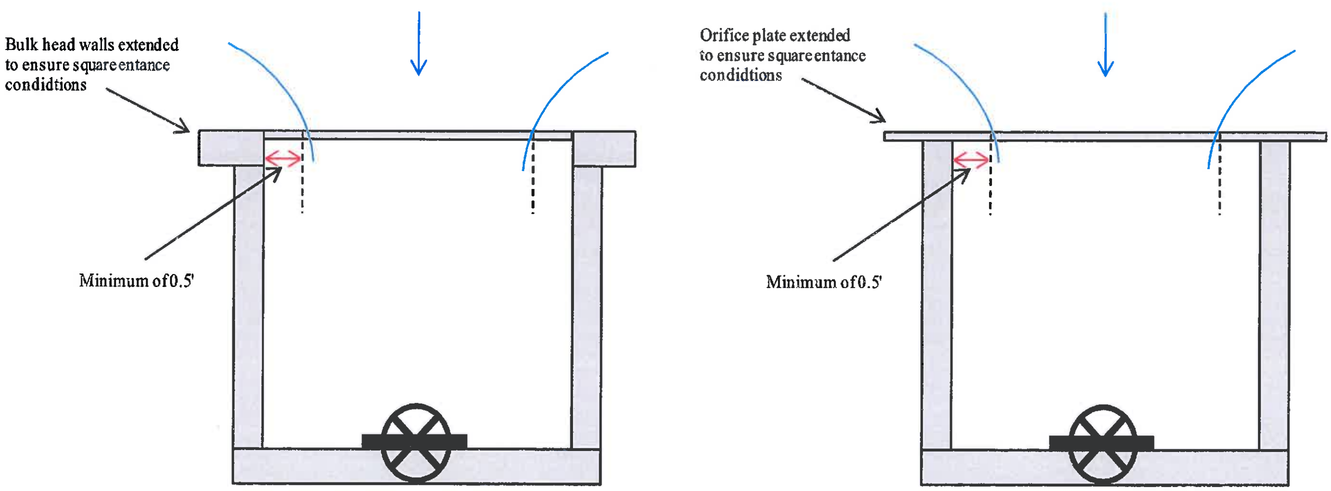


Figure 5. Installation of orifice

3. A single orifice size has a limited flow rate range. This is illustrated in the tables below. At too low a flow rate, the measured head difference is very small, often resulting in major errors in head difference. At too high a flow rate, the measured head difference is excessive, and may well exceed the available head. For this reason, it is common to have a moveable plate that can be adjusted up and down, varying the "Y" dimension.

   The addition of the moveable plate (often a rectangular sluice gate) creates the commonly known "CHO" or "constant head orifice". The device certainly does not create a "constant head", but it does provide an adjustable orifice. It provides the flexibility needed for a turnout to supply different flows at different times, with reasonably accurate head measurements. The opening should be adjusted so that the minimum head difference is greater than 0.2'. A 1' head loss across the orifice plate is more than what is attainable in many California irrigation district turnouts.

Table 5. Orifice size values

	Width of Orifice Opening, ft							
	1.0							
	Height of Orifice Opening, ft							
	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Flow Rate, CFS	Change in Head, ft							
5.0								1.0
4.5							1.0	0.8
4.0						1.0	0.8	0.7
3.5					1.0	0.8	0.6	0.5
3.0				1.0	0.8	0.6	0.5	0.4
2.5			1.0	0.7	0.5	0.4	0.3	0.3
2.0		1.0	0.7	0.5	0.3	0.3	0.2	0.2
1.5	1.0	0.6	0.4	0.3	0.2	0.1	0.1	
1.0	0.5	0.3	0.2	0.1				

	Width of Orifice Opening, ft						
	1.5						
	Height of Orifice Opening, ft						
	0.5	0.6	0.8	1.0	1.2	1.4	1.5
Flow Rate, CFS	Change in Head, ft						
11.0						1.1	1.0
10.0						0.9	0.8
9.0					1.0	0.8	0.7
8.0				1.2	0.8	0.6	0.5
7.0				0.9	0.6	0.5	0.4
6.0			1.0	0.7	0.5	0.3	0.3
5.0			0.7	0.5	0.3	0.2	0.2
4.5		1.0	0.6	0.4	0.3	0.2	0.2
4.0	1.2	0.8	0.5	0.3	0.2	0.2	0.1
3.5	0.9	0.6	0.4	0.2	0.2	0.1	0.1
3.0	0.7	0.5	0.3	0.2	0.1		
2.5	0.5	0.3	0.2	0.1			
2.0	0.3	0.2	0.1				
1.5	0.2	0.1					

Table 5 (continued). Orifice size values

	Width of Orifice Opening, ft								
	2.0								
	Height of Orifice Opening, ft								
	0.5	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
Flow Rate, CFS	Change in Head, ft								
20.0									1.0
19.0								1.2	0.9
16.0							1.0	0.8	0.7
13.0						0.9	0.7	0.5	0.4
10.0				1.0	0.7	0.5	0.4	0.3	0.3
9.0				0.8	0.6	0.4	0.3	0.3	0.2
8.0			1.0	0.7	0.5	0.3	0.3	0.2	0.2
7.0			0.8	0.5	0.4	0.3	0.2	0.2	0.1
6.0		1.0	0.6	0.4	0.3	0.2	0.1	0.1	
5.0	1.0	0.7	0.4	0.3	0.2	0.1	0.1		
4.5	0.8	0.6	0.3	0.2	0.1	0.1			
4.0	0.7	0.5	0.3	0.2	0.1				
3.5	0.5	0.4	0.2	0.1					
3.0	0.4	0.3	0.1						
2.5	0.3	0.2	0.1						
2.0	0.2	0.1							

	Width of Orifice Opening, ft											
	2.5											
	Height of Orifice Opening, ft											
	0.5	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.5
Flow Rate, CFS	Change in Head, ft											
30.0											1.0	1.0
25.0									1.0	0.9	0.7	0.7
20.0							1.0	0.8	0.7	0.6	0.5	0.4
15.0					1.0	0.8	0.6	0.5	0.4	0.3	0.3	0.2
10.0			1.0	0.7	0.5	0.3	0.3	0.2	0.2	0.1	0.1	0.1
9.0			0.8	0.5	0.4	0.3	0.2	0.2	0.1	0.1		
8.0		1.2	0.7	0.4	0.3	0.2	0.2	0.1	0.1			
7.0		0.9	0.5	0.3	0.2	0.2	0.1	0.1				
6.0	1.0	0.7	0.4	0.2	0.2	0.1						
5.0	0.7	0.5	0.3	0.2	0.1							
4.5	0.5	0.4	0.2	0.1								
4.0	0.4	0.3	0.2	0.1								
3.5	0.3	0.2	0.1									
3.0	0.2	0.2										

	Width of Orifice Opening, ft													
	3.0													
	Height of Orifice Opening, ft													
	0.5	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0
Flow Rate, CFS	Change in Head, ft													
45.0													1.2	1.0
40.0												1.1	0.9	0.8
35.0										1.2	1.0	0.8	0.7	0.6
30.0									1.0	0.9	0.7	0.6	0.5	0.5
25.0							1.1	0.9	0.7	0.6	0.5	0.4	0.4	0.3
20.0						0.9	0.7	0.6	0.5	0.4	0.3	0.3	0.2	0.2
15.0				1.0	0.7	0.5	0.4	0.3	0.3	0.2	0.2	0.2	0.1	0.1
10.0			0.7	0.5	0.3	0.2	0.2	0.1	0.1					
5.0	0.5	0.3	0.2	0.1										

If steel theft is a concern, a marine plywood frame could be used to support a steel orifice opening frame. Fasteners used to connect the steel orifice to the plywood frame would need to be countersunk to minimize debris getting caught on them.

Trash Shedding Propeller Meters

For several decades there has been interest in "trash shedding propeller meters". ITRC examined the "cloggability" of an early design about 20 years ago. Boat propellers are sold with "weed shedding" features, which include specially designed propellers as well as fixed vanes upstream of the propeller that are intended to pass the weeds below or to the side of the boat propeller. McCrometer sells a saddle meter with the trash shedding options.

MC® Propeller

MODEL M0300SW

CONFIGURATION SHEET
REVERSE BOLT-ON SADDLE SURFACE WATER FLOWMETER

DESCRIPTION

The M0300SW is a bolt-on reverse-helix* propeller meter designed to shed debris often associated with surface water applications. The M0300SW is designed with the meter body turned 180 degrees from normal, a propeller installed nose-first on the bearing shaft, and a reverse flow style bearing assembly. This configuration allows the ell to curve with the flow, allowing grass or other debris to shed off with ease. The assembly design also reduces the ability of sand and silt to accumulate in the bearing.

The M0300SW features a fabricated stainless steel saddle with McCrometer's unique drive and register design. The stainless steel saddle eliminates the fatigue-related breakage common to cast iron and aluminum saddles and provides unsurpassed corrosion protection. Fabricated stainless steel construction offers the additional advantage of being flexible enough to conform to out-of-true pipe. The Model M0300SW is manufactured to comply with applicable provisions of American Water Works Association Standard No. C704-02 for propeller-type flowmeters. As with all McCrometer propeller flowmeters, standard features include a magnetically coupled drive, instantaneous flowrate indicator and straight reading, six-digit totalizer.

The impellers are manufactured of high-impact plastic, capable of retaining their shape and accuracy over the life of the meter. Each impeller is individually calibrated at the factory to accommodate the use of any standard McCrometer register, and since no change gears are used, the M0300SW can be field-serviced without the need for factory recalibration. Factory lubricated, stainless steel bearings are used to support the impeller shaft. The shielded bearing design limits the entry of materials and fluids into the bearing chamber providing maximum bearing protection.

The instantaneous flowrate indicator is standard and available in gallons per minute, cubic feet per second, liters per second and other units. The register is driven by a flexible steel cable encased within a protective vinyl liner. The register housing protects both the register and cable drive system from moisture while allowing clear reading of the flowrate indicator and totalizer.

INSTALLATION

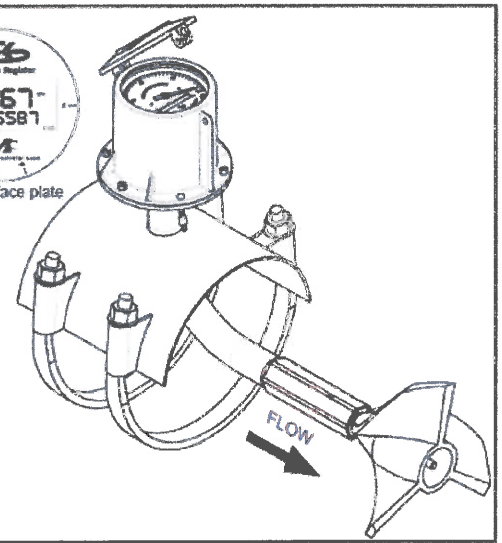
Standard installation is horizontal mount. If the meter is to be mounted in the vertical position, please advise the factory. A straight run of full pipe the length of eight pipe diameters upstream and five diameters downstream of the meter is recommended for meters without straightening vanes. Meters with optional straightening vanes require at least three pipe diameters upstream and two diameters downstream of the meter.

* 4" meters use a forward helix propeller with a reverse register.

Typical face plate

The McCrometer Propeller flowmeter comes with a standard instantaneous flowrate indicator and straight-reading totalizer. An optional FlowCom register is also available.

Typical face plate



APPLICATIONS

- **Surface Water**
- **Water Containing Trash**
- **Sand Producing Wells**
- **Irrigation District Turnouts**

McCrometer will also mount a reverse-facing propeller on a standard open flow meter, which can be mounted on stands above low pressure pipelines.

Propeller

CONFIGURATION SHEET

MODEL M1700

OPEN FLOWMETER

DESCRIPTION

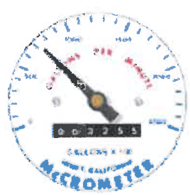
Model M1700 Open Flowmeters are designed to measure the flow in canal outlets, discharge and inlet pipes, irrigation turnouts and other similar installations. The M1700 series meets or exceeds the American Water Works Association Standard C704-02. Constructed of stainless steel, the meter incorporates bronze mounting brackets that permit simple installation and removal. As with all McCrometer propeller flowmeters, standard features include a magnetically coupled drive, instantaneous flowrate indicator and straight reading, six-digit totalizer.

Impellers are manufactured of high-impact plastic, designed to retain both shape and accuracy over the life of the meter. Each impeller is individually calibrated at the factory to accommodate the use of standard McCrometer registers, and since no change gears are necessary, the M1700 can be field-serviced without the need for factory recalibration. Factory lubricated, stainless steel bearings are used to support the impeller shaft. The sealed bearing design limits the entry of materials and fluids into the bearing chamber providing maximum bearing protection.

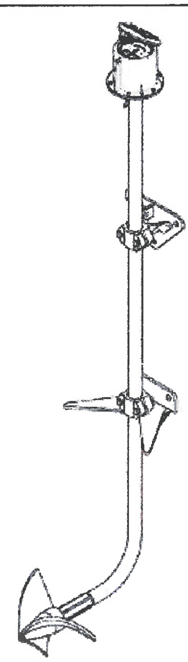
An instantaneous flowrate indicator is standard and available in gallons per minute, cubic feet per second, liters per second and other units. The register is driven by a flexible steel cable encased within a protective, self-lubricating vinyl liner. The die-cast aluminum register housing protects both the register and cable drive system from moisture while allowing clear reading of the flowrate indicator and totalizer.

INSTALLATION

The M1700 must be mounted on a headwall, standpipe or other suitable structure so that the propeller is located in the center of the discharge or inlet pipe. A straight run of full pipe the length of ten pipe diameters upstream and two diameters downstream of the meter is recommended for meters without straightening vanes. Meters with optional straightening vanes require at least five pipe diameters upstream of the meter. Please specify the inside diameter of the pipe when ordering.



The McCrometer Propeller flowmeter comes with a standard instantaneous flowrate indicator and straight-reading totalizer. An optional FlowCom register is also available. *Typical face plates.*



APPLICATIONS

The McCrometer propeller meter is the most widely used flowmeter for municipal water and wastewater applications as well as agricultural and turf irrigation measurements. Typical applications include:

- Water and wastewater management
- Canal laterals
- Gravity turnouts from underground pipelines
- Sprinkler irrigation systems
- Golf course and park water management

A commercially available package that includes a reverse propeller meter and trash-shedding fixed vane, plus flow straighteners, is available from RSA.

Rubicon Transit Time Flow Meter

The Rubicon Sonaray flow meter is an interesting addition for larger turnouts with a canal supply, in that it also has a totalizer. The Rubicon literature cites a flow test in California, but it is unclear if the magmeter used for flow rate verification was recently calibrated. ITRC has found that new magmeters with guaranteed accuracies can be off by several percentage points. The device appears to be new, without substantial field testing in the USA.

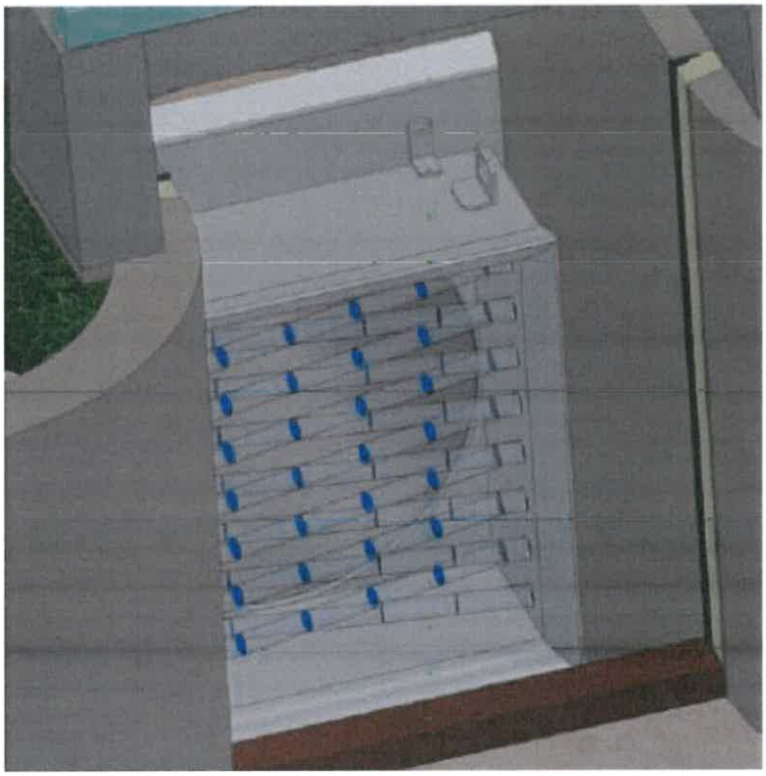


Figure 6. Rubicon Sonaray flow meter

MODESTO IRRIGATION DISTRICT

2020 AGRICULTURAL WATER MANAGEMENT PLAN

APPENDIX H

COMMENTS ON DRAFT AGRICULTURAL WATER MANAGEMENT PLAN

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March 17, 2021

John B. Davids
Modesto Irrigation District
1231 11th Street
Modesto, CA 95354
AWMP@mid.org

Re: Comments on MID's Draft 2020 Agricultural Water Management Plan.

Dear Mr. Davids:

Thank you for the opportunity to comment on MID's draft Agricultural Water Management Plan (AWMP). Following are some recommendations and requests from the Tuolumne River Trust (TRT).

I. Water Pricing

The price MID charges farmers for irrigation water is very low, and heavily dependent on the fixed charge ($44/acre). The tiered pricing structure is fairly insignificant for the first 42 inches of water purchased. If we are reading Table 17 correctly ($2/acre-foot for the first two acre-feet, $5 for the third acre-foot, and $5.63 for an additional half acre-foot), the total cost for 42 inches of irrigation water is $58.63/acre, plus a Facilities and Maintenance charge of $22/acre, bringing the total to $80.63/acre. Divided by 3.5 acre-feet, this comes to $23/acre-foot. Such a low price does not incentivize water use efficiency, and does not generate funds for infrastructure improvements to conserve water.

On December 30, 2019, a Stanislaus County Superior Court Judge ruled in favor of plaintiffs who sued MID for overcharging its electric ratepayers in order to subsidize irrigation customers. The ruling states, "The matter will proceed to the next phase to determine the remedy."[1]

To our knowledge, a remedy has yet to be determined. However, it is likely a ruling will address retroactive compensation to electric ratepayers, and we assume MID will need to raise water rates to make up the multi-million dollar annual deficit in its irrigation division moving forward.

TRT requests that the water rate implications of this court ruling be addressed in the AWMP.

[1] Andrew Hobbs and David Thomas vs. Modesto Irrigation District (Case No. 2019186) – http://media.modbee.com/static/Jim%20Silva/MIDdecision.pdf

II. Recommendation for a New Funding Source

Many of the programs described in the draft AWMP are underfunded. For example, on page 15, the AWMP states (emphasis added):

> MID completed a Programmatic Environmental Impact Report (PEIR) for the CWRMP [Comprehensive Water Resources Management Plan] under a contract with CH2MHill, now Jacobs Engineering Group, Inc. The PEIR is intended to provide a high-level analysis of the potential CWRMP impacts and set the stage for focused individual project specific environmental review as projects warrant and as resources allow. MID completed the PEIR in 2016. ***While implementation of the CWRMP is contingent upon funding, MID sees benefits in the CWRMP as an effort to identify better methods to manage the District's water resources.***

TRT proposes that MID partner with the San Francisco Public Utilities Commission (SFPUC) to help fund infrastructure improvements aimed at reducing water waste. An MID presentation on February 12, 2012 titled "Comprehensive Water Resources Management Plan" stated, "The average amount of water to be retained annually [from infrastructure upgrades] will be between 25,000 and 40,000 acre feet," and, "The total estimated cost of all anticipated improvements will be about $115 million."

We believe the SFPUC would be eager to help fund infrastructure projects in exchange for a commitment from MID to provide drought relief for the SFPUC under extreme conditions. By making more water available to MID on an ongoing basis, and by only providing water to the SFPUC on rare occasions (if ever), such an agreement would be highly favorable to MID.

The reason the SFPUC would likely want to partner with MID is because they're planning for an extremely conservative drought scenario that couples the drought of record (1987-92) with the driest two-year period on record (1976/77) to create a manufactured 8.5-year design drought. At current demand, the SFPUC could manage a repeat of the 1987-92 drought, with the Bay Delta Plan flows in place, without requiring any rationing or developing any new water supplies. Rationing and new water supplies would stretch their water supply even further. The SFPUC's 10-Year Financial Plan projects that water sales will remain flat for at least the next decade, largely due to hefty rate increase on the horizon that will encourage greater efficiency among their customers.

Despite its enviable position, the SFPUC is seeking greater assurance that it won't run out of water. MID could essentially sell the SFPUC an insurance policy that would likely never be needed.

III. Conversion of Seasonal Crops to Permanent Crops

On page 11, the AWMP states, "Irrigators in MID are transitioning from producing field crops such as alfalfa and grains to permanent crops such as trees and vines. As irrigators transition from field crops to permanent crops and shift toward pressurized, low-volume drip and micro-sprinkler systems, the requirements of customer service are changing."

And on page 51, the AWMP states, "Over 50 percent of the cropped acres are planted with permanent crops with almonds being the predominant permanent crop with 27,905 acres. Permanent crops cover about 39,731 acres, and pasture and grain crops used primarily for dairy cattle feed cover about 18,744 acres. All other crops cover less than 4,000 acres."

This conversion from seasonal crops to permanent crops should be alarming to MID. Seasonal crops can be fallowed during droughts, freeing up water to keep permanent crops alive. As the acreage of seasonal crops decreases, and that of permanent crops increases, MID will have a much more difficult time managing droughts. The Sustainable Groundwater Management Act (SGMA) will exacerbate this problem.

TRT recommends that MID impose a moratorium on the conversion of seasonal crops to permanent crops until an environmental and economic impact study can be initiated and completed.

TRT acknowledges that farmers both within and outside the MID service area are pumping groundwater from the Modesto Sub-Basin, and that MID has little control over this practice. We recommend that MID consider adjudicating the portion of the Sub-Basin within its sphere of influence, and partner with the Oakdale Irrigation District and other water agencies that operate within the Sub-Basin to manage it sustainably to prevent a "tragedy of the commons."

IV. Water Use Efficiency

On page 85, the AWMP states, [MID's on-farm irrigation improvement program] "provides up to 50% funding for physical improvements and management practices" and "when state grants are available, MID has contributed up to 67% of the projects' cost."

This program has a lot of potential. For example, after the South San Joaquin Irrigation District (SSJID) initiated a pilot project to automate and pressurize an irrigation system, water and energy use decreased by 30% and crop yield increased by 30%.[2] However, funding is needed to improve on-farm infrastructure to achieve greater water use efficiency. As explained above, increased funding could be obtained through an agreement with SFPUC.

[2] Stantec (2015). "South San Joaquin Irrigation District Water Delivery System Recognized with Grand Award for Engineering Excellence" – https://www.stantec.com/en/news/2015/south-san-joaquin-irrigation-grand-award

On page 87, the AWMP states "MID has installed water flow meters on approximately 70% of its pumps." The remaining 30% of pumps need water flow meters to be more efficient. Again, MID could partner with the SFPUC to fund this project.

On page 89, the AWMP states, "the need to facilitate alternative land use in MID is minimal." SB 1668 requires MID to "facilitate alternative land use for lands with exceptionally high water duties or whose irrigation contributes to significant problems, including drainage."

An environmental and economic impact study on the transition to permanent crops would help determine whether the need to facilitate alternative land use in MID is truly minimal.

V. Definition of Beneficial Uses

On page 51, the AWMP states, "Required minimum flows have an impact on the amount of water available for beneficial uses."

TRT notes that protecting environmental resources is considered a "beneficial use" of water. We respectfully request that MID edit this sentence accordingly.

VI. City of Modesto

On page 55 the AWMP states, "Wastewater from the City of Modesto is treated within the City but then exported outside of MID's irrigation service area and doesn't contribute to local crop water demands or groundwater recharge."

TRT requests that the AWMP explain this issue in greater detail. Where does the treated wastewater go, and could it potentially be used within MID's service area?

Thank you for considering our comments.

Sincerely,

Peter Drekmeier
Policy Director

Caitlin Perkey
Policy Intern