Final

August 2010

Cooperative Water Measurement Study Report

Sacramento River Settlement Contractors in Cooperation with the Bureau of Reclamation

Executive Summary

Background and Objectives

The appropriate level of water measurement has long been a topic of discussion and debate related to agricultural water management. This issue is of particular interest in the Sacramento Valley, considering its historical diversions dating back over a hundred years, a unique hydrologic system with extensive reuse, the geographic/hydrologic relationship to the Sacramento-San Joaquin Delta, and increasing stakeholder interest across the state in water management, efficiency, and beneficial use. The issue of water measurement as it relates to water management in the Sacramento Valley was identified and described as part of the *Sacramento River Basinwide Water Management Plan* (BWMP) completed in 2001.

Following the BWMP, the Cooperative Water Measurement Study (Cooperative Study) was initiated by developing the *Cooperative Water Measurement Study Work Plan* (Work Plan) over 2002 and 2003. The Cooperative Study was initiated in early 2006, after the Sacramento River Settlement Contractors (SRSC) received two grants to fund the scope of the study outlined in the Work Plan. The current phase of the study is funded by a grant from California Department of Water Resources' (DWR) Water Use Efficiency Program under Proposition 50, a grant from Bureau of Reclamation's (Reclamation) Water Conservation Field Service Program, and SRSCs' funding and in-kind services participation.

The purpose of this *Cooperative Water Measurement Study Report* is to document the major components, analysis, conclusions, and recommendations of the Cooperative Study undertaken by the SRSCs in cooperation with Reclamation. This *Cooperative Water Measurement Study Report* describes efforts of the study, beginning in early 2006 and substantially ending in 2008. This final report was completed in mid-2010, after delays due to an extensive review process and funding limitations.

The goal of the Cooperative Study is to assist in determining an appropriate agricultural water measurement program in a cooperative manner between the SRSCs and Reclamation. This goal will be considered to have been achieved by meeting the following objectives:

- Identify cost-effective, feasible measurement methods appropriate for individual SRSC service areas.
- Evaluate the benefits derived from measurement at turnout, lateral, and district levels.
- Identify and evaluate potential water use issues and benefits of pricing water by volume measured at the turnout or customer level.
- Estimate potential costs associated with measurement programs at the district, lateral, and turnout levels.

The Cooperative Study was designed to address these objectives while also meeting the requirements of Reclamation's 2004 *Regional Criteria for Evaluating Water Management Plans for the Sacramento River Contractors*, which require measurement at the customer level within the contractor service area or development of a mutually acceptable water measurement program.

Study Area and Participants

Subsequent to the completion of the BWMP, the SRSCs and Reclamation agreed to pursue a regional approach rather than a typical district-specific water management plan as provided for in the SRSCs' renewed Central Valley Project (CVP) water contracts. The resulting *Sacramento Valley Regional Water Management Plan* (Regional Plan), completed in 2007 (as well as each SRSC CVP water contract), references the Cooperative Study as being an ongoing evaluation to develop a mutually agreeable water measurement approach.

The following ten SRSCs are currently participating in the Regional Plan:

- Anderson-Cottonwood Irrigation District
- Glenn-Colusa Irrigation District (GCID)
- Meridian Farms Mutual Water Company
- Natomas Central Mutual Water Company
- Pelger Mutual Water Company
- Princeton-Codora-Glenn Irrigation District
- Provident Irrigation District
- Reclamation District 108 (RD 108)
- Reclamation District 1004 (RD 1004)
- Sutter Mutual Water Company (SMWC)

The locations of these participants within the Sacramento Valley are shown on Figure ES-1.

A Cooperative Study Work Group, representing a subgroup of the SRSCs participating in the Regional Plan, cooperators, and a technical team, was formed at the study onset and includes the following entities:

- RD 108: study lead and funding coordinator
- Other study participants: SMWC, RD 1004, and GCID
- Reclamation: cooperator and funding entity

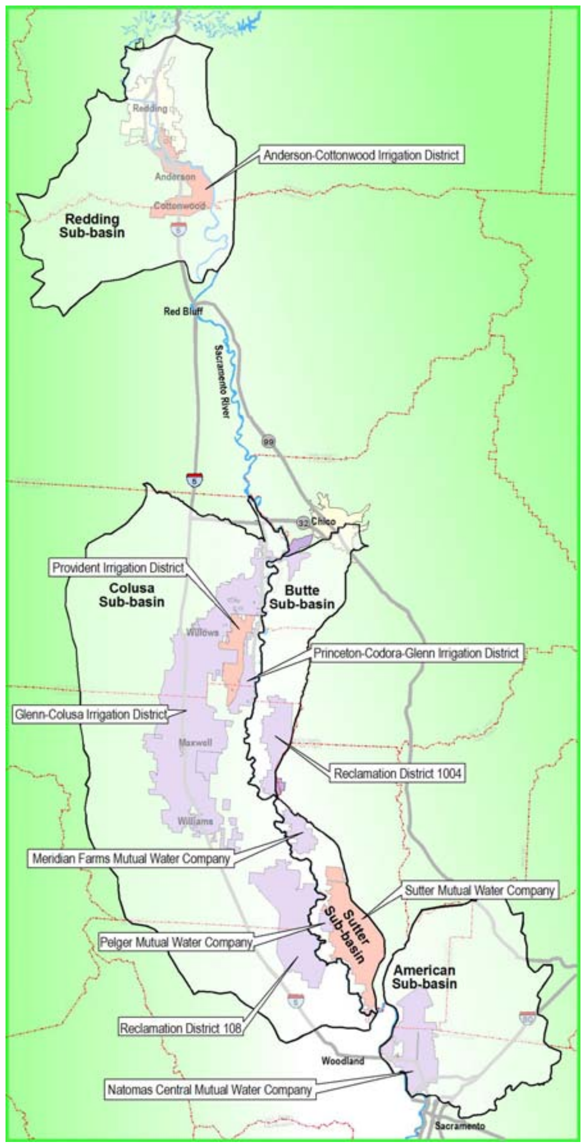

FIGURE ES-1
REGIONAL WATER MANAGEMENT PLAN PARTICIPANTS

- DWR: funding entity
- Technical team: CH2M HILL and MBK Engineers

Additionally, the SRSCs and Reclamation agreed that the development of the Work Plan and subsequent study implementation would involve third-party reviewers to ensure objectivity and to promote stakeholder acceptance. The reviewers' role also included ensuring that approaches and analyses were appropriate for addressing the Cooperative Study objectives. Accordingly, nationally recognized experts in irrigation and agricultural water measurement assisted with the development of the Work Plan and have reviewed aspects of study implementation.

Measurement Study Approach and Analysis

The Work Plan originally intended to measure water at various operational levels within three separate SRSC service areas. As originally conceived, the Cooperative Study was to include rice fields (given the prevalence of this crop across the valley) as well as areas growing various row crops. This scope was proposed to provide a basis for developing appropriate water measurement recommendations over the broad area encompassing the SRSCs. Because of practical funding constraints, the scope of the Cooperative Study was significantly modified on the basis of input from third-party expert reviewers. Modifications to the original study plan (described below and in Section 4) were developed in coordination with the third-party reviewers, Reclamation, and the SRSCs. The scope of the final Work Plan was limited to the following:

- The field study scope was reduced from three SRCSs to one SRSC (RD 108) to significantly reduce the overall budget of the field study and increase its chances of being funded via various grant programs. This narrowed scope also resulted in a study area that was entirely planted to rice production.
- A new study component was added to analyze multiple years of existing customer delivery data for two SRSCs – each with a customer delivery measurement program and each with changes to its pricing policies.
- A new study component was added involving interviews with managers, board members, growers, and field staff from four SRSCs.

In 2003, SRSCs and Reclamation approved the refined Work Plan, and the continuation of the Cooperative Study was referenced in the SRSCs' CVP contracts and the Regional Plan. Thus, this Cooperative Study draws from the following three components to assist in determining water measurement programs appropriate to each participating SRSC:

- Field Measurement Study
- Delivery Data Analysis
- Water Management and Measurement Interviews

Field Measurement Study

The field measurement study involved measuring deliveries and drainage at different operational levels. Deliveries and drainage were measured on two tracts of land, each roughly 500 acres in size. Each tract contained four separate fields that were measured at various levels over a 2-year period. In the first year, deliveries to both sites were measured at the lateral level. During the second year, field- or turnout-level measurement was added to one of the sites.

Over the 2-year study period, conditions affecting meter performance and measurement accuracy were experienced at all measurement levels and with all types of equipment used in the study. Although conditions affecting accuracy of the turnout-level measurements resulted in the inability to make a direct comparison of the turnout-level and lateral-level measurements, information regarding measurement was gained through the Field Measurement Study, especially as it relates to rice fields. In general, obtaining turnout-level data from many of the metering devices was problematic because of the nature of irrigation practices for rice, which require high, early season flood-up flows typically followed by relatively low, season-long maintenance flows. Therefore, it was concluded that use of typical flow metering devices such as propeller meters or even more sophisticated and more expensive ultrasonic or Doppler meters is problematic for areas with similar topography, infrastructure, and operations as RD 108, without significant changes to existing infrastructure. However, it must be recognized that conditions vary across the valley. Propeller meters are in use for turnout-level measurement at some districts where these devices meet district management objectives. Thus, the feasibility of using such devices must be evaluated on a case by case basis and in context with the particular purpose for measurement.

Delivery Data Analysis

The delivery data analysis portion of the study involved a comparative analysis of water use for SRSCs that use a flat-rate pricing structure (water charges based on a cost per acre associated with the crop type) and those that use a volumetric pricing structure (water charges based on the acre-feet of water delivered). SMWC and RD 1004 were chosen for this analysis because both have changed from one pricing structure to another. SMWC changed from a volumetric pricing structure in 2003, to a flat-rate pricing structure. Conversely, RD 1004 changed from a flat rate to a volumetric pricing structure in 1994. The study focused on the collection, organization, and analysis of data immediately preceding and following the changes in pricing structures.

The intention of this study was to analyze changes in diversions from the Sacramento River and field-level deliveries within SMWC and RD 1004 as a result of changes in their pricing structures. Because it was discovered that insufficient data were available from RD 1004 for the period prior to its implementation of volumetric pricing, the study focused on SMWC.

The analysis determined that crop and surface water factors including hydrologic and climatic conditions, water transfers, as well as commodity prices can significantly influence water diversions and deliveries from the Sacramento River. The analysis found no single factor to provide a correlation between surface water deliveries and pricing structure within SMWC. The analysis also found no strong correlation between SMWC's pricing structure and SMWC's diversions from the Sacramento River, or its field-level deliveries.

Water Management and Measurement Interviews

Water management and measurement interviews were included in the study to gain insight into current practices and perspectives across the SRSCs' service areas. The interviews were conducted to assist in addressing the study objectives and to better understand the perceptions and roles of water measurement by managers, operators, and growers. The interviews were also used to document current measurement methods used by the SCRCs.

Four SRSCs (RD 108, SMWC, GCID, and RD 1004) were interviewed to obtain a representative sample of current practices that could be observed throughout most of the service area of the SRSCs. Interview participants within each SRSC were selected to gather a cross section of perspectives that might be present, rather than to determine which perspectives were statistically dominant within the study area. Interview participants included general managers, operator staff (superintendents and ditch riders), landowners, and growers. General trends and conclusions were drawn through careful analysis of the responses across common staff roles, district sizes, growers and crop types, and similar factors.

The interviews conducted for the Cooperative Study yielded valuable information about water measurement practices and perceptions in the Sacramento Valley, which are fully documented in the main report. Example summaries of interview responses follow:

- **Appropriate level of measurement** – Some general trends in interview responses were apparent when interviewees were asked about appropriate level of measurement. Both superintendents and ditch riders generally agreed that improved measurement at the head of major supply laterals would provide operational benefits. Both also suggested that measurement at the turnout level could potentially help resolve disputes between growers, but benefits to districts may be limited. Ditch riders and growers both expressed concerns about maintenance and accuracy of turnout-level measurement devices. Ditch riders and growers also emphasized the importance of training and experience over precise measurement for water management. Grower responses indicated that monitoring flow through a turnout was less important than monitoring flow over drain boards at the end of their fields. Some growers indicated a belief that turnout-level measurement would be tied to government intervention and additional costs to landowners.
- **Measurement opinions among growers that farm rice, row crops, or orchards** – Although responses across districts varied, rice growers generally expressed that they saw the least benefit from measuring water at turnouts. Because rice growers focus on managing a specific depth of water and volume of flow through a field to manage temperature and salinity, and not to meet a specific volume of consumptive use, rice growers expressed less need for flow measurement than growers of other crops. Rice growers at districts without turnout-level measurement also expressed concern that measurement devices could physically limit their ability to flood and drain rapidly, which is important for seed establishment, weed management, and vector control. Responses of row and orchard crop growers varied. Some growers who irrigate using siphon tubes or drip systems expressed that they could use turnout measurement to best determine the number of siphons to use at a given time, or to verify that they received the flow they ordered from the district.

Benefits and Costs

Numerous issues affected the accuracy of data collected in the field study at RD 108; and thus, the specific benefits of added measurement were determined to most appropriately be identified in qualitative terms. Table ES-1 summarizes the potential benefits of various levels of water measurement identified as part of the Cooperative Study through the field study, the water management and measurement interviews, and input from study participants. Table ES-1 also lists the potential beneficiary of the various levels of measurement and other considerations or issues.

Cost information was compiled from the equipment purchase, installation, calibration, and maintenance costs associated with the field study conducted in RD 108 during 2006 and 2007, and relevant cost information provided by RD 1004, GCID, and Reclamation. The costs presented in Table ES-1 are for example purposes, are based on conceptual measurement programs, and demonstrate the order of magnitude of costs associated with different levels of measurement. Capital costs annualized over the life of the measurement device and annual operating and maintenance costs were added. Annualized total costs were divided by number of acres the devices served to provide a per-acre cost comparison.

Conclusions and Recommendations

To address the study objectives, the Cooperative Study participants developed a focused approach that included field data collection, historical data collection, and interviews of water district staff and management to obtain additional information. Key focus areas/ limitations included the following:

- The field study was focused on rice given it is the predominant crop among those SRSCs participating in the Regional Plan.
- The field study was conducted in a single water district, RD 108, on relatively small acreage (approximately 1,000 acres). This district was selected for the field study because district staff were available to assist the effort. Although the data obtained provided valuable insight and are applicable to a similar application and district conditions, differences in district infrastructure and cropping patterns across the Sacramento Valley must be taken into account when drawing conclusions from the data.
- The field study did not include the evaluation of the benefits and issues associated with on-farm efficiency changes, reduction of tailwater, or agricultural water reuse, which are important considerations given the extensive reuse of water in most of the Sacramento Valley.
- In general, the data and information collected in the Cooperative Study and the analyses performed demonstrated the complexity of determining appropriate levels of water measurement. Although the study components attempted to address the study objectives, this study should be considered an incremental step towards developing and implementing water measurement programs agreeable to the SRSCs and Reclamation.
- Recommendations regarding future studies are included in this *Cooperative Water Measurement Study Report* to address specific study objectives and further assist the SRSCs and Reclamation in developing appropriate water measurement programs.

TABLE ES-1
Summary of Measurement Benefits and Costs
Cooperative Water Measurement Study Report

Measurement Level	Estimated Annualized Cost per Acre	Potential Benefits	Potential Beneficiary	Identified Issues/ Considerations
Turnout Level	**$30**	• For districts choosing to implement metered delivery pricing policies, acceptable turnout measurement is necessary for equitable implementation of that policy. • Turnout-level measurement can assist growers in managing water deliveries to meet outflow targets, assuming the field and/or crop type will allow for feasible measurement at the turnout level.	• District • Grower	• High cost for initial installation and annual operation and maintenance • Inaccurate for rice lands because of extreme flow range • Installation of meters does not result in less water use • Field-level conservation measures can negatively impact district or basin reuse or conjunctive use operations • Dependent on lateral-level management
Lateral Level	**$5 to $12**	• Additional data at the lateral level would assist districts in making daily operational decisions. Remote access to real-time lateral-level flow and level data could improve operational efficiencies. • Additional data at the lateral level would be useful for planning purposes (e.g., operational studies and infrastructure planning). • Lateral-level measurement would provide information regarding sub-basin efficiency improvements and coordination among growers. • Lateral-level measurement would optimize district reuse operations. • Lateral-level measurement would allow for better evaluation of facility improvements.	• District • District • District, growers • District • District	• Conservation measures such as reducing lateral-level spill can negatively impact district-wide or basinwide reuse or conjunctive use operations

TABLE ES-1
Summary of Measurement Benefits and Costs
Cooperative Water Measurement Study Report

Measurement Level	Estimated Annualized Cost per Acre	Potential Benefits	Potential Beneficiary	Identified Issues/ Considerations
District Level	**$1.50**	• District-level measurement provides an operational tool to manage deliveries on a daily or hourly basis to meet district-wide demands. Improved access to existing measurement information on a real-time basis could result in more efficient operation at the district or company level. • District-level measurement is required for compliance with water rights and contract provisions. • Improving outflow measurement at the district level would assist in understanding district-level water balances and may assist with regional coordinated management among sub-basins.	• District, state • District, region, state • Region, state	• Successful program already implemented and maintained by Reclamation for SRSCs • District-level outflow measurement is not currently implemented but has been identified as a potentially useful management tool with regional benefits; the annualized district-level measurement cost do not include outflow measurement

Conclusions

The primary Cooperative Study conclusion is that the use of many metering devices for turnout-level measurement and management of deliveries to rice fields appears to be generally ineffective. The reasons for this as determined in this study are as follows:

- In general, irrigation practices for rice require high, early season flows to flood fields (basins) quickly to a certain level, followed by much lower flows to account for crop evapotranspiration, evaporation, and other losses, and maintain water levels over the course of the irrigation season. Visual monitoring of field outflow does not require the capital investment of turnout measurement and may be a more useful tool for growers in their water supplies than accurately quantifying the inflow to the field. Although some amount of flow through the fields is important to maintain crop yields, excessive outflow may result in higher operational or fertilizer costs.
- The technical complexity of measuring turnout deliveries for rice fields is a major consideration. Irrigation practices require extreme range of flow rates, very high flows during flood-up, and much lower maintenance flows for the majority of the growing season. The lower maintenance flows are often outside the accurate calibrated flow range of measurement devices sized for flood-up flows. Sediment deposits and buildup further complicate measurement in the low-lying basins in which rice is typically grown. As evidenced in this study, sediment buildup can clog propeller meters and can alter the pipe cross section, thereby affecting accurate flow measurement. Because the pipes are submerged throughout the irrigation season, sediment issues may be undetectable to operators or growers until the fields are drained in the fall.

Additional conclusions organized by study objective are provided in Table ES-2. Each of these conclusion statements is developed further in the report.

TABLE ES-2
Additional Cooperative Study Conclusions
Cooperative Water Measurement Study Report

Study Objective	Conclusions
Objective 1: Identify cost-effective, feasible measurement methods appropriate for the individual SRSCs' service areas.	• The use of many metering devices for turnout-level measurement and management of deliveries to rice fields appears to be generally ineffective. • The Cooperative Study provides additional technical information regarding different levels of water measurement for the SRSCs and reinforced the premise that the measurement approach must be evaluated on the basis of the specific characteristics of a given service area. • District-level water measurement is already occurring for all SRSCs. • Lateral-level water measurement is an appropriate level of measurement for operational purposes. • Lateral-level water measurement may assist in the equitable distribution of water supplies and for billing. • Turnout-level measurement can be used for volumetric pricing for districts choosing such a pricing policy and if water users have accepted the level of measurement accuracy.

TABLE ES-2
Additional Cooperative Study Conclusions
Cooperative Water Measurement Study Report

Study Objective	Conclusions
	• Turnout-level measurement may not be the best water management tool available for many service areas. • System reconfiguration would be required for accurate turnout-level water measurement within many SRSC service areas. • Current measurement methods and intensity are influenced by a combination of factors unique to each district, including crop mix, district infrastructure, topography, operating budget, and management need.
Objective 2: Evaluate benefits derived from measurement at turnout, lateral, and district levels.	• Refer to Table ES-1.
Objective 3: Identify and evaluate potential water use issues and benefits of pricing water by volume measured at the turnout or customer level.	• The analysis of historical delivery data at SMWC was inconclusive regarding the influence of pricing policy on field-level deliveries. • In the interview portion of the study, pricing policy was noted by some growers and managers as a possible tool for improving water management; however, a wide range of perceptions on pricing by volume was evident. • Grower/landowner acceptance of the measurement method and program is critical in the implementation of pricing by volume.
Objective 4: Estimate potential costs associated with a measurement program at the district, lateral, and turnout levels.	• Turnout-level measurement equipment can be relatively expensive, especially when the cost of installation, maintenance, calibration, administration, and data management is considered. • Estimated annualized costs per acre are as follows: - District Level: $1.50/acre - Lateral Level: $5 to $12/acre - Turnout Level: $30/acre • Adding both lateral-level measurement and turnout-level measurement where it does not exist could increase the per-acre water costs by $35 to $42. For one SRSC, this would equate to a 55 to 66 percent increase in water cost to growers, which is likely to be infeasible, especially if the added measurement has beneficiaries beyond the grower.

Recommendations and Areas for Further Study

On the basis of the observations and analysis of the Cooperative Study, the following recommendations are made:

- It is recommended that districts develop and maintain programs to continually ensure that all measurement devices are properly installed, maintained, and accurately calibrated.
- It is recommended that districts provide continued and ongoing training for field operators.

- It is recommended that districts develop and implement quality assurance/quality control programs to ensure that all measurement data are accurately recorded, documented, and archived.
- It is recommended that the results of this Cooperative Study be used to inform DWR regarding the implementation of recently passed Senate Bill SBX7 7, Water Conservation – Agricultural Measurement Requirement.

As noted previously, the focused nature of the Cooperative Study limited the broader applicability of study results. The following areas were identified for further study:

- **Water management options other than turnout-level water measurement should be identified and evaluated.** Other water management tools might be more effective in meeting the goal of reduced Sacramento River diversions, particularly for rice. Other tools such as incentivized drainwater management, minimizing rice basin outflow, and district-level reuse may provide quantifiable benefits. It is recommended that the SRSCs identify and analyze other water management practices that could have benefits that are more quantifiable than water measurement.
- **The sub-basin-level measurement program should be revisited and evaluated, and coupled with a sub-basin-level water balance analysis.** The sub-basin-level measurement program was identified in the BWMP, and the concept was studied through a DWR Water Use Efficiency Program grant in 2003. A first step could be to measure drain flow at key locations to understand and quantify the maximum possible benefit. Additionally, analysis of the sub-basin-level water balance would provide valuable information about data gaps and, ultimately, could provide information about benefits of additional measurement on a broader scale.
- **Additional investigation of different levels of water measurement for crops other than rice, particularly at the turnout level, should be undertaken.** The field measurement portion of the Cooperative Study was limited to studying deliveries to rice fields. This narrowed focus was deemed appropriate given the predominance of rice within the SRSC service areas. It is acknowledged that many other crops are grown within SRSC service areas and the measurement requirements or issues for these crops may be different. Measurement of deliveries to crops other than rice should be studied. RD 108's voluntary turnout-level measurement program for row crop growers, which was initiated in 2010, may provide an opportunity for this type of study. The study should include an evaluation of measurement that can assist in reducing applied water requirements and energy usage, and, if so, the effects of reductions in applied water on crop yields and quality.

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Acronyms and Abbreviations

BWMP	*Sacramento River Basinwide Water Management Plan*
Cal Poly	California Polytechnic State University
CBDA	California Bay-Delta Authority
cfs	cubic feet per second
CIMIS	California Irrigation Management Information System
CMP	corrugated metal pipe
Cooperative Study	Cooperative Water Measurement Study
CVP	Central Valley Project
DWR	California Department of Water Resources
ETc	crop evapotranspiration
FAO	Food and Agriculture Organization
GCID	Glenn-Colusa Irrigation District
ITRC	Irrigation Training and Research Center
O&M	operations and maintenance
RD 1004	Reclamation District 1004
RD 108	Reclamation District 108
Reclamation	Bureau of Reclamation
Regional Criteria	*Regional Criteria for Evaluating Water Management Plans for the Sacramento River Settlement Contractors*
Regional Plan	*Regional Water Management Plan*
SCADA	supervisory control and data acquisition
SMWC	Sutter Mutual Water Company
SonTek	SonTek/YSI Argonaut SL 3000
SRSC	Sacramento River Settlement Contractor
Work Group	Cooperative Study Work Group
Work Plan	*Cooperative Water Measurement Study Work Plan*
WUE	Water Use Efficiency Program

section 1

Introduction and Purpose

1.1 Study Background

The appropriate level of water measurement has long been a topic of discussion and debate related to agricultural water management. This issue is of particular interest in the Sacramento Valley, considering its historical diversions dating back over a hundred years, a unique hydrologic system with extensive reuse, the geographic/hydrologic relationship to the Sacramento-San Joaquin Delta, and increasing stakeholder interest across the state in water management, efficiency, and beneficial use. The issue of water measurement as it relates to water management in the Sacramento Valley was identified and described as part of the *Sacramento River Basinwide Water Management Plan* (BWMP) completed in 2001 (SRSCs, 2004).

Following the BWMP, the Cooperative Water Measurement Study (Cooperative Study) was initiated by developing the *Cooperative Water Measurement Study Work Plan* (Work Plan; SRSCs, 2003b) over 2002 and 2003. The Work Plan was an initial step to support the Sacramento River Settlement Contractors (SRSC) and the Bureau of Reclamation (Reclamation) in establishing mutually agreeable surface water delivery measurement programs for the SRSCs. The Work Plan was developed for the following reasons:

- The BWMP, prepared by the SRSCs with assistance from the California Department of Water Resources (DWR) in cooperation with Reclamation, recommended that improved water measurement be further evaluated to promote optimal management and continued reuse of water.
- The BWMP was used to establish a basis for the SRSCs' Central Valley Project (CVP) contract renewals with Reclamation. As part of the SRSC long-term contracts executed in 2005, contractors must develop periodic water management plans. The *Regional Criteria for Evaluating Water Management Plans for the Sacramento River Settlement Contractors* (Regional Criteria) stipulates that the participating contractors implement a water measurement program. The Regional Criteria also require either (1) development of a mutually acceptable water measurement program or (2) measurement at the customer level within a given contractor service area. The development of the Work Plan reflected the decision by SRSCs to develop a mutually acceptable water measurement program in cooperation with Reclamation.

The Work Plan originally intended to measure water at various operational levels within three separate SRSC service areas. As originally conceived, the Cooperative Study was to include rice fields (given the prevalence of this crop across the valley) as well as areas growing various row crops. This scope was proposed to provide a basis for developing appropriate water measurement recommendations over the broad area encompassing all the SRSCs, as determined appropriate from the study. Because of practical funding constraints, the scope of the Cooperative Study was significantly modified on the basis of input from third-party expert reviewers. Modifications to the original study plan (described below and in Section 4) were developed in coordination with the third-party reviewers, Reclamation, and the SRSCs. The scope of the final Work Plan was limited to the following:

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In 2003, SRSCs and Reclamation approved the refined Work Plan, and the continuation of the Cooperative Study was referenced in the SRSCs' CVP contracts and the *Sacramento Valley Regional Water Management Plan* (Regional Plan; SRSCs, 2006).

The Cooperative Study was initiated in early 2006, after the SRSCs received two grants to fund the reduced scope of the study. The current phase of the study is funded by a grant from DWR's Water Use Efficiency Program (WUE) under Proposition 50, a grant from Reclamation's Water Conservation Field Service Program, and SRSCs' funding and in-kind services participation.

The Cooperative Study will support the SRSCs and Reclamation in continuing to develop surface water delivery measurement programs for each district and company, as determined mutually appropriate. Many local and site-specific factors will influence the choice of measurement methods, both between and within SRSC service areas. Water measurement decisions within a given water district or company boundary are typically influenced by the following key factors common to the majority of SRSC service areas:

- Scheduled water deliveries (as opposed to on-demand or rotation)
- Primarily open-channel distribution systems with unlined earthen canals
- Relatively flat topography with limited fall across a district (low head)
- Extensive reuse of drainwater
- Predominance of particular crops (such as rice) with specific cultural practices
- Varying irrigation methods within a given district

The current extent of water measurement, the methods used, and the levels of recording and documentation of measurement data vary greatly among individual SRSCs. Considerations regarding the purposes for water measurement and the measurement program to be implemented within a district dictates the extent to which measurement occurs. In addition, budgetary constraints for the operation and maintenance (O&M) of water measurement facilities also are evaluated on an individual district or company basis. Current water measurement programs range from extensive measurement and reporting at all operational levels (i.e., Sacramento River diversions, main supply distribution canals and sublaterals, field turnouts, field drains, and district outflow) to less-intensive measurement programs that include only key supply (i.e., Sacramento River diversions) and distribution points.

1.2 Purpose

The purpose of this *Cooperative Water Measurement Study Report* is to document the major components, analysis, conclusions, and recommendations of the Cooperative Study undertaken by the SRSCs in cooperation with Reclamation. This *Cooperative Water Measurement Study Report* describes efforts of the study, beginning in early 2006 and substantially ending in 2008. This final report was completed in 2010, after study delays due to an extensive review process and funding limitations.

1.3 Study Area and Participants

Ten SRSCs are currently participating in the Regional Plan:

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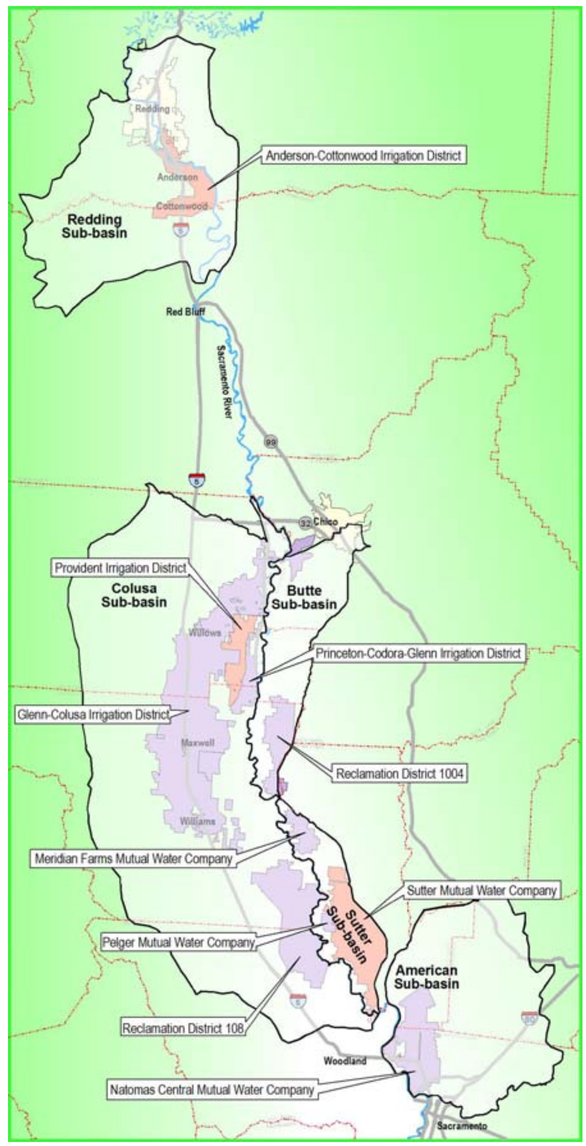

FIGURE 1-1
REGIONAL WATER MANAGEMENT PLAN PARTICIPANTS

1.4 Study Goals and Objectives

The goal of the Cooperative Study is to assist in determining an appropriate agricultural water measurement program in a cooperative manner between the SRSCs and Reclamation. This goal will be considered to have been achieved by meeting the following objectives:

- Identify cost-effective, feasible measurement methods appropriate for individual SRSC service areas.
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- Identify and evaluate potential water use issues and benefits of pricing water by volume measured at the turnout or customer level.
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The Cooperative Study was designed to address these objectives while also meeting the requirements of the Regional Criteria, which require measurement at the customer level within the contractor service area or development of a mutually acceptable water measurement program.

1.5 Third-party Review

The SRSCs and Reclamation agreed that the development of the Work Plan and subsequent study implementation would involve third-party reviewers to ensure objectivity and to promote stakeholder acceptance. The reviewers' role also includes ensuring that approaches and analyses are appropriate for addressing the Cooperative Study objectives.

Accordingly, nationally recognized experts in irrigation and agricultural water measurement assisted with the development of the Work Plan and have reviewed aspects of study implementation. Dr. Jack Keller, Dr. Mark Roberson, Stuart Styles, and Dr. Charles Burt provided varying degrees of input and/or third-party expert review during phases of the Cooperative Study, including the study's revised scope, technical approaches, and study conclusions. Additional details on the third-party reviewers and the review process are provided in Section 2 of this *Cooperative Water Measurement Study Report*.

1.6 Limitations of the Cooperative Water Measurement Study

To address the study objectives, the Cooperative Study participants developed a focused approach that included field data collection, historical data collection, and interviews of water district staff and management to obtain additional information. Key focus areas/ limitations included the following:

- The field study was focused on rice given it is the predominant crop among those SRSCs participating in the Regional Plan.
- The field study was conducted in a single water district, RD 108, on relatively small acreage (approximately 1,000 acres). This district was selected for the field study because

district staff were available to assist the effort. Although the data obtained provided valuable insight and are applicable to a similar application and district conditions, differences in district infrastructure and cropping patterns across the Sacramento Valley must be taken into account when drawing conclusions from the data.

- The field study did not include the evaluation of the benefits and issues associated with on-farm efficiency changes, reduction of tailwater, or agricultural water reuse, which are important considerations given the extensive reuse of water in most of the Sacramento Valley.
- In general, the data and information collected in the Cooperative Study and the analyses performed demonstrated the complexity of determining appropriate levels of water measurement. Although the study components attempted to address the study objectives, this study should be considered an incremental step towards developing and implementing water measurement programs agreeable to the SRSCs and Reclamation.
- Recommendations regarding future studies are included in this *Cooperative Water Measurement Study Report* to address specific study objectives and further assist the SCRSs and Reclamation in developing appropriate water measurement programs.

1.7 Organization of Final Report

This *Cooperative Water Measurement Study Report* is organized as follows:

- **Section 1, Introduction and Purpose** – provides the study's background, purpose, participants, and goals.
- **Section 2, Third-party Review** – documents the involvement by third-party reviewers.
- **Section 3, Study Coordination and Outreach** – documents study coordination efforts and outreach among key stakeholders and study participants.
- **Section 4, Study Components and Analysis** – describes the approach for each study component and resulting analysis from the 2-year study.
- **Section 5, Benefits and Costs** – describes the potential benefits and costs of varied levels of water measurement programs.
- **Section 6, Study Conclusions and Recommendations** – presents the conclusions, recommendations for further study, and next steps that resulted from the Cooperative Study.
- **Appendix A, Field Study Analysis** – presents a summary of the detailed analysis of measurement data collected during the 2-year field study.
- **Appendix B, SonTek Data Collection Summary** – summarizes the data collected and an analysis of measurement data collected at the lateral level with SonTek instruments.
- **Appendix C, Delivery Data Study Analysis** – includes additional data and analysis from the delivery data analysis portion of the Cooperative Study.

- **Appendix D, Interview Questions** – presents questions and answers from the Cooperative Study's interview process.
- **Appendix E, Cost Data** – documents the costs for the RD 108 field study and cost estimates used to support conceptual measurement programs.
- **Appendix F, Summary of Conclusions from Other Measurement Studies** – presents summaries of conclusions of other water measurement studies.

Section 2 Third-party Review

During the development of the Work Plan in 2002-2003, the SRSCs and Reclamation agreed to have a third-party reviewer apply independent expertise to the process and to assist in developing approaches and broad support of the study. The SRSCs and Reclamation agreed upon Dr. Jack Keller as the designated third-party reviewer. Dr. Keller was engaged throughout the Work Plan development, and the overall approach and scope of the Cooperative Study were altered significantly as a result of his input. Because the basic approaches and overarching objectives of the study were agreed to during the Work Plan development, third-party input during the implementation of the Cooperative Study was focused on technical measurement issues, the interview process, and data analysis methodology, as well as on the general study conclusions.

During the early stages of the Cooperative Study implementation, the following objectives for third-party involvement were reaffirmed:

- Help build broad-based support of the measurement study's approaches and conclusions among many stakeholders.
- Provide technical input on field study methods and equipment.

2.1 Approach

In 2006, participating members of the SRSCs and Reclamation collaboratively developed an approach for the third-party review process, chose reviewers, and dedicated a study budget to this effort. Prior to the installation of equipment in February 2006, the Work Group met with Stuart Styles to discuss approaches and appropriate equipment for the field study. In August 2006, the technical team met with Dr. Mark Roberson and Dr. Jack Keller, both working as consultants for the California Bay-Delta Authority (CBDA) at the time, to review the study components, approaches, and the need for third-party review.

It was determined that a team of reviewers would be beneficial for use throughout the 2-year study, with primary review provided by Dr. Roberson. Following are reviewer roles and brief summaries of qualifications:

- **Mark Roberson, Ph.D.,** was the study's primary reviewer for the broader issues of water measurement, including the interview questionnaire development and results, input on study approaches, benefits and costs documentation, and review of the overall study conclusions. Dr. Roberson was engaged in the Work Plan development in 2002–2003, and is familiar with the Cooperative Study history and objectives. Dr. Roberson has extensive experience working on innovative water management and measurement solutions at the district and farm levels. He is an independent consultant currently under contract with the CBDA and a member of the technical team for the Agricultural Water Measurement element of the CALFED WUE.

- **Jack Keller, Ph.D., P.E.,** provided study input in 2002–2003 that resulted in significant changes in the study approach. Dr. Keller remained involved in the study when it was re-initiated in 2006, because of his past experience as third-party reviewer of the Work Plan, but primary third-party review starting in 2006 was performed by Dr. Roberson as described above. Dr. Keller has been an advisor to the CALFED WUE and is on the CALFED Independent Science Board, where he has reviewed many elements of CALFED, including agricultural water use and measurement. He was a member of the Independent Panel on Appropriate Measurement of Agricultural Water Use convened by the CBDA. Dr. Keller is a Principal of Keller-Bliesner Engineering, is Professor Emeritus at Utah State University, and is a member of the National Academy of Engineering. Dr. Keller is an international advisor on water resources and development focused on agricultural water use. He is considered an expert in irrigation, water conservation, and water resources planning in irrigated regions.
- **Charles Burt, Ph.D., P.E., D.WRE.,** provided a technical review and comment to the final draft of the *Cooperative Water Measurement Study Report*. Dr. Charles Burt is a professor at California Polytechnic State University (Cal Poly), San Luis Obispo, and is the chairman of the Irrigation Training and Resource Center (ITRC). Dr. Burt has extensive experience in the implementation of irrigation technologies, including supervisory control and data acquisition (SCADA); irrigation system design; on-farm and irrigation district-level irrigation management; and the evaluation of water use and energy efficiencies. Dr. Burt has over 30 years experience in the field of irrigation as an engineering consultant and has managed projects in the western United States and in 25 other countries.
- **Stuart Styles, P.E., D.WRE.,** was consulted on this study for technical input regarding the types of measurement equipment used for the field measurement portion of the study. Stuart Styles is a professor at Cal Poly, San Luis Obispo, and is the director of the ITRC. Professor Styles specializes in irrigation project efficiency improvement studies; on-farm irrigation management, design, and evaluation; and emerging flow measurement technologies. Professor Styles has over 20 years of field experience in irrigation as a consultant and engineer.

2.2 Review Activities and Input

Third-party review and input was initiated at the onset of the study in early 2006, and was maintained at key milestones of the study through the study conclusion phase. The review approach and team of reviewers were formalized as the study progressed in the first year. Table 2-1 describes the completed review activities throughout the Cooperative Study.

TABLE 2-1
Completed Third-party Review Involvement
Cooperative Water Measurement Study Report

Task	Completed Third-party Input and Review	Completion Date
Field Measurement Study	Reviewed potential sites	February 2006
	Assisted with equipment selection and measurement methods	February 2006
	Recommended potential improvements for Year 2 of the field study	Winter 2006-07
	Reviewed summary of Year 1 data and field observations	January 2007
	Reviewed methodology for data analysis	January 2007
	Reviewed complete data analysis	April–May 2008
Water Management and Measurement Interviews	Reviewed approach and objectives of interview process	Fall 2006
	Provided input on draft interview questionnaire	Fall 2006
	Provided input on approach to synthesizing interview responses and reviewed summary results of interviews	July 2007
	Participated in Work Group discussion of interview results and conclusions	August 2007
Delivery Data Analysis	Reviewed methodology for analyzing delivery data at SMWC and RD 1004 (sample size, data analysis)	January 2007
	Reviewed methodology for analyzing delivery data at SMWC and RD 1004 (sample size, data analysis)	January 2008
	Reviewed conclusions and provided input on additional required analysis	March 2008
Benefits and Costs Documentation	Reviewed cost and benefit results	May–June 2008
Annual Summary Reports	Reviewed draft of Year 1 report	January 2007
	Reviewed overall study conclusions	January–June 2008
	Participated in Work Group draft final review meeting	June 13, 2008
	Reviewed and provided comments on revised draft final report	September 2008

Section 3 Study Coordination and Outreach

The implementation of this Cooperative Study required either a participating district or a consulting engineer to take the lead role in coordinating all study components, providing technical support, and working as a centralized repository for collected flow data. Because most participating districts did not have adequate staff or resources available to lead such an effort, RD 108 and a technical team consisting of CH2M HILL and MBK Engineers assisted in the study preparation. The Work Group also includes staff from SMWC, RD 1004, GCID, Reclamation, and DWR, all of whom participated regularly in meetings, conference calls, and task development.

Study coordination activities included planning and scheduling installation and calibration of measurement devices with the participating RD 108 staff. This process was followed by a training session for system operators on common indicators of improperly functioning measurement devices. The technical team facilitated coordination of the field study, the interviews, and the delivery data analysis among Reclamation, the participating districts, and other SRSCs. Project management activities included contract administration, budgeting, and schedule management.

Study outreach included regular manager meetings and conference calls with representatives from the SRSCs and Reclamation as necessary. DWR's WUE office was involved to ensure that the study was consistent with WUE objectives and the intent of the Proposition 50 grant program. For the Work Group and all interested entities, regular updates were provided in the form of progress reports. Regular conference calls were held to review progress and to keep the group informed of all study developments.

To allow for a broader group of SRSCs to receive updates on study developments, the technical team attended the meeting of the Sacramento River Water Contractors Association in November 2006. The team presented a mid-point summary of the Cooperative Study components and the status of the study's progress. Broader outreach efforts during the final stages of the study included an SRSC manager meeting in May 2008.

Table 3-1 presents outreach activities that occurred throughout the Cooperative Study.

TABLE 3-1
Outreach Activities
Cooperative Water Measurement Study Report

Outreach Activity	Date
Year 1	
Study kickoff meeting at RD 108	June 6, 2006
Coordination calls	July 18 and September 19, 2006
Quarterly progress reports	Quarterly throughout the study
Field tour with Reclamation	August 15, 2006
Third-party reviewer approach meeting at CBDA	August 15, 2006
Regional Plan meeting with Sacramento River Water Contractors Association	November 27, 2006
Interview outreach letter	November through December 2006
SMWC interviews	November 29, 2006
RD 108 interviews	December 1, 2006
GCID interviews	December 19, 2006
RD 1004 interviews	December 20, 2006
Year 2 through Study Completion	
Quarterly progress reports	Quarterly throughout the study
Agricultural Water Management Council's Best Management – published article on Year 1 of the Cooperative Study to broaden support of study	March 2007
Coordination call to discuss Year 1 report	January 2007
Cooperative Water Measurement Study Year 1 Summary Report distributed to Work Group	March 2007
Year 2 kickoff meeting at RD 108 and field visit	April 13, 2007
Work Group meeting to review interview results	August 16, 2007
Work Group meeting at Mid-Pacific Water Users Conference to review preliminary study results	January 24, 2008
Manager meeting with Regional Plan participants at Association of California Water Agencies conference to review preliminary draft report sections	May 8, 2008
Work Group meeting to review draft report	June 13, 2008
Work Group meeting to review third-party review comments and develop approach to address comments	November 5, 2008
Manager meeting with Regional Plan participants at Mid-Pacific Water Users Conference to discuss approach and proposal to finalize report	January 21, 2009
Work Group meeting to confirm approach and funding options to finalize report	November 12, 2009
Manager meeting to review revised draft final report	May 2010

section 4

Study Components and Analysis

The Cooperative Study draws from the following three components to assist in determining water measurement programs appropriate to each participating SRSC:

1. Field Measurement Study
2. Delivery Data Analysis
3. Water Management and Measurement Interviews

The study components were identified during the development of the Work Plan with input from critical sources. Reclamation provided input on water conservation and technical-level input on measurement, as well as input on a plan that would satisfy the intent of the Regional Criteria. Input on the study approach also was provided by a third-party reviewer, Dr. Jack Keller. Work Plan development was also coordinated with CALFED WUE staff to ensure that Cooperative Study approaches and goals were consistent with WUE objectives. Lastly, SRSCs provided direct input and involvement throughout the development of the Work Plan.

The findings of each of the three components listed will contribute to the basis for establishing mutually agreeable surface water delivery measurement programs for the SRSCs.

As planned, implementation of the three primary study components occurred in both Year 1 and Year 2 (2006 and 2007 irrigation seasons). Study analysis was undertaken in Year 2 after the irrigation season and extended into 2008. These study activities and associated analysis are summarized under each Cooperative Study task in this section.

4.1 Field Measurement Study

In accordance with the Work Plan, the purpose of the Field Measurement Study was to provide a scientific and practical basis for evaluating appropriate levels of agricultural water measurement within the Sacramento Valley. More specifically, the purpose of this component of the Cooperative Study was to evaluate approaches to field-level measure-ment. As discussed in Chapter 1, because of scope and budget constraints, the Field Measurement Study was limited to evaluating different methods of field-level measurement to tracts of land within a single district. During the development of the Work Plan it was determined that the Field Measurement Study should focus on deliveries to rice fields for the following reasons:

- Rice represents the single largest acreage within the SRSCs.
- Rice requires irrigation deliveries that are highly variable (wide range of flow) because of cultural practices.
- Rice is generally grown in low-lying basins and is flood irrigated. Deliveries are usually by gravity (non-pressurized), presenting special challenges regarding measurement.

Accordingly, the Field Measurement Study involved measuring deliveries and drainage within a group of rice fields at different operational levels. Two tracts of land, each containing four separate fields, all of which were planted to rice, were selected for study. Deliveries and drainage to both tracts, each encompassing approximately 500 acres, were measured at various levels over a 2-year period. In the first year, deliveries to both sites were measured at the lateral level. During the second year, field- or turnout-level measurement was added to one of the sites. An additional level of measurement not contemplated in the Work Plan or the original scope of the project was added during Year 2 of the study on RD 108's Lateral 14B.

This section describes the sites and equipment selected for the Field Measurement Study as well as the data collected. Analysis of the data is also discussed.

4.1.1 Site Selection and Location

The sites selected for the Field Measurement Study were located in the southeastern portion of RD 108, as shown on Figure 4-1. Each of the two sites consists of four individual fields, totaling approximately 500 acres, as identified in Table 4-1. The sites were selected, in part, to minimize variation. For example, the sites are located adjacent to each other, thereby minimizing potential differences in soils and microclimates. The lands within the study area are owned by RD 108 and were leased to a single grower. All fields within the study area were planted to rice and were irrigated during both years of the study.

TABLE 4-1
Selected Measurement Sites
Cooperative Water Measurement Study Report

Field-level Sites			Lateral-level Sites		
Field	**Crop**	**Acres**	**Field**	**Crop**	**Acres**
193	Rice	157	199	Rice	149
194	Rice	139	200	Rice	107
195	Rice	103	201	Rice	107
196	Rice	147	202	Rice	151
	Total	**546**		**Total**	**514**

Efforts were made to ensure that site conditions were typical to other fields within RD 108; however, some variables were unavoidable. The grower that farmed these fields did so for the first time in 2006, and, therefore, was learning about the conditions particular to such fields, including drainage characteristics, grading, and other factors that affect water use. Also, unusual climatic conditions in 2006 created unique irrigation circumstances. Wet weather late into the spring led to later than normal planting for some growers, a consolidated initial flood-up period, and high demands on the district's operations staff.

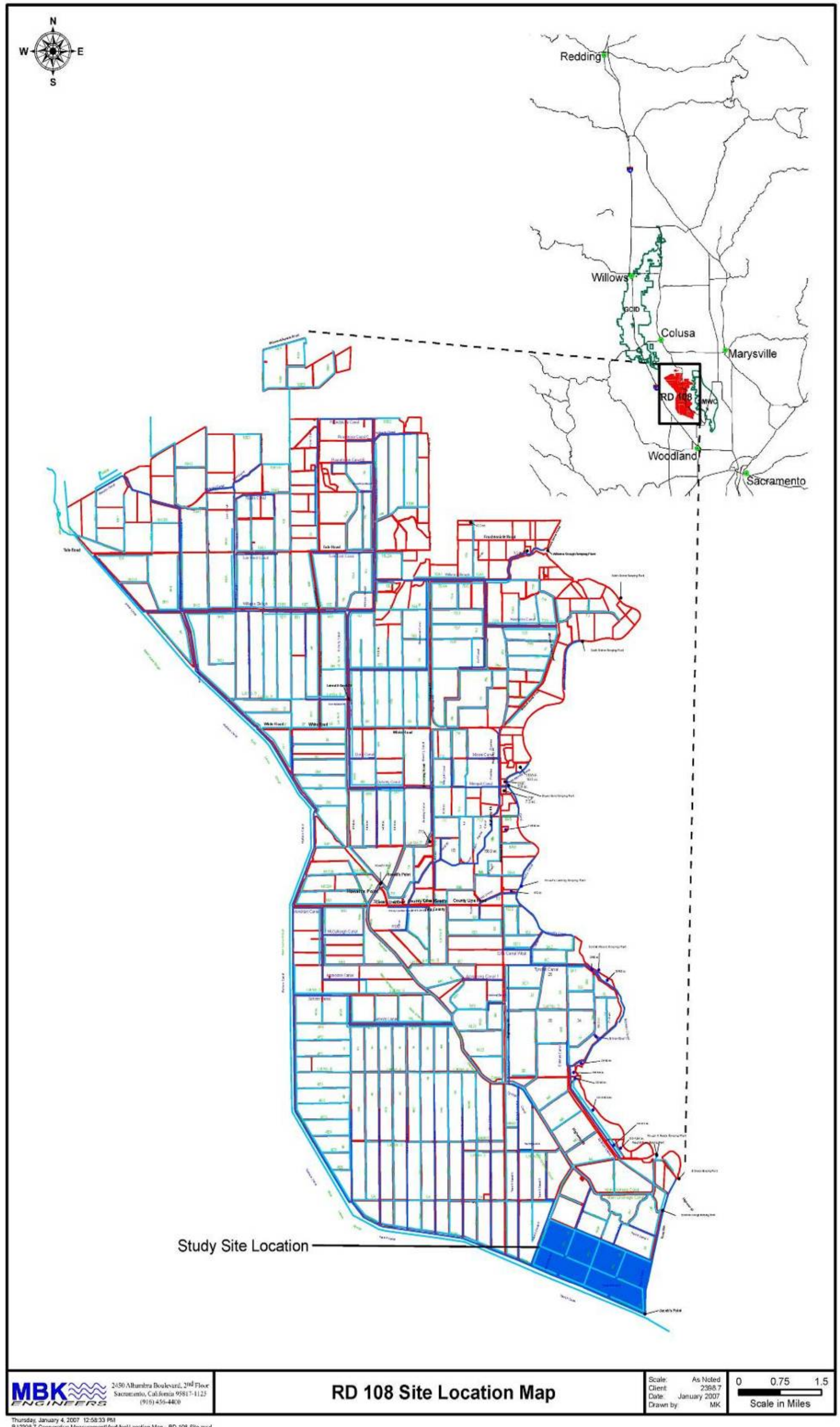


FIGURE 4-1
RECLAMATION DISTRICT 108 SITE LOCATION MAP

4.1.2 Equipment Selection and Installation

Deliveries to the fields and laterals within the Field Measurement Study sites are made through gated, corrugated metal pipes (CMP) of various sizes. The technical team considered various approaches to measuring deliveries for the study. The approaches considered ranged from using "high-tech" devices such as Doppler and ultrasonic flow meters to a "low-tech" approach using water level sensors on either side of the turnout to calculate deliveries. Ultimately, the technical team recommended the use of propeller meters because of their ease of use and familiarity among district staff, relatively low cost, availability, and the ability to install the meters with minimal modifications to existing infrastructure. This recommendation was discussed with RD 108, Reclamation staff, and Stuart Styles. On the basis of these discussions, McCrometer propeller meters were purchased and installed for both turnout-level and lateral-level measurement within both sites. Each meter was properly sized for the turnout and equipped with totalizers. The propeller meters were installed at the downstream end of the CMPs at each turnout and the downstream end of the CMPs at the head of Laterals 1B1 and 1B3. Propeller meters were also installed to measure drain flows as described below. AquaRod water level sensors were installed at the control points located at the downstream end of Laterals 1B1 and 1B3 to capture any operational spill from these laterals. These sensors were equipped with data loggers programmed to record water levels at 15-minute intervals. An additional AquaRod was installed to capture any spill from a supply lateral to the drain that runs along the northern edge of the study area. Example site installations for a propeller meter and AquaRod are shown on Figures 4-2 and 4-3, respectively.

FIGURE 4-2
TYPICAL PROPELLER METER INSTALLED FOR FIELD-LEVEL MEASUREMENT

FIGURE 4-3
TYPICAL AQUAROD INSTALLED FOR FIELD-LEVEL MEASUREMENT

All of the McCrometer propeller meters were calibrated at the factory. A factory representative visited the site and inspected RD 108's initial installation. The AquaRods are factory calibrated to read depth relative to the length of the rod. During the installation of the AquaRods, levels were run to establish the point of zero flow for each of the spill structures.

4.1.2.1 Year 1 Measurement Sites

Tables 4-2 and 4-3 identify the equipment installed at each measurement location at both the Field- and Lateral-level Sites in Year 1, respectively. Year 1 measurement locations are shown on Figure 4-4.

TABLE 4-2
Year 1 Field-level Site Meter and Measurement Description
Cooperative Water Measurement Study Report

Site Designation	Meter Size (inches)	Measures
Delivery Points		
S1	24	Deliveries from Lateral 14A and deliveries to Field 193
S1A	18	Deliveries from Lateral 14A and deliveries to Field 194
S11	24	Deliveries from Lateral 14B and deliveries to Lateral 1B3
Drains and Control Points		
CP3	34 (flashboard)	Spill from Lateral 1B3
D2	30	Drainage from Fields 193 and 196
D6	30	Drainage from Fields 194 and 195

TABLE 4-3
Year 1 Lateral-level Site Meter and Measurement Description
Cooperative Water Measurement Study Report

Site Designation	Meter Size (inches)	Measures
Delivery Point		
S16	24	Deliveries from Lateral 14B and deliveries to Lateral 1B1
Drains and Control Points		
CP4	18 (flashboard)	Spill from Lateral 1B3
D4	30	Drainage from Fields 199 and 202
D8	24	Drainage from Fields 194 and 195

As described in Section 4.1.3, during Year 1, deliveries were made at the locations designated as S13, S14, S17, and S18 between May 24 and May 31; but measurement devices were not installed at those sites. Also in Year 1, some deliveries were made to fields within the field-level site prior to the installation of the meters. Deliveries were also made in Year 1 to the Lateral-level Site between May 24 and May 28.

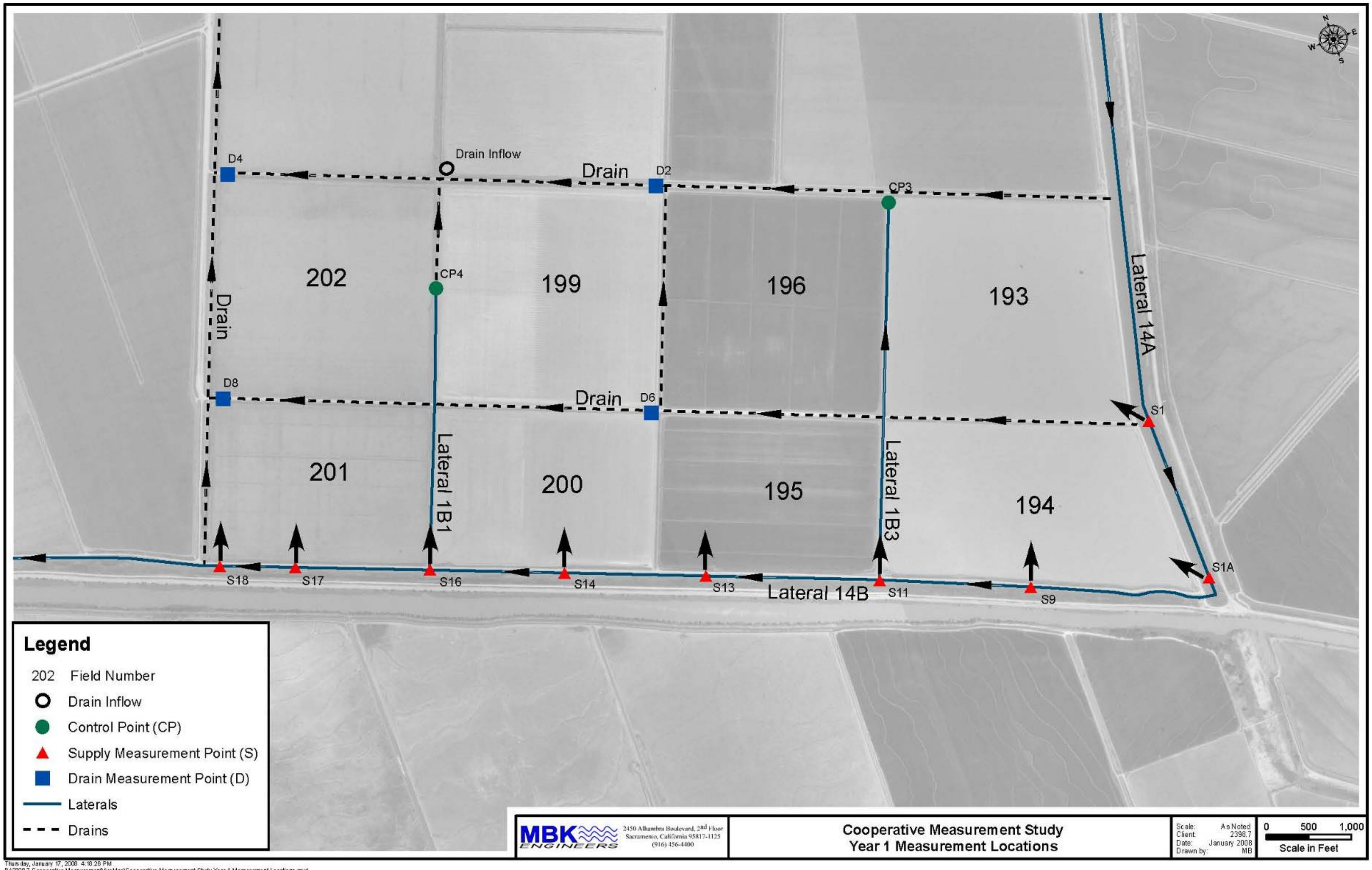


FIGURE 4-4
YEAR 1 MEASUREMENT LOCATIONS

4.1.2.2 Year 2 Measurement Sites

All of the measurement devices used in Year 1 were reinstalled in Year 2. Additional meters were installed to allow for individual measurement of the deliveries and drainage for Fields 193, 194, 195, and 196. Table 4-4 identifies the additional equipment installed at the Field-level Sites for Year 2. Year 2 measurement locations are shown on Figure 4-5.

TABLE 4-4
Additional Year 2 Field-level Site Meter and Measurement Description
Cooperative Water Measurement Study Report

Site Designation	Meter Size (inches)	Measures
Delivery Points		
S2	30	Deliveries from Lateral 1B3 to Field 193
S10	24	Deliveries from Lateral 1B3 to Field 194
S12	24	Deliveries from Lateral 1B3 to Field 195
S3	30	Deliveries from Lateral 1B3 to Field 196
S4	30	Deliveries from Lateral 1B3 to Field 196
Drains and Control Points		
D1	24	Drainage from Field 193
D5	24	Drainage from Fields 194

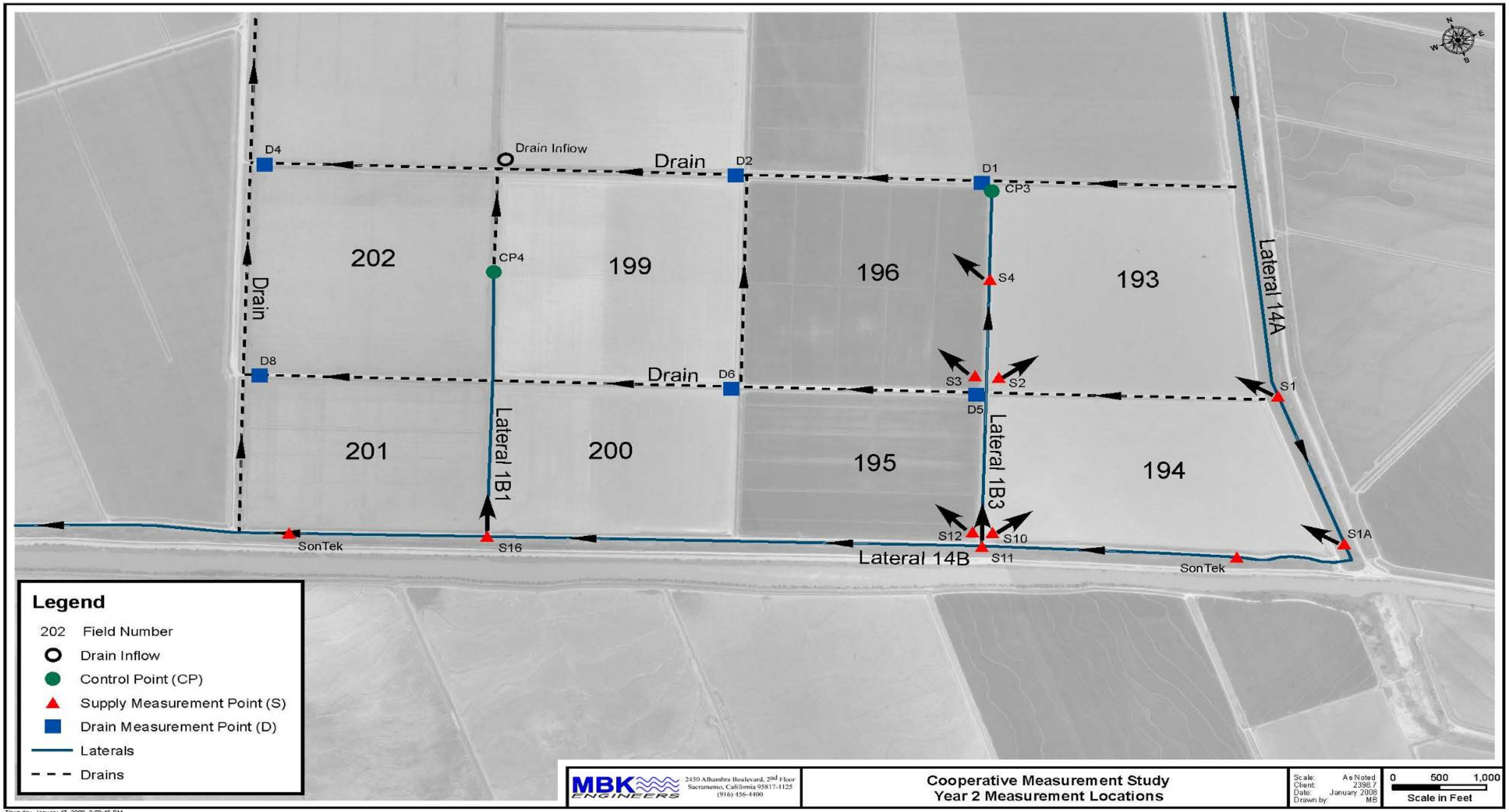
No water was delivered in Year 2 at the sites designated as S9, S13, S14, S17, and S18.

During Year 1 of the study, the technical team identified the potential opportunity to measure deliveries within the study area at a main lateral level, as well as sub-lateral and field levels. However, this level of measurement was beyond the scope of the study. The technical team recognized the potential value of this additional information; and, as a result, Reclamation obtained, installed, and maintained two SonTek/YSI Argonaut SL 3000 (SonTek) side-looking Doppler flow meters. In Year 2, one of these Doppler meters was installed upstream of Lateral 1B3, and the second was installed downstream of Lateral 1B1, as shown on Figure 4-5. An example of the SonTek installation located upstream of Lateral 1B3 is shown on Figure 4-6.

4.1.3 Data Collection

This section presents the data and information collected during the Field Measurement Study. The tables in this subsection (4.1.3) provide the raw data collected during Years 1 and 2 summarized on a monthly basis. Analysis of the data is discussed in Section 4.1.4.

RD 108 staff recorded the flow rate and totalizer readings for each of the propeller meters daily. During the flood-up period in Year 1, water levels and gate openings were also measured and recorded for the delivery gates designated as S9, S13, S14, S17, and S18 which did not have measurement devices installed. The quantity delivered through those gates was calculated for the particular gate size and gate opening.



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R:\2398.7 Cooperative Measurement\ArcMap\Cooperative Measurement Study Year 2 Measurement Locations.mxd

FIGURE 4-5
YEAR 2 MEASUREMENT LOCATIONS

The daily data recorded by RD 108 staff were provided to the technical team at the end of each month. The data were reviewed and entered into a database for analysis. Irregularities in the daily data, such as negative flow volumes from one day to the next and apparently open gates with little or no flow rate or volume recorded, were noted. In most cases, the irregularities in the data were determined to be the result of meters being misread or numbers being transposed when they were recorded. In some instances, it was determined that the meters were not recording data for periods of time because of debris or weed growth that blocked the propellers from turning. The technical team inspected the study sites regularly. During these visits the technical team downloaded electronic data from the AquaRods and observed conditions within the study sites. Conditions affecting meter performance and measurement accuracy, such as propellers impeded by debris or weed growth, or pipes not fully submerged, were communicated to RD 108 staff who worked to rectify the problems in a timely manner.

FIGURE 4-6
ACOUSTIC DOPPLER METER INSTALLATION ON LATERAL 14-B

Prior to the irrigation season in Year 2, Reclamation installed two side-looking SonTek meters within Lateral 14-B. The meters were installed on sliding tracks to allow for proper placement within the flow column and to allow for easy access for cleaning and servicing. Each SL 3000 meter was connected by cable to solar power supplies located nearby, and equipped with a data logger. The SonTek meters were installed, calibrated, and maintained by Reclamation staff. Data were downloaded by Reclamation and provided to the technical team for analysis and use. Irregularities were observed in the data from both of the SonTek meters. It was determined that the meters were not properly calibrated for the full range of flow. Additionally, weed growth in the channel near the meters during the irrigation season resulted in changes in the cross-sectional area. The extent of the change in area was not documented or accounted for in the calibration. Because of the uncertainty regarding the accuracy of the data recorded by the SonTek meters and because these measurements were outside of the original scope of the Field Measurement Study, the data were not analyzed. Details of the SonTek installations, data collected, and issues encountered are presented in Appendix B.

4.1.3.1 Year 1

The propeller meters were ordered on March 28, 2006; however, some meters did not arrive from the manufacturer in time for installation prior to the time deliveries to the study sites began. RD 108 staff monitored gate openings and water levels upstream and downstream of the delivery gates at locations where a totalizing meter was not installed. These water deliveries in Year 1 were calculated by using the difference in water levels upstream and downstream of the turnouts and the gate openings. Because of miscommunication with the grower prior to flood-up in Year 1, deliveries were made at the location designated as S13 between May 28 and May 31. The quantities of water delivered through these gates were calculated by using information obtained from RD 108 staff regarding the difference in water levels in Lateral 14B and the rice fields and the gate openings and an orifice flow equation with an assumed coefficient of flow of 0.61.

More than 7 inches of rain fell in the Sacramento Valley between the beginning of March and mid-April 2006. Because of the heavier than normal precipitation, preparation of many rice fields for planting, including those within the study area, was delayed until the latter part of April. These conditions resulted in an accelerated and condensed flood-up period.

Field-level Sites. Deliveries to Fields 194 and 195 began on May 27, 2006. Deliveries to Field 193 began on May 29, 2006, and to Field 196 on June 1, 2006. Deliveries through the gates without totalizing devices ended prior to June 1.

Table 4-5 summarizes the monthly volume of water recorded at each delivery point, including the calculated deliveries at S13, and drainage point, within the Field-level Sites during Year 1.

TABLE 4-5
Year 1 Deliveries and Drainage at Field-level Sites (acre-feet) – Fields 193, 194, 195, and 196
Cooperative Water Measurement Study Report

		Month					
Delivery Gate	**Field**	**May**	**June**	**July**	**August**	**September**	**Total**
Delivery Summary							
S1	193	0	223	329	286	137	975
S1A	194	123	200	190	202	34	749
S11	All	0	361	191	251	149	952
S13[a]	195	90	0	0	0	0	90
Total		213	784	710	739	320	2,766
Operational Spill							
CP3	Sub-lateral 1B3	0	2	0	0	0	2
Drainage Summary							
Drain Measurement Point							
D2	193 and 196	[b]	22	19	68	126	235
D6	194 and 195	[b]	136	69	289	197	691
Total		[b]	158	88	357	323	926

[a]Gate without a totalizing device. The quantity of water delivered is calculated on the basis of gate size, gate opening, and difference in upstream and downstream water levels using an orifice flow equation [$Q = CA(2gh)^{1/2}$] with an assumed coefficient of discharge, “C,” of 0.61.

[b]May flows at these locations are included in the totals for June.

Table 4-5 indicates there was very little operational spill from Lateral 1B3, approximately 2 acre-feet total, in 2006.

Lateral-level Sites. Deliveries to Lateral 1B1 began on May 24, 2006. Deliveries to Fields 200 and 201 also began on May 24, 2006. Deliveries to Fields 199 and 202 began on June 1, 2006. As with the Field-level Site, miscommunication with the grower resulted in deliveries at S14, S17, and S18 between May 24 and May 28 that were not measured with a totalizing device. The quantities of water delivered through these gates were calculated by using information obtained from RD 108 staff regarding the difference in water levels in Lateral 14B and the rice fields and the gate openings, and an orifice flow equation with an assumed coefficient of flow of 0.61.

Because of the configuration of the drainage system within the study areas, the drainage measured at Drain Measurement Points D4 and D8 includes drainage from the Field-level Sites. Therefore, to determine the drainage from the Lateral-level Sites, the flow volume at D2 and D6 must be subtracted from the flow volume at D4 and D8, respectively. The quantities shown in Table 4-6 for D4 and D8 have been adjusted accordingly.

TABLE 4-6
Year 1 Deliveries and Drainage at Lateral-level Sites (acre-feet) – Fields 199, 200, 201, and 202
Cooperative Water Measurement Study Report

		Month					
Delivery Gate	**Field**	**May**	**June**	**July**	**August**	**September**	**Total**
Delivery Summary							
S14[a]	200	43	0	0	0	0	43
S15[a]	200	89	0	0	0	0	89
S16	All	[b]	508	610	571	233	1,922
S17[a]	201	78	0	0	0	0	78
S18[a]	201	59	0	0	0	0	59
Total		269	508	610	571	233	2,191
Operational Spill							
CP4	1B1	0	0	0	0	0	0
Drainage Summary							
Drain Measurement Point							
D4[c,d]	199 and 202	[b]	139	97	204	225	665
D8[d]	200 and 201	[b]	119	139	91	116	465
Total		[b]	258	236	295	341	1,130

[a]Gate without a totalizing device. The quantity of water delivered is calculated on the basis of gate size, gate opening, and difference in upstream and downstream water levels using an orifice flow equation [$Q = CA(2gh)^{1/2}$] with an assumed coefficient of discharge, "C," of 0.61.

[b]May flows at these locations are included in the totals for June.

[c]Drainage recorded at D4 includes an undetermined quantity of inflow from outside of the study area.

[d]Drainage measured by meters at these locations includes drainage from Field-level Sites. Therefore, the value shown for D4 is calculated as the D4 metered flow minus metered flow at D2. The value shown for D8 is calculated as the D8 metered flow minus the metered flow at D6.

Water from an emergency spill structure located on the supply canal just to the east of the study sites can enter the drain between Drain Measurement Point D2 and D4. The emergency spill structure is similar to the control structures at CP3 and CP4, consisting of a flashboard riser pipe with a 1.5-foot crest to control water levels. To account for this drain flow that originates outside of the study area, a 0.5-meter AquaRod was installed to monitor water levels at the emergency spill structure. Spill from the supply canal to the drain above D4 was estimated using a weir equation. The drain flows for D4, shown in Table 4-6, have been adjusted to account for the calculated inflow to the drain from the emergency spill. The AquaRod at the emergency spill became submerged sometime during the late afternoon of June 17 and early morning of June 18, and ceased recording water depths after 9:45 a.m. on June 18. The AquaRod was removed and sent to the manufacturer for repair, and reinstalled and calibrated on August 21. Data recorded prior to the submergence were not lost; however, no data that would indicate the amount of water spilling into the drain from this canal were recorded between June 18 and August 21.

On the basis of Table 4-6, total recorded deliveries to the Lateral-level Site in Year 1, including calculated deliveries from gates without installed devices, were approximately 2,191 acre-feet. As identified above, the drain flows recorded at Drain Measurement Point D4 include an unknown quantity of inflow to the drain from the emergency spill structure located on a supply canal adjacent to the drain. Therefore, the quantity of drain flow originating from within the Lateral-level Site during Year 1 includes an unknown volume from D4.

4.1.3.2 Year 2

In Year 2, propeller meters were added to allow the delivery and drainage to and from each field within the Field-level Sites to be measured. In addition, Reclamation installed and maintained SonTek ultrasonic Doppler flow meters on Lateral 14B. The purpose of these meters was to measure flow in the main lateral supplying the majority of the study area and to provide another level of measurement for comparison. No water was delivered through the gates at S13, S14, S15, S17, and S18 in Year 2.

With the exception of the meters at Drain Measurement Points D1 and D5, the propeller meters were installed in mid-April 2007. The D1 and D5 sites required RD 108 to install or replace culverts to facilitate the installation of the meters. These modifications were completed, and the meters were installed prior to the delivery of irrigation water.

The technical team visited the study site at the beginning of the irrigation season to install the AquaRods on Laterals 1B1 and 1B3, and the emergency spill sites on the adjacent supply canal. Technical team staff also visited several times during Year 2 to download data from the AquaRods. During these field visits, the meter installations and operation were observed at the study sites. Conditions affecting meter operation and accuracy observed during these visits, such as pipes not fully submerged, weed growth, or debris, were communicated to RD 108 staff who worked to address any issues in a timely manner.

Field-level Sites. Field-level Site deliveries and drainage were monitored at both the lateral level, as in Year 1, and at the individual field level. Deliveries within the Field-level Sites began about May 18, 2007, and ended between September 8 and 12, 2007. Observations during field visits and review of the daily operator's logs indicate velocities observed at the drain locations were at times below the rated range for the propeller meters. This is also true for the field delivery meter during the maintenance flow period. Data collected for the delivery to Field 194 at S1A indicate this meter was not operating properly. RD 108 staff made several attempts to clean the meter and the channel below the meter, but had little success.

Table 4-7 summarizes the monthly volume of water recorded at lateral-level delivery and drainage points within the Field-level Sites during Year 2.

TABLE 4-7
Year 2 Deliveries and Drainage at Field-level Sites (acre-feet) – Fields 193, 194, 195, and 196
Cooperative Water Measurement Study Report

		Month					
Delivery Gate	**Field**	**May**	**June**	**July**	**August**	**September**	**Total**
Delivery Summary							
S11	All	266	297	280	227	79	1,149
S1	194	197	264	219	170	63	913
S1A	193	133	183	11	0	0	327
Total		596	744	510	397	142	2,389
Operational Spill							
CP3	Sub-lateral 1B3	0	0	0	0	0	0
Drainage Summary							
Drain Measurement Point							
D2	193 and 196	29	64	42	99	135	369
D6	194 and 195	108	185	47	133	149	622
Total		137	249	89	232	284	991

Tables 4-8 through 4-11 summarize the monthly volume of water recorded at delivery and drainage points for each individual field within the Field-level Sites during Year 2.

TABLE 4-8
Year 2 Deliveries and Drainage at Field-level Sites (acre-feet) – Field 193
Cooperative Water Measurement Study Report

		Month					
Delivery Gate	**Field**	**May**	**June**	**July**	**August**	**September**	**Total**
Delivery Summary							
S1	193	197	264	219	170	63	913
S2	193	7	0	6	0	0	13
Total		204	264	225	170	63	926
Drainage Summary							
Drain Measurement Point							
D1	193	44	65	20	21	41	191
Total		44	65	20	21	41	191

TABLE 4-9
Year 2 Deliveries and Drainage at Field-level Sites (acre-feet) – Field 194
Cooperative Water Measurement Study Report

		Month					
Delivery Gate	**Field**	**May**	**June**	**July**	**August**	**September**	**Total**
Delivery Summary							
S1A	194	133	183	11	0	0	327
S10	194	86	35	17	0	1	139
Total		219	218	28	0	1	466
Drainage Summary							
Drain Measurement Point							
D5	194	49	97	21	66	52	285
Total		49	97	21	66	52	285

TABLE 4-10
Year 2 Deliveries and Drainage at Field-level Sites (acre-feet) – Field 195
Cooperative Water Measurement Study Report

		Month					
Delivery Gate	**Field**	**May**	**June**	**July**	**August**	**September**	**Total**
Delivery Summary							
S1A	194	132	110	64	68	36	410
Total		132	110	64	68	36	410
Drainage Summary							
Drain Measurement Point							
D6[a]	194	59	88	26	68	96	337
Total		59	88	26	68	96	337

[a]Drainage measured at D6 includes drainage from Field 194 measured at D5. Therefore, drainage for Field 195 is calculated as D6 minus D5.

TABLE 4-11
Year 2 Deliveries and Drainage at Field-level Sites (acre-feet) – Field 196
Cooperative Water Measurement Study Report

		Month					
Delivery Gate	**Field**	**May**	**June**	**July**	**August**	**September**	**Total**
Delivery Summary							
S3	196	63	62	128	93	19	365
S4	196	73	58	54	75	15	275
Total		136	120	182	168	34	640
Drainage Summary							
Drain Measurement Point							
D2[a]	194	-15	-1	22	77	94	177
Total		-15	-1	22	77	94	177

[a]Drainage measured at D2 includes drainage from Field 193 measured at D1. Therefore, drainage for Field 196 is calculated as D2 minus D1. Negative values occur when the flow recorded at D1 is greater than the flow recorded at D2.

Deliveries shown in Tables 4-7 and 4-9 do not include unrecorded flow to Field 194 at S1A, as previously discussed.

Lateral-level Site. Deliveries to the fields within the Lateral-level Sites from Lateral 1B1 began about May 18 and ended about September 14, 2007. Table 4-12 summarizes the monthly volume of water recorded at lateral-level delivery and drainage points within the Lateral-level Site during Year 2.

As in Year 1, the AquaRod installed to monitor inflow from outside the study area above the meter at Drainage Measurement Point D4 failed. Numerous attempts were made to have the sensor repaired or replaced by the manufacturer, with no success. Various levels of inflow to the drain at this location were observed by the technical team during visits to the study site. Therefore, the calculated drainage at D4 for Fields 199 and 202 includes an unknown quantity of unmeasured inflow.

TABLE 4-12
Year 2 Deliveries and Drainage at Lateral-level Site (acre-feet) – Fields 199, 200, 201, and 202
Cooperative Water Measurement Study Report

		Month					
Delivery Gate	**Field**	**May**	**June**	**July**	**August**	**September**	**Total**
Delivery Summary							
S16	All	356	764	606	585	282	2,593
Total		356	764	606	585	282	2,593
Operational Spill							
CP4	1B1	0	0	0	0	0	0
Drainage Summary							
Drain Measurement Point							
D4[a]	199 and 202	8	57	46	76	119	306
D8[a]	200 and 201	51	58	51	78	52	290
Total		59	115	97	154	171	596

[a]Drainage measured by meters at these locations includes drainage from Field-level Sites. Values shown for D4 are calculated as the metered flow at D4 minus the metered flow at D2. The values shown for D8 are calculated as the D8 metered flow minus the metered flow at D6.

4.1.4 Data Analysis

The data collected during the 2-year Field Measurement Study were reviewed. The review included comparisons of total deliveries, drainage, and net deliveries measured at lateral, sub-lateral, and field levels for both years of the Field Measurement Study. The analysis is included in Appendix A. Conditions affecting performance of the measurement devices and accuracy of the measurement data collected were experienced at all measurement levels and with all types of the equipment used in the study. Following are some of the conditions that were observed by the technical team or RD 108 staff during the field study:

- Deliveries through gates without totalizing measurement devices at S13, S14, S15, S17, and S18 in Year 1

- Unmeasured inflow to the drain above the meter at D4 resulting from malfunctioning water level sensor
- Drain meters observed at times to be only partially submerged (non-full pipe condition)
- Sediment (as shown on Figures 4-7A and 4-7B), debris, and weeds observed to be interfering with the operation and accuracy of the propeller meters
- Meters on turnouts observed at times to be registering zero velocity when gates were open and water was observed flowing into fields
- Observed flow rates at turnouts below manufacturer's published minimum specifications for the propeller meters
- SonTek calibration procedures were not well documented and did not account for changing conditions, i.e., weed growth along the canal resulted in changes to the cross-sectional area
- SonTek meters recorded flows outside of the range for which they were calibrated

FIGURE 4-7A
SEDIMENT AT PIPE OUTLET

FIGURE 4-7B
SEDIMENT AT PIPE OUTLET

Other conditions also affected the accuracy of the data collected during the Field Measurement Study. The propeller meters used to measure turnout-level deliveries to the fields were installed on the downstream or field side of the delivery pipes. During the initial flood-up, delivery pipes operated in a non-full pipe condition until sufficient water had been delivered to the field to cause the pipe to be fully submerged. Non-full pipe conditions were also observed at several of the drain meter locations.

The analysis included in Appendix A is based on the actual data collected during the study as described and summarized in Section 4.1.3 of this *Cooperative Water Measurement Study Report*. Many of the conditions affecting accuracy of the data collected for the Field Measurement Study were observed after the fact, and little or no information was available as to how long any of the conditions might have existed before they were observed.

4.1.5 Conclusions

The goal of the Field Measurement Study was to examine different approaches to field-level measurement. Specifically, this study attempted to compare measurement to fields at the turnout level and at a lateral level. Because of the very small data set and questions regarding accuracy, it is not possible to draw conclusions regarding field-level measurement of flow rate and volume at the lateral level versus the turnout level by using the data collected for the Field Measurement Study. Although conditions affecting accuracy of the turnout-level measurements resulted in the inability to make a direct comparison of the turnout-level and lateral-level measurements, information regarding measurement was gained through the Field Measurement Study, especially as it relates to rice fields. The following identifies some of the lessons learned and provides recommendations for future studies and consideration.

Although sediment was observed to have affected measurement at many of the turnouts, sediment was not observed to affect the meters installed at the head of Laterals 1B1 and 1B3. Velocities observed at these meters were generally above the manufacturer’s stated minimum of approximately 4.5 cubic feet per second (cfs), whereas meters installed at some turnouts were observed at times to be registering no flow when water was observed flowing into the fields.

Because of the need to quickly flood rice fields, many fields have two or more turnouts. Because of the costs associated with the purchase and O&M of meters, sophisticated measurement equipment such as Doppler or ultrasonic devices might not be economically feasible for turnout-level measurement to rice fields. These devices have relatively high initial investment costs and require regular O&M; strict calibration procedures; and skilled, knowledgeable operators to provide accurate and useful information.

Where pipes and screw gates are used for delivery to rice fields, they are sized to quickly flood the field. These same pipes are typically used to deliver much smaller flows to maintain a targeted water level in the rice field. Conditions that affected the performance and accuracy of the propeller meters used in this study, such as sediment buildup and the inability to accurately measure flows over a wide velocity range, would also have been experienced with more sophisticated types of measurement devices such as Doppler or ultrasonic meters. In addition, propeller meters require full-pipe conditions to provide accurate measurement. In some instances, turnouts or delivery systems might need to be reconfigured to achieve accurate measurement. The feasibility of installing and maintaining smaller turnouts for maintenance flows in addition to the larger pipes used for flood-up should be explored. These smaller turnouts would require smaller meters that are calibrated for a lower range of velocity. The smaller delivery pipe would also result in higher velocities and possibly fewer sedimentation issues. Costs associated with any required reconfiguration should be included in determining the feasibility of using propeller meters for turnout-level measurement.

Accuracy of measurement devices such as rated or meter gates might also be affected by sediment and weed growth. Overflow structures such as weirs and check boards might be less affected by these conditions. All devices require a sufficient amount of headloss to provide reasonably accurate measurement. It is recommended that rated and meter gates be calibrated regularly to verify the accuracy of the measurement devices.

4.2 Delivery Data Analysis

4.2.1 Approach

The delivery data analysis portion of the Cooperative Study involves a comparative analysis of water use for SRSCs that use a flat-rate pricing structure (water charges based on a cost per acre associated with the crop type) and those that use a volumetric pricing structure (water charges based on the acre-feet of water delivered). SMWC and RD 1004 were chosen for this analysis because both SMWC and RD 1004 have changed from one pricing structure to another. SMWC changed from a volumetric pricing structure in 2003, to a flat-rate pricing structure. Under a volumetric pricing structure, growers are charged for water on the basis of the quantity delivered to the field. Under a flat-rate pricing structure, growers are charged for water on the basis of the crop grown and the number of acres planted. The charge varies by crop and is generally based on some estimate of the water needs for the individual crops. SMWC's pricing structure is evaluated annually by the Board of Directors, and the subsequent year's practice is decided prior to the irrigation season. RD 1004, on the other hand, changed from a flat rate to a volumetric pricing structure in 1994.

During Year 1 of the study, the technical team met with the managers of both SMWC and RD 1004 to discuss the availability and format of existing data. During the meetings, they determined that some modifications would need to be made in the planned analysis on the basis of data availability. Specifically, it was determined that records of deliveries to fields within RD 1004 were not available for the periods immediately preceding and subsequent to the pricing structure change in 1994. Additionally, although records of monthly diversions by RD 1004 from the Sacramento River are available, records of its diversions from Butte Creek are not. For these reasons it was not possible to analyze the impact of the pricing structure change on diversions by and deliveries within RD 1004. Field delivery and diversion data were available and were obtained from SMWC for the period 2000 through 2006. This period includes 3 years before and 4 years after SMWC's change in pricing structure. Although the analysis of the effect of the change in pricing structure focused on SMWC, delivery data were obtained from RD 1004 for the 2000 through 2006 study period; and the trends in field-level unit rice deliveries within the two service areas are compared.

4.2.2 Data Collection

Delivery and diversion data as well as SMWC/RD 1004 operation and policy information were obtained from both SMWC and RD 1004 for the 2000 through 2006 period. Additionally, to assist in isolating and analyzing the effect of SMWC's pricing structure, hydrologic data, California crop statistics, and information pertaining to contract supplies were reviewed and analyzed. Descriptions of data and information obtained are provided below.

4.2.2.1 Sutter Mutual Water Company Delivery and Diversion Data

SMWC measures deliveries to each field at each turnout. Turnouts within SMWC generally consist of either rated check structures or rated gates. In the case of the rated check structures, measurement consists of measuring the depth of water flowing over the check boards. The flow rate is then obtained from a table by looking up the flow rate associated with the observed depth. For rated gate turnouts, the gate opening and the difference in water surface levels on either side of the gate are determined. The flow rate is then found from a table that identifies the flow rate for the particular gate opening and head. The volume of water at a particular turnout is calculated by using the flow rate over time. Typically, the volume is totalized every 24 hours. Although SMWC changed to a flat-rate pricing structure prior to the 2003 irrigation season, it continued to collect delivery data for each turnout, field, and water user. Canal operators generally check and record gate openings and head at each turnout daily, and when operational changes are made to the system. A separate daily log is kept for each turnout.

Prior to the change in pricing structure, delivery data from the daily logs were entered into an electronic database used by SMWC for billing purposes. A copy of the billing database was obtained from SMWC for the 2000, 2001, and 2002 irrigation seasons. The electronic data obtained from SMWC include field ID number, field name, crop type grown, irrigation method, and volume of water delivered in acre-feet by date. Acreage and canal operator service area information are not included in the electronic data file; however, information was obtained through other records provided by SMWC. As identified above, the electronic data obtained from SMWC was developed for billing purposes; therefore, a certain amount of data post-processing was required for analysis of use on canal operator service area, crop, and acreage basis. Post-processing included identifying billing credits for crop changes and billing errors, identifying lands that were double cropped, and identifying fields that were either split or combined with other fields.

Although SMWC continued to measure and record turnout delivery data after it changed its pricing structure, the data were not entered into an electronic database. Therefore, hard copies of the daily delivery logs were obtained for the 2003 through 2006 irrigation seasons. The logs contained the canal operator service area, field ID number, grower name, acreage, crop planted, and the daily delivery in acre-feet for each turnout. The data from the daily delivery logs for the years 2003 through 2006 were compiled into an electronic format and summarized for each turnout by the technical team.

Monthly Sacramento River diversion data for SMWC were obtained through Reclamation's CVP Operations Web site. These data were used to compare SMWC's deliveries with monthly diversions from the Sacramento River.

4.2.2.2 Reclamation District 1004 Delivery and Diversion Data

RD 1004 changed from a flat rate to a volumetric pricing structure in 1994. To implement the change, propeller meters were installed on all turnouts within RD 1004. Each meter is capable of providing both instantaneous flow rates and totalized volume. The meters are read and cleaned regularly by staff, generally every 2 days. RD 1004 personnel record the flow rates and the total volume delivered at each turnout. RD 1004 delivery data for the 2000 through 2006 irrigation seasons were obtained in an electronic billing format. As with the electronic billing data obtained from SMWC, post-processing of the data was required for it to be used in analyzing water use within RD 1004. RD 1004 is essentially a single-crop district in that the only harvested crop grown is rice. RD 1004 also delivers water for waterfowl habitat. Data regarding RD 1004's deliveries to rice fields were used to assist in the analysis of deliveries for rice within SMWC. Fields irrigated for waterfowl habitat were not included in the analysis.

Surface water supplies available to RD 1004 include both the Sacramento River and Butte Creek. In addition, RD 1004 has developed an extensive tailwater recovery and recirculation system. Diversions from the Sacramento River are measured and recorded monthly by Reclamation. Entire records of diversions from Butte Creek are not available, and only estimates of the quantities of recirculated water were available for the study period. Additionally, although crop and billing data prior to 2000 are available, records of water deliveries by RD 1004 are not. As a result, although RD 1004's diversions from the Sacramento River prior to and after the pricing structure change in 1994 can be compared, changes in the total amount of water diverted from surface sources could not be accurately determined.

4.2.2.3 Hydrologic Conditions and Weather Data

Data concerning water conditions, including water-year type, contract supplies, and other limiting factors, were obtained from Reclamation, DWR, and SMWC.

Weather data were obtained from the California Irrigation Management Information System (CIMIS) Web site. These data consist of a reference evapotranspiration as defined and calculated using the Food and Agriculture Organization (FAO) Penman-Monteith equation further described in the *FAO Irrigation and Drainage Paper 56: Crop Evapotranspiration, Guidelines for Computing Crop Water Requirements*. The reference evapotranpsiration calculation is based on measured solar radiation, air temperature, soil temperature, relative humidity, wind speed and direction, and precipitation. Because no CIMIS station is located within SMWC, data were obtained for stations located near the Towns of Nicholas, Colusa, and Zamora (CIMIS Stations 30, 32, and 27, respectively).

4.2.2.4 Crop Data

In addition to crop data obtained from SMWC and RD 1004 for the study period, statewide data for the crops grown within SMWC and RD 1004 were obtained from the California Rice Commission, the U.S. Department of Agriculture, and the California Department of Food and Agriculture. Additionally, regional information was obtained through interviews with the Northern California Regional Director of Shipping Point Inspections, representatives of Pacific Coast Producers, and SRSC managers. The data obtained include state and regional cropping patterns, pricing information, planting and harvesting dates, and acreages for the study period.

4.2.3 Analysis

Because of the unavailability of Butte Creek diversion data and field-level delivery data prior to 2000, analysis of the impacts of the pricing structure change within RD 1004 was not possible; therefore, the delivery data analysis is focused on SMWC. Data collected regarding RD 1004's deliveries, diversions, and crop patterns for the 2000 through 2006 study period were used to compare the trends in unit deliveries for rice within RD 1004 to those within SMWC.

To isolate and analyze the effects of SMWC's change in pricing structure, numerous other factors that might affect decisions regarding water diversions and use at the field level and company level were reviewed and analyzed. These factors include cropping patterns, varietal changes, irrigation methods, water transfers, hydrologic and weather conditions, and commodity prices. Additionally, the effect of the change in surface water supply available to SMWC resulting from the renewal of its contract with Reclamation prior to the 2005 irrigation season was reviewed and analyzed.

4.2.3.1 Sutter Mutual Water Company

Table 4-13 summarizes the total irrigated acreage, diversions, and deliveries within SMWC for each year during the study period. Table 4-13 also identifies the total number of irrigated crops grown within SMWC and the three crops with the largest irrigated acreage, as well as the percentage of lands devoted to rice production within SMWC during the study period.

TABLE 4-13
Sutter Mutual Water Company Summary of Delivery Data Analysis
Cooperative Water Measurement Study Report

Year	Total Irrigated Acres	Acre-feet of Water Delivered	Acre-feet of Water Diverted	Number of Crops Irrigated	Three Largest Irrigated Crops	Percentage of Acres Planted to Rice
2000	42,200	165,700	224,800	15	Rice, tomatoes, corn	57
2001	37,500	143,500	163,500	15	Rice, tomatoes, corn	47
2002	38,300	140,300	181,500	14	Rice, tomatoes, beans	48
2003	30,100	137,400	174,500	13	Rice, tomatoes, beans	63
2004	43,200	199,200	237,500	11	Rice, tomatoes, melons	72
2005	35,500	156,600	190,900	13	Rice, tomatoes, sunflowers	64
2006	37,800	196,100	215,300	13	Rice, tomatoes, sunflowers	72

SMWC participated in water transfer programs on behalf of some of its landowners in 2001, 2003, and 2005. These transfers involved a small amount of crop idling, but were mainly accomplished through shifting to crops with lower water use requirements or to non-irrigated crops. The quantity of water made available for transfer in each of these years was limited to the difference between the consumptive use of the crops grown versus the crops that would have been grown absent the transfer program. The changes in diversions, deliveries, and irrigated acreages as a result of these transfers are reflected in the values shown in Table 4-13. Not all landowners within SMWC participated in the transfer programs. The water supplies available to those landowners who did not participate were not affected by the transfers. These types of transfer programs do not account for changes in quantities either delivered or diverted by SMWC. The transfers, together with other factors such as hydrologic conditions, crop patterns changes, commodity prices, and other items discussed below, make it difficult to isolate and analyze the effects of the change in pricing structure within SMWC.

Annual Deliveries and Diversions. Figure 4-8 shows SMWC's irrigation-season surface water deliveries and diversions for the study period. In addition, the chart identifies the change in billing practice and the available water supply each year under SMWC's contract with Reclamation. Figure 4-8 indicates a general increase in both diversions and deliveries within SMWC after 2003. To determine whether this change was the result of the change in pricing structure, the effects of other factors were analyzed as described below.

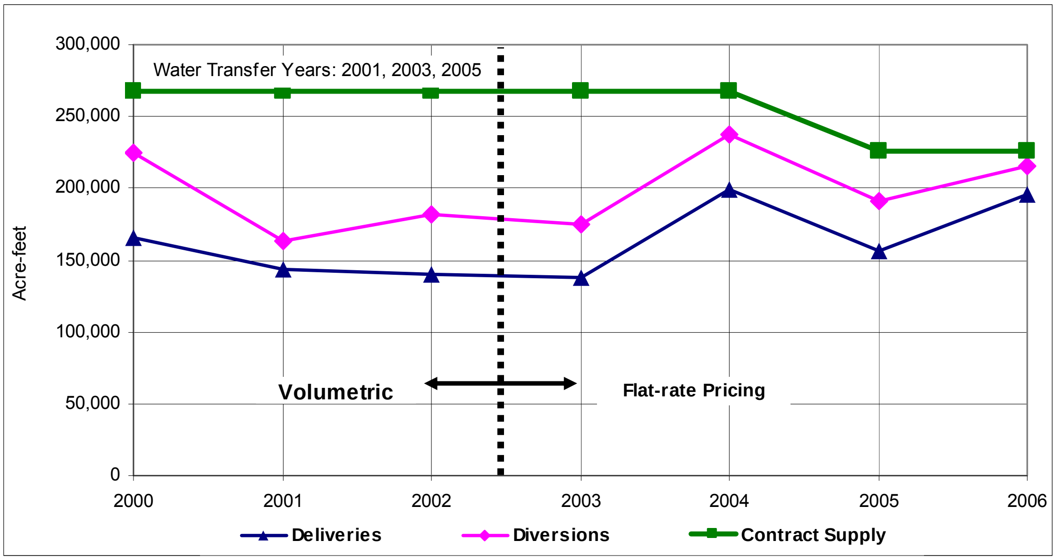

FIGURE 4-8
IRRIGATION-SEASON SURFACE WATER DIVERSIONS
AND DELIVERIES WITHIN SUTTER MUTUAL WATER COMPANY

Crop Patterns, Varietals, and Commodity Prices. The total irrigated acres during the study period varied from a low of approximately 30,100 acres in 2003, to a high of approximately 43,200 acres in 2004. As previously identified, SMWC participated in transfer programs on behalf of it growers in 2001, 2003, and 2005. These transfer programs result in shifting to crops with lower water use requirements, shifting to non-irrigated crops, and, to a minor extent, idling cropland. Thus, there were more reductions in irrigated acreage, deliveries, and diversions than would have occurred absent the transfer programs.

Figure 4-9 shows the total acreage irrigated within SMWC each year during the 2000 through 2006 study period. Figure 4-9 indicates a slight decreasing trend in irrigated acreage during the 7-year study period.

Other crop-related factors were identified and analyzed to evaluate their potential effect on SMWC's diversions and deliveries. These factors include changes in cropping patterns, crop varieties, irrigation methods, and commodity prices as described below. Commodity prices, and as a result, cropping patterns within SMWC, were found to have the greatest potential effect on deliveries within SMWC. Major crops within SMWC include rice, tomatoes, beans, corn, melons, and sunflower, as identified on Figure 4-10. These six crops comprised approximately 87 to 94 percent of the total irrigated acres during the study period. The price of rice increased significantly in 2002, as is reflected in the increase in rice production within SMWC following the 2002 irrigation season. Of the crops grown within SMWC, rice has the highest delivery requirement; and, therefore, accounts for the majority of diversions and deliveries of surface water. More acreage devoted to rice production would directly increase the amount of water diverted from the Sacramento River. The amount of water returned to the Sacramento River would also increase proportionally. Changes in irrigation methods within SMWC were also analyzed and were found to have a less than significant effect on company-wide diversions and deliveries. The effects of changes in the cropping pattern, crop varieties, irrigation methods, and commodity prices are discussed in detail in Appendix C.

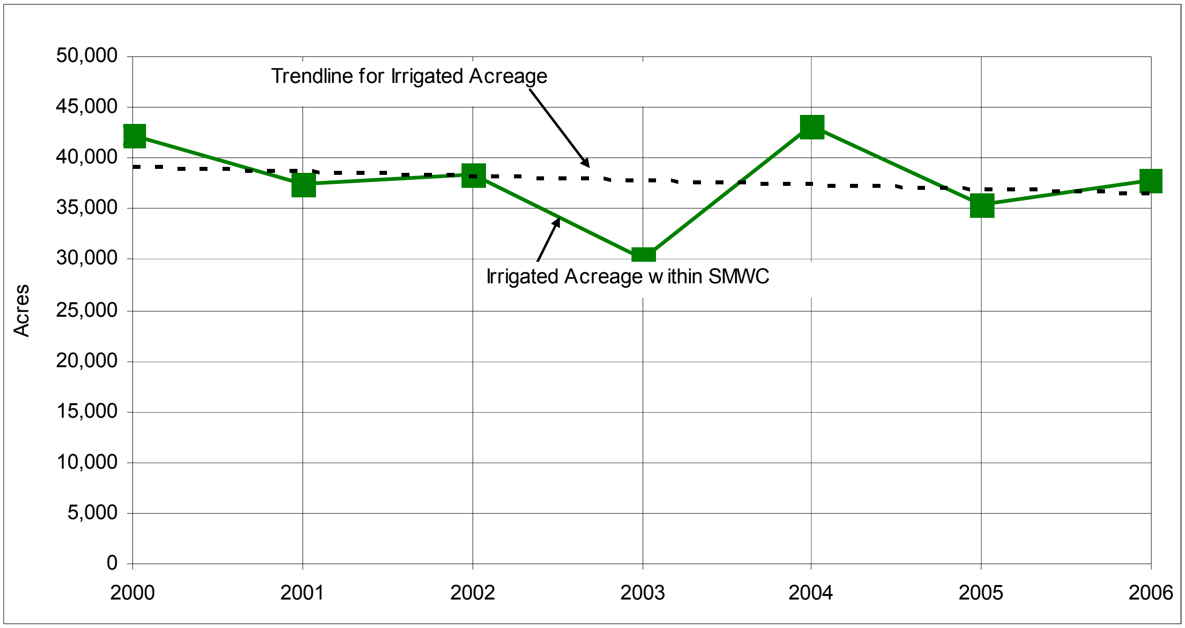

FIGURE 4-9
IRRIGATED ACRES WITHIN SUTTER MUTUAL WATER COMPANY

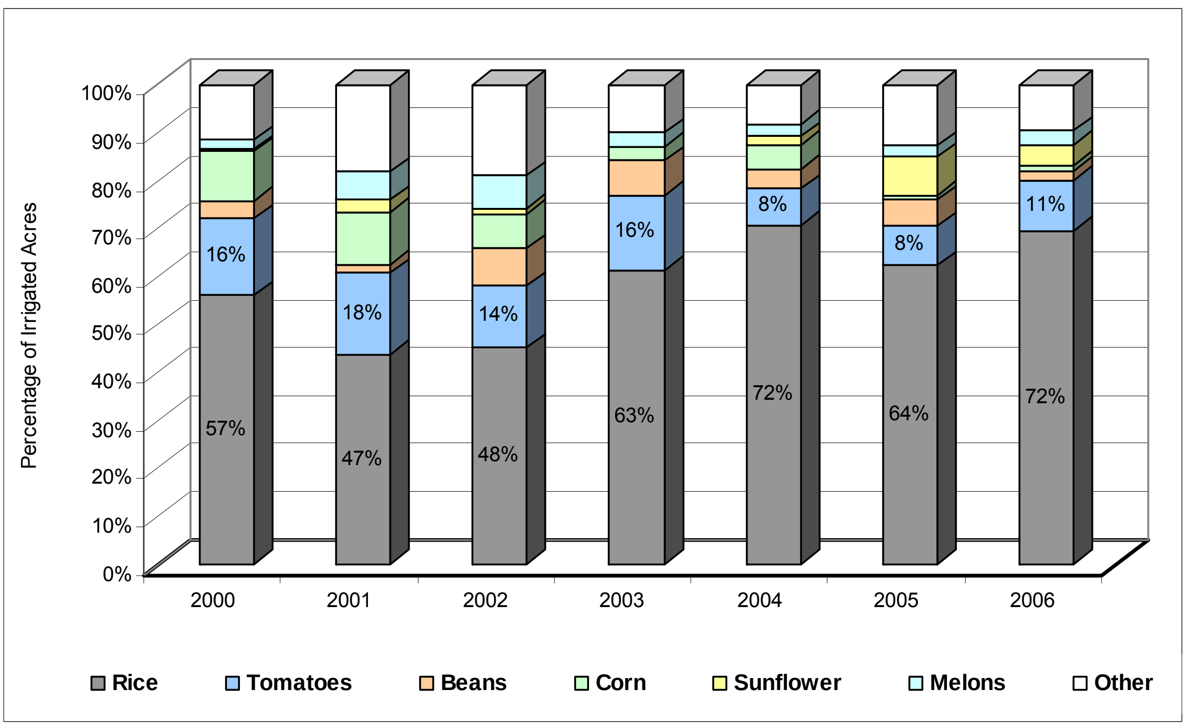

FIGURE 4-10
SUTTER MUTUAL WATER COMPANY CROPPING PATTERN

Hydrologic Conditions and Weather Data. Table 4-14 identifies the year type for each year of the study period according to the Sacramento Valley Water Year Type Index (40-30-30 Index).

TABLE 4-14
Sacramento Valley Water-year Type Index
Cooperative Water Measurement Study Report

Year	Sacramento Valley Water-year Type Index (40-30-30)	SMWC Contract Supply Quantity (acre-feet)
2000	Wet	267,900
2001	Dry	267,900
2002	Dry	267,900
2003	Above normal	267,900
2004	Below normal	267,900
2005	Below normal	226,000
2006	Dry	226,000

According to the provisions of its contract, SMWC received a full water supply under its contract each year. However, SMWC's contract supply was reduced by 41,900 acre-feet in 2005, through the contract renewal process with Reclamation.

Precipitation, regional average temperatures, and consecutive days over 100 degrees Fahrenheit were also analyzed to determine the potential effects that weather might have had on SMWC's diversion and deliveries. Overall, the annual rainfall and average temperatures near the SMWC service area were within the normal range. The Sacramento Valley experienced above-average maximum temperatures during the months of July and August in both 2001 and 2006. In addition, a higher number of consecutive days in which the maximum temperature exceeded 100 degrees Fahrenheit was experienced during summer 2006.

In general, according to the available data, it does not appear that differences in precipitation or average temperatures had a significant affect on SMWC's diversions and deliveries during the study period. However, the above-average and consecutive number of days in which temperatures exceeded 100 degrees Fahrenheit during the irrigation season might partially explain the increase in deliveries during the 2006 irrigation season. Further detail concerning this area of the analysis is provided in Appendix C.

Crop Evapotranspiration. Estimates of crop evapotranspiration (ETc) were developed and compared with diversions and deliveries within SMWC for the study period. In general, the trend in ETc within SMWC is consistent with the recorded deliveries and diversions within SMWC during the study period. A more detailed analysis in regards to the ETc is further described in Appendix C.

Average Unit Deliveries. As indicated above, analysis of the effect of the change in pricing structure on deliveries and diversions is difficult and complicated because of changes in cropping patterns, contract supplies, and other factors that occurred during the study period. To isolate the effect of the change in pricing structure, average unit deliveries (acre-feet/acre) were computed for the crops grown within SMWC for each year of the study period. The unit deliveries were used to compare general trends in deliveries within SMWC. Figure 4-11 shows the average deliveries for five crop categories for each year of the 2000 through 2006 study period. As the figure shows, with the exception of 2006, average unit deliveries during the study period were relatively consistent from year to year for each crop category. Figure 4-11 indicates that, except for "other crops," the average unit deliveries were higher than in previous years for all crop categories in 2006. Late spring rainfall delayed planting of rice and other crops, and shifted the growing season for the major crops, including rice, into the hotter months of July and August. This delay, coupled with the above-average temperatures experienced during the summer, might account for the increase seen in the average unit deliveries in 2006. However, this slight increase may be attributed to a variety of factors, including weather and crop shifting, further discussed in Appendix C.

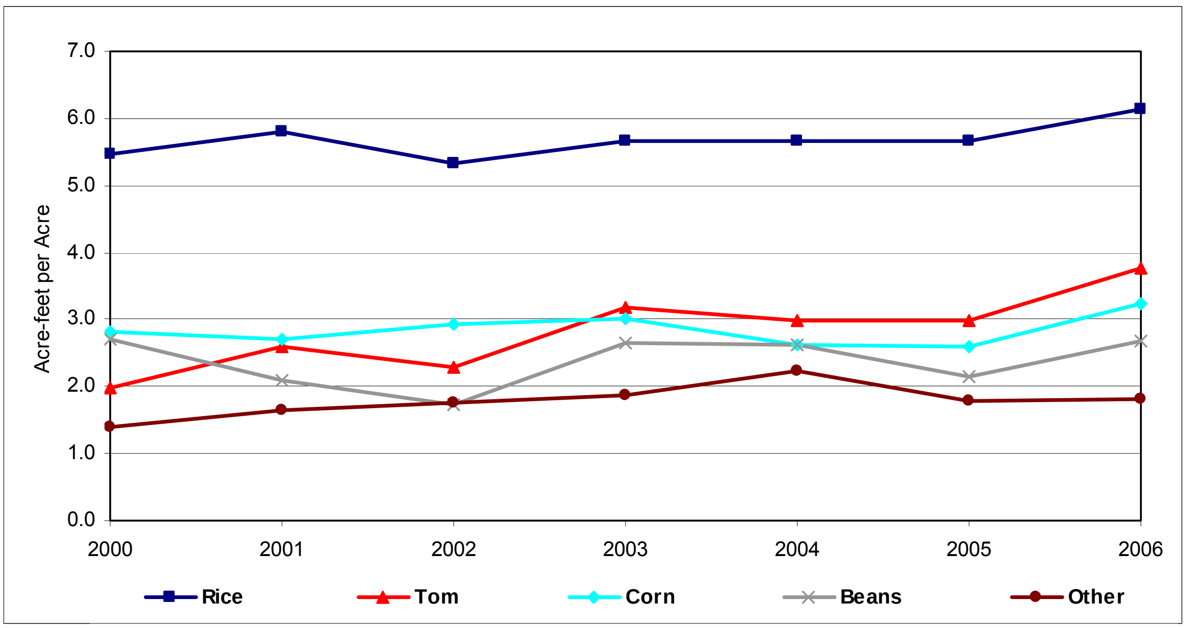

FIGURE 4-11
AVERAGE UNIT DELIVERIES TO IRRIGATED LANDS WITHIN SUTTER MUTUAL WATER COMPANY

Table 4-15 compares the average unit deliveries for the 3 years prior to the pricing structure change, 2000 through 2002, and the 3 years after the change, 2003 through 2005. Table 4-15 indicates that unit deliveries for rice were slightly higher following the pricing structure change. Increases in unit deliveries for tomatoes and beans after 2003 were greater than seen for rice. Table 4-15 indicates little change in the unit deliveries for corn between the two periods.

TABLE 4-15
Comparison of Average Unit Deliveries within Sutter Mutual Water Company
Cooperative Water Measurement Study Report

Crop	2000–2002	2003–2005
Rice	5.5	5.7
Tomatoes	2.3	3.1
Corn	2.8	2.8
Beans	2.2	2.5

4.2.3.2 Sutter Mutual Water Company and Reclamation District 1004 Company/District-level Comparison

As previously discussed, the preliminary intention of this portion of the study was to analyze changes in deliveries within SMWC and RD 1004 as a result of changes in their pricing structures. However, data were not available from RD 1004 prior to the implementation of volumetric pricing. The technical team was able to obtain delivery records for the period 2000 through 2006, which have been used to analyze RD 1004 deliveries on both field and district levels. Because RD 1004 is primarily devoted to rice production, with some acreage devoted to waterfowl habitat, the comparative analysis of deliveries within the two service areas is limited to rice.

Figure 4-12 and Table 4-16 show a comparison between SMWC and RD 1004's unit deliveries on a company/district-wide basis. The unit deliveries shown on Figure 4-12 are based on total deliveries to rice acreage within each service area. As Figure 4-12 shows, the calculated unit deliveries to rice fields within RD 1004 are higher than in SMWC during the study period. Figure 4-12 also shows a slight increasing trend in average unit deliveries to rice fields in both service areas during the study period.

TABLE 4-16
Comparison of Company/District-wide Average Unit Deliveries for Rice between Reclamation District 1004 and Sutter Mutual Water Company
Cooperative Water Measurement Study Report

Crop	2000–2002	2003–2005
SMWC	5.5	5.7
RD 1004	6.2	6.5

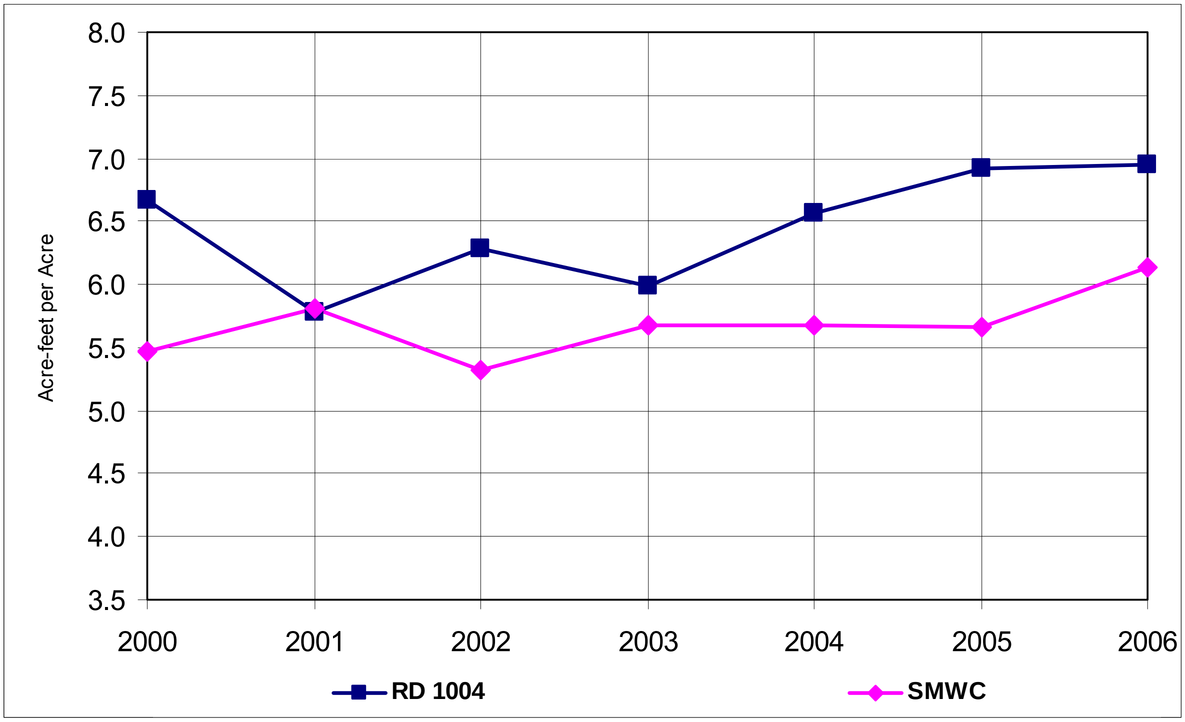

FIGURE 4-12
COMPANY/DISTRICT-WIDE AVERAGE ACRE-FEET PER ACRE UNIT RICE DELIVERY COMPARISON OF SUTTER MUTUAL WATER COMPANY AND RECLAMATION DISTRICT 1004

4.2.3.3 Sutter Mutual Water Company and Reclamation District 1004 Field-level Comparison

The technical team compared individual field average unit deliveries for rice within RD 1004 and SMWC. As previously described in the Data Collection portion of this *Cooperative Water Measurement Study Report*, delivery data developed for billing purposes was received in electronic and hard copy format for SMWC and RD 1004. Discrepancies in billing and field and landowner identification and delivery data were found for both service areas, which resulted in a wide range of calculated field-level unit delivery values. For example, a single field might be served by multiple delivery devices, or multiple landowner fields might be served by a single delivery device; therefore, the unit deliveries calculated for these fields might appear to be disproportionately high or low. The technical team worked with SMWC and RD 1004 managers and staff, and reconciled all but a small portion of these discrepancies. A statistical analysis of the field-level unit deliveries was performed, taking into account these discrepancies, or outliers, to determine individual field unit delivery variances within and between SMWC and RD 1004. A brief summary of the results of the statistical analysis is described below. The detailed statistical analysis is further described in Appendix C.

Table 4-17 shows average unit deliveries for rice within SMWC and RD 1004 measured at the field level. The unit deliveries are different than those shown in Table 4-16 because the field-level analysis accounts for outliers as described in Appendix C.

TABLE 4-17
Comparison of Average Field-level Unit Deliveries for Rice between Reclamation District 1004 and Sutter Mutual Water Company
Cooperative Water Measurement Study Report

Crop	2000-2002	2003-2005
SMWC	6.0	6.0
RD 1004	6.8	6.9

4.2.3.4 Statistical Analysis

Descriptive statistics were used to compare field-level unit deliveries for rice within SMWC and RD 1004. Tables 4-18 and 4-19 show the population size (number of fields), number of outliers within the data sets, the percentage of outliers within the given data set, and the average field size within each service area. As shown on Figures 4-13 and 4-14, analysis of the delivery data provided by SMWC and RD 1004 found no significant difference in the mean and median deliveries to the two sample populations, which indicates normal distribution of the data set.

TABLE 4-18
Sutter Mutual Water Company Unit Delivery Descriptive Statistics
Cooperative Water Measurement Study Report

Year	Standard Deviation	Mean	Median	Maximum	Minimum	Number of Fields within SMWC (population)	Number of Outliers within SMWC	Percentage of Outliers within SMWC	Average Field Size within SMWC (acres)
2000	1.4	5.9	5.5	11.2	3.5	152	25	16	152
2001	1.4	6.3	6.1	11.6	3.7	114	12	11	150
2002	1.5	5.7	5.2	11.6	3.6	129	16	12	143
2003	1.6	5.9	5.5	10.6	3.5	138	11	8	133
2004	1.8	6.1	5.1	12.0	3.5	201	37	18	147
2005	1.5	5.9	5.8	11.9	3.5	146	23	16	146
2006	1.6	6.2	5.7	11.8	3.6	188	15	8	138

TABLE 4-19
Reclamation District 1004 Unit Delivery Descriptive Statistics
Cooperative Water Measurement Study Report

Year	Standard Deviation	Mean	Median	Maximum	Minimum	Number of Fields within RD 1004 (population)	Number of Outliers within RD 1004	Percentage of Outliers within RD 1004	Average Field Size within RD 1004 (acres)
2000	1.8	7.0	6.9	10.1	3.6	73	5	7	153
2001	2.0	6.6	6.3	11.7	3.7	67	10	15	164
2002	2.0	6.8	6.6	11.7	3.6	66	11	17	167
2003	1.9	6.3	5.9	11.5	3.5	68	9	13	158
2004	2.0	7.1	6.6	11.4	3.6	70	6	9	156
2005	2.0	7.4	7.3	11.7	3.6	64	9	14	167
2006	1.7	7.3	7.2	11.3	4.2	67	10	15	162

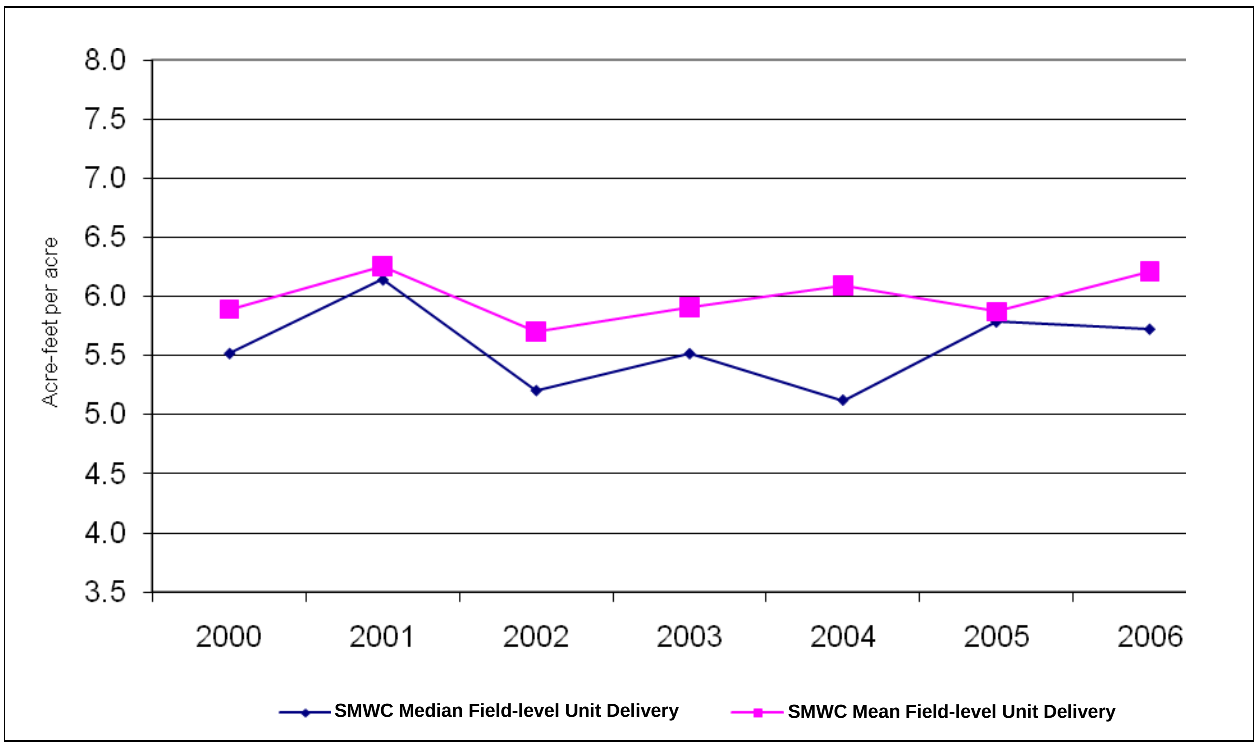

FIGURE 4-13
SUTTER MUTUAL WATER COMPANY MEAN AND MEDIAN COMPARISON OF FIELD-LEVEL UNIT DELIVERIES

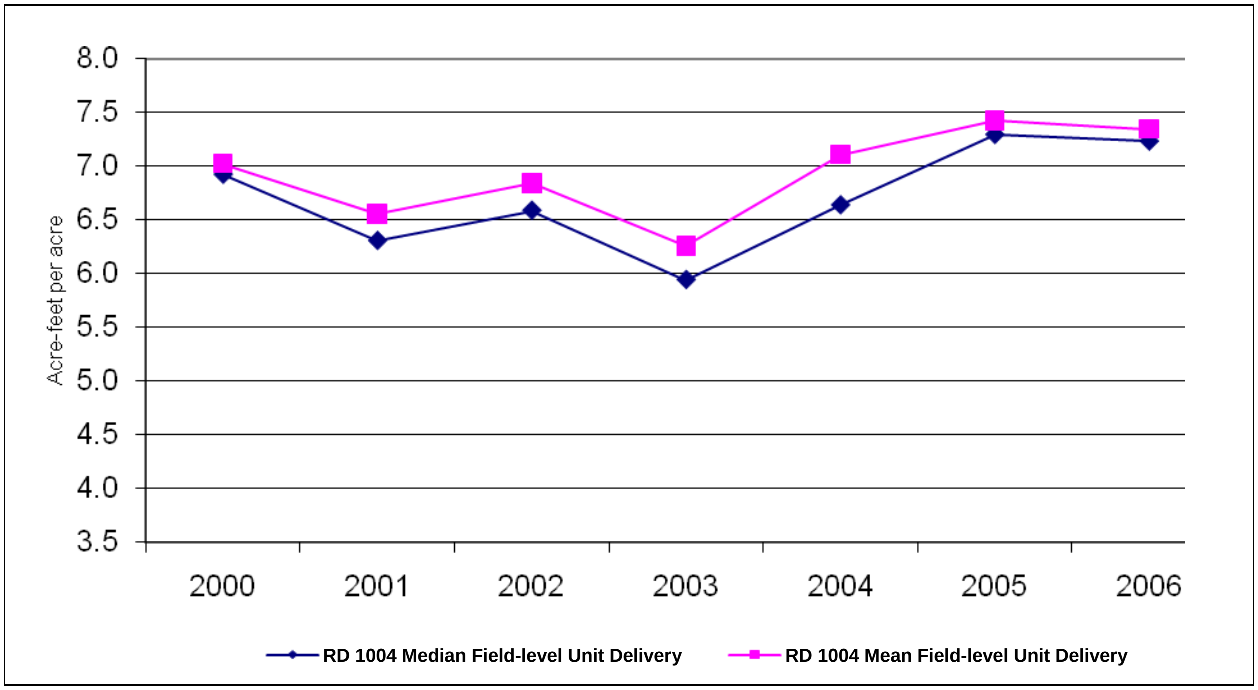

FIGURE 4-14
RECLAMATION DISTRICT 1004 MEAN AND MEDIAN COMPARISON OF FIELD-LEVEL UNIT DELIVERIES

A comparison of the average field size for each year of the study indicates that the fields within both service areas are similar in size, with an approximate 10 percent larger average field size within RD 1004 compared to SMWC in all years except 2000. Although there is some variation from year to year, the overall percentage of outliers within each data set during the study period is also similar.

Two-tailed, pooled-variance t-tests were performed to determine whether there is a statistically significant difference between the means of the two populations for three scenarios, further described below.

In Scenario 1, the two population samples were defined as SMWC's average field-level unit deliveries for rice for the period 2000 through 2002 (the period prior to the pricing structure change) and average field-level unit deliveries for rice for the period 2003 through 2006 (the period after the change in pricing structure).

The results of the t-test performed for Scenario 1 indicate that at a 0.05 level of significance there is no statistically significant difference in the unit rice deliveries at a field level within SMWC between the periods before and after the change in pricing structure.

Additional t-tests, similar to Scenario 1, were performed comparing the average field-level unit deliveries within SMWC and RD 1004. Scenario 2 compared the average field-level unit deliveries within the two service areas for the years 2000 through 2002, the 3-year period prior to the change in pricing structure. Scenario 3 compared the average field-level unit deliveries for the 4-year period after the pricing structure change, 2003 through 2006. The results of these analyses indicate a statistically significant difference in the average field-level unit deliveries to rice fields within the two service areas, as would be expected based on Figure 4-15. However, the statistical analysis does not provide insight as to the impact on deliveries to rice fields within SMWC as a result of the change in pricing structure.

Figure 4-15 shows the average field-level unit deliveries for the two sample populations during the study period. As indicated in the t-test comparison, the mean unit deliveries are statistically different; however, field-level unit deliveries for both are within the typical range of the rice cultivation unit delivery requirements. Figure 4-15 shows a generally increasing trend in the average field-level unit rice delivery trends within both the SMWC and RD 1004 service areas. Figure 4-15 also indicates the average field-level unit rice delivery within RD 1004 is slightly higher in all study years and has a greater increasing trend in unit rice deliveries than within SMWC.

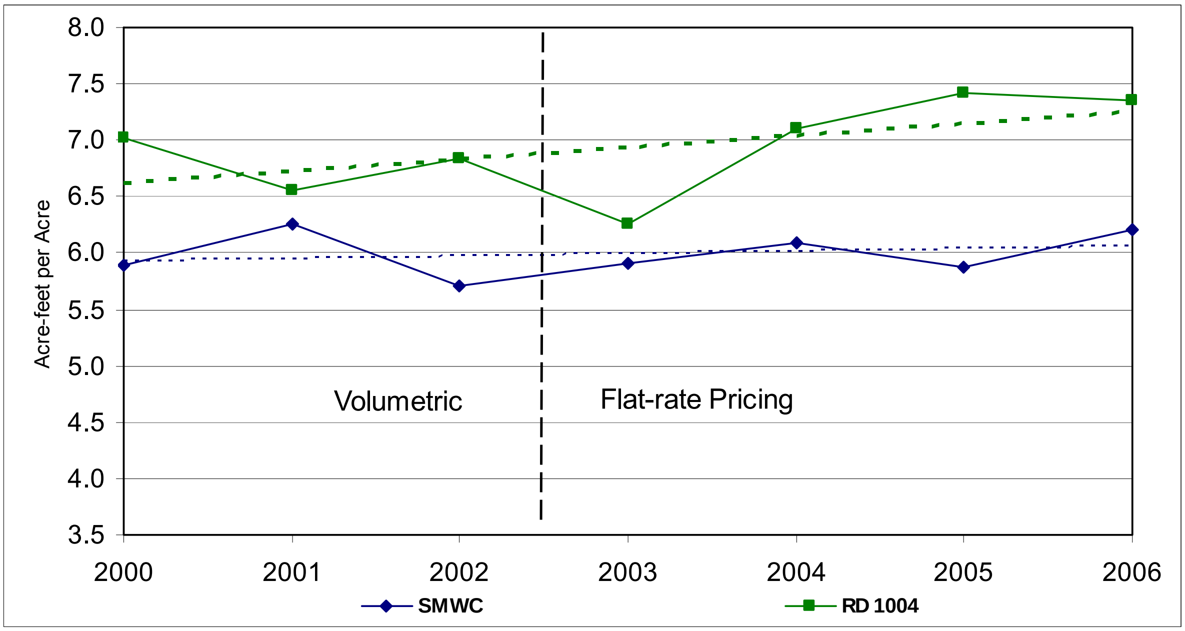

FIGURE 4-15
FIELD-LEVEL AVERAGE ACRE-FEET PER ACRE RICE DUTY COMPARISON

4.2.4 Conclusions

Crop and surface water factors including hydrologic and climatic conditions and commodity prices can significantly affect water diversions and deliveries from the Sacramento River. This analysis found no single factor provided a correlation between surface water deliveries and pricing structure within SMWC. The analysis found no strong correlation between SMWC's pricing structure and its diversions from the Sacramento River or its field-level deliveries. Increases in rice acreage, coupled with decreases in the acreages for other major crops, resulted in a proportional increase in company-level diversions and average unit deliveries. SMWC staff indicated that the change in pricing structure might have contributed to a small increase of relatively marginal lands being cultivated for rice production within SMWC; however, this increase might also be partially attributed to the significant increase in the commodity price. The statistical analysis of SMWC average field-level unit deliveries for rice did not show a statistically significant difference in unit deliveries after the change in pricing structure in 2003. The data indicate that the unit deliveries for rice within both the SMWC and RD 1004 service areas are within the expected range for the Sacramento Valley region. However, the data also indicate that the unit deliveries for rice within SMWC were generally lower than within RD 1004 in each year of the study period except for 2001 on both the district and field levels regardless of SMWC's pricing structure. The analysis found similar trends in unit deliveries for rice within both service areas during the study period.

The analysis of multiple years of delivery data for two of the participating SRSCs did reveal an important aspect of water management. The Cooperative Study delivery data analysis required significant effort to reconcile the delivery data obtained from both districts that participated in this study and to organize it in a format useful for analysis. If measurement data is collected by a district or company, not only must the data be accurate, but the data must also be well organized, well maintained, and readily available in order to provide value.

4.3 Water Management and Measurement Interviews

In addition to the field measurement and water delivery data analysis tasks, water management and measurement interviews were included in the study to gain insight into current practices and perspectives. The interviews were conducted to assist in addressing the objectives specified during the development of the Work Plan in 2002–2003, and further refined in a better defined interview approach that was endorsed by the Work Group in October 2006. The objectives of the survey and interview process are as follows:

- Provide a better understanding of current SRSCs' measurement practices at the district, lateral, sub-lateral, and turnout levels.
- Document the role of water measurement among many factors influencing sound water management practice at the manager, operator, and grower levels.
- Document whether changes in water pricing influenced water management, and gather current perceptions of water pricing.
- Better understand perceptions of water measurement at the manager, operator, and grower levels. Explore how water management and use practices affect Sacramento River diversions and return flows.
- Contribute to overall Cooperative Study conclusions.

This section focuses on the results of the interview process and provides conclusions based solely on interview responses and not actual data from the field measurement and water delivery data analysis. Therefore, all costs or quantified benefits stated in this *Cooperative Water Measurement Study Report* were provided directly from interview responses.

4.3.1 Approach

The interview approach was developed during the Work Plan phase with Dr. Jack Keller, a noted expert in the field of agricultural water use and management, and a third-party review participant in the development of the Work Plan. A questionnaire was developed for each group of participants (general manager, superintendent or head operator, ditch tender, and grower) based on concepts in the Work Plan and discussions with the Work Group. To avoid bias, input from public relations specialists was incorporated. The questionnaire was reviewed by Dr. Mark Roberson, the study's principal third-party reviewer. Dr. Roberson agreed with the approach and process for interviews, and provided input on the questionnaire.

Four SRSCs, RD 108, SMWC, GCID, and RD 1004, were interviewed, as agreed to by the Work Group. Although all SRSCs have unique physical and policy characteristics, four were interviewed to provide a representative sample of current practices that could be observed throughout most of the Sacramento Valley. Interview participants within each SRSC were selected to obtain a cross section of perspectives that might be present, rather than to determine which perspectives were statistically dominant within the study area. General managers from the participating districts helped to identify participants, consciously selecting those who could contribute to the cross section of opinions that might occur within the district.

Interview participants included general managers, operations staff, landowners, and growers from the four SRSCs. Participants included growers who were members of the district governing board and those who were not. Participants were provided background information on the study and why the interviews were being conducted (with the exception of the general managers; as Work Group members, they were provided with the interview questions beforehand). Prior to the interviews, participants were reminded that their responses would remain anonymous. A complete list of interview questions, subdivided by type of participant, is provided in Appendix D. Following are samples of the types of questions asked:

1. What role does water measurement play in water management? Do districts pay close attention to water measurement as part of their daily activities?
2. What improvements could be made to current water measurement devices or practices that would improve operations or assist in water management?
3. What is an appropriate level of water measurement? Would turnout-level measurement assist in daily management activities?
4. How do growers determine how much water to order? Do growers monitor their water use?
5. How would turnout-level measurement affect O&M activities?
6. How do general managers, district field staff, and growers view turnout-level measurement?
7. Would grower irrigation practices change if turnout measurement were implemented? Would crop distribution be affected?
8. Do opinions about water measurement differ among farmers who grow rice, those who grow row crops, and those who have orchards?
9. How has the change from volume-based pricing to acre-based pricing affected your district?

10. How has the change from acre-based pricing to volume-based pricing affected your district?
11. How would growers and staff at your district respond if the district changed from pricing water by acre to pricing water by volume?

Finally, general trends and conclusions were drawn through careful analysis of the responses across common staff roles, district sizes, growers and crop types, and similar factors. The approach and process of the interviews were documented in the *Cooperative Water Measurement Study, Year 1 Summary Report* (SRSCs, 2007). This *Cooperative Water Measurement Study Report* summarizes the interview responses and analysis.

4.3.2 District Profiles

As agreed to by the Work Group, four districts were identified to participate in the interview process. Table 4-20 shows the general characteristics of the four districts. To encourage objective responses, Work Group participants developing and providing input to the study approach agreed that the results should be presented in a way that preserves anonymity. Accordingly, this *Cooperative Water Measurement Study Report* will identify responses by generalized individual (grower, ditch tender, and so on), and their associated district will be identified alphanumerically.

TABLE 4-20
Profiles of Districts Interviewed
Cooperative Water Measurement Study Report

District ID	Size (Irrigated Acres/ Turnouts)	Typical Rice Acreage (Percent of Total Irrigated)[a]	Each Turnout Measured?	Billing Method	Other Notable Characteristics
District A	47,000 acres 600 turnouts	65	N	Acreage[b]	Large recirculation system recycles 60,000 acre-feet per year, or 33 percent of total diversions.
District B	125,000 acres 2,611 turnouts	80	N	Acreage[c]	Several recapture pumps located at spill locations allow spills to be reclaimed. An average of 96,000 acre-feet was reclaimed annually over the last 3 years.
District C	46,700 acres 426 turnouts	50	Y	Acreage[c]	Billing method changed from turnout to acreage approximately 5 years ago. Recirculation system recycles an average of about 15,500 acre-feet per year, but has recently recycled nearly 25,000 acre-feet per year.
District D	14,000 acres[d] 140 turnouts	95	Y	Turnout[e]	Billing method changed from acreage to turnout approximately 11 years ago. District operates an extensive recirculation system, and water is reused approximately three times.

[a]May vary from year to year.
[b]Charge per acre irrigated, varies by rice/row crop.
[c]Charge per acre irrigated, varies by each crop.
[d]Total district acreage is 23,500 acres, including 9,500 acres managed for waterfowl habitat.
[e]Charge per acre-foot delivered.

4.3.2.1 Current Measurement Methods

For the purposes of this Cooperative Study, a water measurement method is defined as a technique that indicates a numerical flow rate. This includes devices or structures that communicate only a water level but have been rated to allow irrigators or district staff to calculate flow. Also included in this definition are flow estimates based on observations and past experience of the canal operator or observer.

Many measurement methods are used within the Sacramento Valley. Measurement might be used for monitoring system operations, indicating the result of a system adjustment (such as opening a gate), or for customer water accounting. Districts generally select measurement methods that allow efficient day-to-day system management, early detection of maintenance issues, seasonal water accounting, and evaluation of water use efficiency programs (including drainwater reuse). Table 4-21 identifies examples of measurement methods used by the districts.

Table 4-22 lists typical measurement methods used at various locations (such as at the turnout level, canal level, district level, or drains) by each of the four districts in the study.

Measurement methods and intensity are influenced by a number of factors, including, but not limited to, the crop mix, the conveyance and drainage system design (which, in some cases, were implemented nearly a century ago), economic efficiency, and management need. District boards and general managers continually balance revenues with operating costs and the need for system maintenance, staff, and improved management equipment, including measurement devices.

A district’s crop mix, for example, influences what measurement and management equipment is used. Because of seeding and pesticide requirements, it is generally important for rice growers to flood their fields to a predetermined depth as quickly as possible, and then to maintain that depth by managing flows into and out of a field. Districts with significant rice acreage were designed to allow rapid water delivery to rice growers at the beginning of the season, and to enable modification to deliveries and drain flows to maintain a constant field water depth. However, row crops with drip irrigation depend on regular irrigation events with a set flow rate, and ditch tenders and irrigators must be equipped to gauge each water delivery accurately.

Implementing new water measurement programs can be costly for districts, and district boards and general managers must weigh the costs of new equipment with the benefits of improved accuracy or increased frequency of data collection at a particular measurement site.

TABLE 4-21
Example Measurement Methods Used by Sacramento River Settlement Contractors
Cooperative Water Measurement Study Report

Method	Description
Rated Weirs, Check Structures, and Checkboxes	Flow passing over the check is estimated either by developing a rating for the structure by using a series of stream flow measurements or by using theoretical weir flow equations. Flow is determined by measuring the head or depth of water passing over the structure and converting this to flow using the rating or equation.
Ramp Flumes	Ramp flumes are engineered structures that can be used to control water levels and for flow measurement. As with check structures and weirs, the depth of water passing through the flume is measured to determine the flow rate.
Propeller Meters	Propeller meters directly measure the flow passing through a pipe or culvert using a propeller extending into the water column. They typically provide both an instantaneous flow rate in gallons per minute or in cfs as well as a totalized flow in acre-feet. Propeller meters must be sized properly for the pipe in which they are to be installed.
Handheld Propeller Meters	A handheld propeller meter is a small, handheld device similar to an installed propeller meter; however, these meters measure velocity only. To determine flow rate or volume, the area inflow must be known or measured.
Doppler Meter	A Doppler meter is an electronic device that uses acoustic Doppler technology to detect the velocity of water particles. It measures both open channel and pipe flow. It is typically used in conjunction with a data logger that records flow rates and volume at predetermined intervals.
Rated Gates	Rate gates are typically screw gates used to control flow in a canal or delivery of water to a lateral or field. Flow is determined by measuring the difference in water levels on both sides of the gate and the size of the gate opening. Rating is achieved by measuring the flow passing through the gate at various water levels or gate openings, or flow might be estimated using standard orifice flow equations.
Meter Gates	Meter gates are similar to rated gates, but the ratings are developed by the gate manufacturer.
Pump Curves or Pump Ratings	Flow is calculated on the basis of the relationship between the quantity of water pumped per hour or the amount of energy required to pump water. Pump curves or ratings are typically developed by the pump manufacturer or based on the pump's performance tests.
Staff Gage	A staff gage is a device installed upstream of the check structure and used to determine the head or depth of water passing over a weir or within a canal or lateral.
ITRC Weir Stick	The ITRC weir stick is a calibrated device developed by ITRC at Cal Poly, San Luis Obispo. It is used to measure the flow passing over a weir.
Notched Weir Boards	Notched weir boards are similar to the weirs or check structures previously described but provide better accuracy at low flows. They are typically used to control outflow from rice checks.
Estimate	Flow estimate is based on observations and past experience of the canal operator or observer.

TABLE 4-22
Typical Measurement Methods
Cooperative Water Measurement Study Report

District	River Diversion	Canals/Laterals	Field Turnouts	Drains
District A	• In-line flow (cumulative hour) meter on pumping plant	• Rated weirs and checks • Mass balance between checks • ITRC weir stick • Ramp flumes • Estimates	• Meter gates (new turnouts) • ITRC weir stick • Estimates	• Pump curves
District B	• Pump ratings	• Doppler meter (main canal) • Propeller meters • Handheld propeller meters • ITRC weir stick over weirs or check boards • Rated gates • Rated checks or weirs • Estimates	• Handheld propeller meters • ITRC weir stick • Rated gates • Rated checkbox • Estimates	• Notched weir board (drain flow indicator at field level)
District C	• Pump ratings (power usage)	• Rated gates • Rated weirs and checks • ITRC weir stick over weirs or check boards • Estimates	• ITRC weir stick over weirs or check boards • Rated checkboxes • Estimates • Rated gates	• Pumping plant (power use) has been used in the past; currently flows are moni-tored using sized and rated structures
District D	• Pump ratings (power usage)	• Propeller meters	• Propeller meters	• Pump records (totalized acre-feet)

4.3.2.2 Water Ordering Methods

For all districts interviewed, the water delivery process typically involves several steps as water changes hands from Reclamation to the district, and from the district to the grower. The SRSCs schedule their water deliveries with Reclamation. Reclamation releases water according to this schedule, and the SRSCs divert the water at their diversion point(s) along the Sacramento River. Next, water is conveyed to the districts' customers. This involves two steps between the district and grower. First, the grower applies for irrigation service from the respective district prior to or during the beginning of an irrigation season. Next, when a grower needs water for irrigation, the grower requests water delivery from the district.

Specific details of these steps vary among the districts interviewed. Table 4-23 describes the process by which the district schedules water from Reclamation, and the process by which the grower orders water from the district.

TABLE 4-23
Water Order Methods and Policies
Cooperative Water Measurement Study Report

District	Central Valley Project Water Order (District-Reclamation)	Annual Water Application (Grower-District)	Each Irrigation Event/Delivery (Grower-District)
District A	Formal water order process for all SRSCs is dictated by the CVP contracts. For District A, Reclamation assumes that the district's contracted quantities are monthly water orders. Quantities/schedule can be amended as the season progresses.	Prior to the start of the irrigation season, the grower informs the district what crops and acreage the grower intends to plant.	Just prior to each delivery, the grower calls the ditch tender (typical) or the district office. Growers provide the field ID number, the amount of water needed, and the time the grower wants the turnout gate opened and closed. Rice growers usually feel comfortable that the ditch tenders know what flow is needed at their turnouts, so they might only specify the field number and whether the purpose of the irrigation is for flooding or maintenance. Growers of other crops will order a particular flow rate or gate adjustment, or they might order by the number of siphons they are using to irrigate, relying on the ditch tender to determine the flow rate needed. Ditch tenders tally water orders each day to determine the total diversion needed at the headgates the following day, and make adjustments accordingly. (Daily deliveries are not recorded as they occur, however.) Ditch tenders operate the turnouts to deliver water. Growers contact the ditch tenders again when they want to stop irrigating. By district policy, growers should order water from their ditch tender at least 1 day prior to irrigating; however, growers might call anywhere from 15 minutes to 24 hours prior to when they want their field irrigated, and the ditch tenders will try to meet those requests.
District B	Formal water order process for all SRSCs is dictated by the CVP contracts. At the beginning of each calendar year, District B provides Reclamation with a schedule of projected deliveries for the irrigation season (given by monthly acre-feet). Quantities/schedule can be amended as the season progresses.	Prior to the start of the irrigation season, the grower informs the district what crops and acreage the grower intends to plant.	Prior to each delivery, the grower orders water by contacting his ditch tender (typical) or the district office. Growers of row crops and orchards typically order water by flow rate, and rice growers typically order water by gate opening, by inches on stem, or simply by the type of irrigation (flooding or maintenance) and the amount of time the gate should be open. Experienced ditch tenders translate all orders into cfs. At 1:00 p.m. the day before irrigation, ditch tenders contact their supervisors and relay water orders and other management data. Ditch tenders tally water demand in cfs, and the supervisors complete a summary sheet for all water at a given point. Ditch tenders operate the turnouts to deliver water. Growers contact the ditch tenders again when they want to stop irrigating, and ditch tenders then close the turnout gates. Most deliveries are recorded daily by ditch tenders. By district policy, the grower orders water at least 24 hours in advance, prior to 1:00 p.m. the day before irrigation, year-round. Minor adjustments can be made with less notice if water is available.

TABLE 4-23
Water Order Methods and Policies
Cooperative Water Measurement Study Report

District	Central Valley Project Water Order (District-Reclamation)	Annual Water Application (Grower-District)	Each Irrigation Event/Delivery (Grower-District)
District C	Formal water order process for all SRSCs is dictated by the CVP contracts. District C notifies Reclamation weekly about what flow it projects to use that week. The schedule is provided in cfs. Quantities/schedule can be amended as the season progresses.	A farmer applies for water at the beginning of the year, before the irrigation season begins. A farmer gives the field ID number, number of acres, and crop type that will be irrigated in the coming year. This information is entered into a computerized spreadsheet.	Just prior to each delivery, the grower calls the operator and makes a field request, telling the ditch tender when he/she will irrigate. The operator calls the front desk and makes sure an application has been filled out. An invoice for the water delivery is generated when water is actually delivered to the field. The grower's order is matched with his/her application to approximate a water need. Growers may also request a particular flow rate, a totalized volume (acre-feet), or, for rice growers, a flooding head or maintenance head, depending on the grower's preference. Ditch tenders tally water orders for each day to determine the total diversion needed from the Sacramento River pumps the following day and set the pumps accordingly. The district typically opens and closes all turnout gates at the requested times. Deliveries are recorded daily by ditch tenders. By policy, a grower should order water 3 days prior to irrigation; however, ditch tenders report that growers allow a lead time anywhere from 1/2 day to 1 week. Water is generally delivered on a "first in time, first in right" policy, however; and more lead time might be required in the early spring if several rice growers are ordering water at the same time.
District D	Formal water order process for all SRSCs is dictated by the CVP contracts. At the beginning of each calendar year, District D provides Reclamation with a schedule of projected deliveries for the irrigation season (given by monthly acre-feet). Quantities/schedule can be amended as the season progresses.	Prior to the start of the irrigation season, the grower informs the district what crops and acreage the grower intends to plant.	Typically, the grower faxes the district office when he wants to irrigate. The administrative assistant takes the order then calls the general manager, who contacts the grower to better understand his plans. The general manager also keeps an eye on things to anticipate when growers will want water. Orders are tallied at least daily, and the general manager and ditch tender open the district headgates enough to meet the demand. The district supplies water to the growers, but the irrigators maintain their own turnout gates, opening and closing them as they need. Ditch tenders do not record water deliveries. The general manager would prefer that the grower calls 24 hours before he/she wants to irrigate, but the district will always deliver water as soon as possible. The ditch tender interviewed was not aware of an established system for ordering water from the district.

4.3.2.3 Water Pricing and Billing Practices

Variations of two generalized billing methods are practiced by irrigation districts in the Sacramento Valley. Districts charge their customers either by the crop grown and acreage irrigated or by the volume of water applied, and most charge additional fees to cover overhead expenses.

All districts must set water rates to cover their operating and water costs. Districts that charge by acreage typically divide the district's total operating cost by the total number of irrigated acres served to arrive at a per-acre delivery price, then charge their customers by the number of irrigated acres they have. Districts set the per-acre charge to account for the different irrigation delivery requirements of various crops (at least differentiating between rice versus row crops) or water application systems. Using this method, districts have greater certainty of covering their annual operating cost.

Some districts measure the water delivered or allocated to each customer and charge by the volume of water delivered. These districts must set water charges so that customers' estimated water payments (based on projected water use for the year) will cover their operating costs. Using this method, a district's revenue might fluctuate because growers' water use can fluctuate depending on a number of factors. These districts might levy other charges by acre, such as O&M charges, to ensure their operating costs will be met.

Both billing practices were represented in this study. Districts A, B, and C price water on a per-acre basis, by crop. District D charges a deposit based on an assumed duty for the crop to be grown and measures deliveries to each field at each turnout. Growers within District D may receive a refund of a portion of the deposit if the measured deliveries indicate they used less water than estimated by the crop duty. If the measurements indicate deliveries to a field were greater than the crop duty, then the grower is charged for the volume of additional water. According to District D, approximately 65 to 75 percent of its customers have received rebates in recent years because their measured water deliveries were less than the estimated crop duty.

District A charges by acre distinguishing between rice and row crops. The per-acre charges were developed using applied water values. The rate charged for rice is about 20 percent more per acre compared to row crops. The rates are established annually by using the district's estimated expenses and water costs. All fixed or non-operational expenses are met through income derived from district-owned land. District A owns farmland that was paid for by other landowners in the district, which provides the income equivalent to a $25-per-acre assessment, enough to cover overhead expenses. District-owned farmland is usually leased to local growers. Landowners who do not irrigate are not charged.

District B charges growers an assessment fee, a standby charge, and an irrigation charge. The assessment fee is levied on every acre in the district, regardless of water use. For every irrigable acre, a standby charge is also charged to have the right to receive water. Finally, an irrigation charge is levied specific to the type of crop and the number of acres irrigated. Irrigation charges are based on unit duties for each crop that have been developed using typical ETc and an assumed level of efficiency. The assessment fee and water charges are adjusted annually in order to recover the district's targeted revenue for the year.

District C collects a maintenance assessment and a water charge. The maintenance assessment is applied to all acres of landowner stock land in the service area regardless of whether a grower takes water for irrigation. This assessment generally covers most fixed costs for facilities maintenance as well as administrative, labor, support service, and project costs. The water charge is based on a crop duty and acreage planted. Individual crop duties have been established by the district on the basis of historical water use records. The water charge is established at the beginning of the year so that all of the district's costs can be recovered. Crops that do not require irrigation are charged only the maintenance assessment, not the water charge.

District D levees a three-component charge. The first component, the water charge, is based on actual water use, determined by propeller meters installed at every turnout. For this component, water users pay a deposit at the beginning of the year for their water use. The deposit is based on an assumed acre-foot/acre duty, by crop type. At the end of the irrigation season, growers are refunded for unused water, or charged an additional amount if water use exceeds the crop duty. The remaining components of the charge consist of an administration fee and a benefit fee to cover district overhead expenses, neither of which is refundable. These charges are levied by the acre and paid at the beginning of the irrigation season.

4.3.2.4 Staff Roles and Responsibilities

Irrigation district staff responsibilities are shared among four generalized staff positions: general managers, superintendents (or operations managers), ditch tenders (also known as operators or watermen), and office personnel, including controller and assistants.

General managers are responsible for implementing district policy, managing the administrative and operational functions of the district, and overseeing all district staff and activities. General managers are also responsible for ensuring the financial health of the district, developing and managing the annual budget, coordinating legal affairs, maintaining a safety program, providing annual reporting and environmental compliance, and developing long-term strategic plans and policies. General managers are typically hired or elected by a district board of directors who guide the decisions and policies of the district.

Superintendents are primarily responsible for overseeing field staff and O&M activities, work plans, and monthly and annual reporting to district boards. They oversee system O&M and coordinate ditch tender activities. Superintendents might also manage pesticide and herbicide reporting and training.

Ditch tenders are responsible for the day-to-day maintenance and operations of the canal system. They may receive water orders from growers by phone, open canal structures to balance the canal system and keep water levels consistent, open turnout gates for growers, check the end of the system for spills, and observe laterals for problems and adjust the system as necessary. Ditch tenders are often responsible for ensuring that the requested flow and quantity is delivered to each turnout. They are responsible for water delivery accounting and pertinent O&M record keeping. Some ditch tenders are on call 24 hours a day if problems arise. Depending on the size of the district, some ditch tenders might manage between 5,000 and 15,000 acres or more.

Office personnel conduct regular and normal day-to-day business affairs such as accounting, financial administration, regulatory paperwork, agency reporting, appointments and scheduling, and all other functions needed to assist the management and field staff.

4.3.3 Key Interview Response Summary

Survey participants were asked a series of identical questions across the four participating districts. Participants included general managers, superintendents, ditch tenders, and growers from each district. Some of the participants were also members of district boards. Table 4-24 lists the number and role of participants from each district.

TABLE 4-24
Interview Participants
Cooperative Water Measurement Study Report

	District A	District B	District C	District D
General Manager	1	2[a]	1	1
Superintendent	1	1	1	
Ditch Tender	2	2	2	1
Grower (Board Member)	2	2	2	2
Grower (Non-board Member)	2	2	1	2

[a]The assistant general manager was interviewed with the general manager.

Participants were asked a particular set of questions based on each participant's role at a district; for example, a general manager's questions were different from a ditch tender's questions. General managers from different districts were asked the same questions, and ditch tenders from different districts were asked the same questions. Responses varied by district, an individual's role, primary crop type served by a district, and current measurement practice.

Summaries of responses to some of the survey's key interview questions follow.

What role does water measurement play in water management? Do districts pay close attention to water measurement as part of their daily activities?

Water measurement combined with staff experience plays a significant role in water management at all levels of district operations. District staff use water measurement to the extent that it assists them with their particular management responsibilities.

General managers use water measurement data to prepare annual reports, grant applications, financial and water budgets, and to estimate system efficiency to determine how much water was diverted and how much exited the district boundaries. Water measurement also meets the requirements of certain water rights contracts. The general manager at District A placed greater emphasis on the importance of properly designed water management facilities, such as different types of weirs and gates suited to managing a particular irrigation system, rather than on water measurement equipment.

Superintendents are more typically involved with day-to-day measurement than general managers, but might use measurement data to coordinate with other irrigation districts, monitor contract compliance, prepare annual reports, track spills, and gauge system efficiency.

Ditch tenders focus on daily operations and measurement, making deliveries, and keeping the irrigation system balanced. Their overall goal is to deliver water while maintaining a constant water level in the canal, but the techniques and tools used by each ditch tender to accomplish this goal vary. Most ditch tenders interviewed rely on their experiences, in addition to measurement equipment where available, to determine the canal gate and check adjustments necessary to meet customer needs. Ditch tenders might use a trial-and-error process, establishing the correct adjustment to a structure, then readjust if necessary after observing the effect on the canal. A few ditch tenders interviewed use measurement where available on gates, staff gages, and weirs to help them manage deliveries and balance their systems; but most ditch tenders do not rely on numeric flow measurement to do their jobs. In general, each ditch tender takes a personalized approach to water management by developing customized measurement techniques to best manage his responsibilities in the system and report data to superintendents and general managers.

What improvements could be made to current water measurement devices or practices that would improve operations or assist in water management?

District staff and growers suggested some improvement options for measurement devices and practices. Staff from all districts interviewed agreed that propeller meters on canals or at turnouts frequently clog with silt, pondweed, or other debris. Any device that protrudes into the flow of water is subject to damage by debris or by flood flows, and requires frequent checks and maintenance. Of those interviewees who were familiar with acoustic Doppler technology, all preferred this water measurement method over propeller meters because of its non-mechanical nature, perceived accuracy, and imperviousness to debris. Some general managers and ditch tenders at Districts A, B, and C suggested that better access to measurement at drains would assist with managing water and identifying spills.

All districts indicated that they would and do implement improved or more accurate measurement if the benefits of the new equipment exceed the costs of installation and operation. Management staff at most districts think that installing more acoustic Doppler flow meters to measure flows in major canals would be beneficial; however, at this time, the costs of installing Doppler technology outweigh the perceived benefits. One superintendent would like to install stilling wells at rated weir box turnouts to assist in obtaining accurate water level measurements, which are used to determine flow rates through the weir boxes; however, he indicated that this approach is not economical with over 400 turnouts. Generally, district managers agreed that grant funding would be helpful at improving the benefit-cost ratio of the capital expenditure, but expressed that ongoing O&M costs must also be considered.

It was noted that measurement and management devices were not always clearly differentiated by either growers or district staff. Many responses included improvements for management devices that might or might not be linked to measurement. For example, some general managers, supervisors, and ditch tenders thought that improved telemetry and SCADA would assist them with management because it would allow quick access to measurement data and enable quick implementation of management actions. Other ideas for improvements included piped turnouts and automated turnout gates. At larger districts, telemetry at major canal measurement points has been implemented, as it provided significant improvements in management capability and efficiency for relatively low cost, according to general managers. Significant telemetry on all major laterals and automated turnout gates is generally not being implemented because of cost constraints, according to general managers, particularly for large districts with several hundred turnouts.

How do growers determine how much water to order? Do growers monitor their water use?

The amount of water a grower orders depends on the crop, soil type, weather, irrigation type or system, the time of year, the amount of drop in a furrow or ditch or the slope of a field, the number of siphon pipes or sprinkler heads, and pesticide requirements. Growers might not know the exact volume of water they will need when they order water, because the amount and frequency of irrigation depends on environmental factors and climatic conditions, which can vary greatly from day to day and from year to year. In general, growers expressed that they want to apply only as much water as a crop needs.

Farmers who grow row crops or orchards typically watch crop behavior and growth stage, feel the soil, and use their experience to judge when more water is needed or when enough water has been applied. These growers said they do not want to apply too much water because of the threat of root rot.

Many rice growers monitor their drainwater. Rice growers are careful not to apply too much water in order to avoid coldwater sterility and to avoid producing drain flow that is in excess of district drain flow policies, if applicable. Some rice growers said they are careful not to drain too much water because fertilizer will be lost, and other growers expressed that they must drain enough water to flush salts from the soil to prevent a reduction in crop yield.

Some rice growers interviewed at District D use turnout meters to monitor their water use and manage irrigation. Two growers indicated that they keep a diary of the amount of water they use on a daily basis. They use meter measurements to manage irrigation by looking back on the previous year's records. One grower said he did not know how he would manage irrigation if he could no longer use a water meter.

Districts B and D use notched boards to control water draining from rice fields, which is a common way for rice growers and districts who serve rice crops to monitor field drainage. If drainwater flows above the notch, a grower can be penalized for excess drain flows. This gives district staff and growers the ability to monitor drain flows without precisely measuring them. One general manager expressed his belief that it is more important for water conservation purposes to control field drainage than to control field inflow through turnouts.

What is an appropriate level (intensity) of water measurement? Would turnout-level measurement assist in daily management activities?

Opinions expressed about the appropriate level of water measurement were highly varied among levels of district staff and growers; however, some trends across districts and within levels of district staff could be identified.

The superintendents at Districts B and C said that measurement at the turnout could assist in daily operations by helping to balance the system, but all expressed concerns that it would not be practicable because they believed capital and maintenance costs (and increased O&M time) would outweigh any regular benefits to management. Sample responses given by superintendents included the following:

- It would be most helpful to measure at upstream locations on major laterals and at each delivery gate (if accuracy could be assured) because it would help balance the system.
- Measurement at turnouts would be helpful but would need to be customized by location.
- Measuring at the turnout level would help resolve disputes with growers, but would not bring regular benefits to the district.

Most ditch tenders think measuring water at regular intervals at upstream locations on major laterals and performing spot checks at turnouts when necessary is adequate to deliver water to all crop types. They also believe this level of measurement is adequate to isolate or diagnose problems on the canal system. Ditch tenders expressed the importance of employing experienced field staff who understand how to manage the overall system and that regular turnout measurement is not a necessary tool. Ditch tenders at District D, where turnout meters are installed, agreed that turnout measurement is not useful in their duties. Instead, these ditch tenders emphasized improving management tools, such as implementing long-crested weirs to buffer changes in the canal system, and installing telemetry or automatic gates on major canals. Sample responses given by ditch tenders regarding measurement include the following:

- Turnout-level measurement would be helpful to deliver water to each farmer, but there could be drawbacks such as device clogging and extra maintenance.
- Measurement at the headgates of each canal branch would be helpful.
- Measurement at each turnout would not help with daily operations. Measuring water on major laterals is important to balance the system.
- It is enough to employ experienced field staff who understand how to manage a system without turnout measurement. Performing spot checks at turnouts when necessary using a staff gage or weir is adequate.
- Measuring flow in laterals at the top of the system would help to isolate problems like wasted water or excessive vegetation.

The majority of District D growers agreed that turnout-level measurement was appropriate and useful to track their own water use. Growers at Districts A, B, and C expressed a variety of perspectives that generally corresponded to their crop mix. In general, rice growers in

Districts A, B, and C were not in favor of measuring water at the turnout level because it would not help them manage their water, and they felt monitoring a numerical water flow would not be useful for optimizing their irrigation. This group of growers had the strongest negative responses to measuring water at the turnout. Example responses from rice growers in Districts A, B, and C included the following:

- Good water management is acquired by experience, not measurement.
- There is no need for measurement equipment on my land. During flood-up, I need as much water as possible through the turnout, then the water is held.
- I do not use gages to manage my irrigation; I look at the drainage over the drain boards, and adjust what is coming in the turnout accordingly.
- Turnout measurement devices might help me manage water, but they might clog or require maintenance, and they are expensive. If they require maintenance at a critical flood-up time and I am unable to use my turnout, I could lose thousands of dollars.
- There is no use for metering except to generate revenue. Metering gives government a reason to limit water. The government just wants to raise prices and steal water, which I consider personal property.
- Maintenance of measurement devices are a pain. They might help when they work, but they are prone to clogging. In most situations, the crop needs what the crop needs.

Responses varied among growers of row or orchard crops. Some of these growers thought that measurement data would be useful for management, but other growers expressed strong opinions that turnout measurement would not help them and would not change the way they irrigate. Example responses given by these growers included the following:

- Most growers prefer there be no measurement at the turnout level. There is a common fear of government intervention, and that, ultimately, it could cost the landowner more.
- It is more important to have ditch tenders who understand growers' fields and preferences than for growers to know exactly how much water they are being delivered.
- I would not use turnout measurement to assist with my irrigation, but I think it could be useful for district staff as a management tool.
- I would use turnout measurement as a tool to manage how many siphons are needed and how many irrigators I need to work, but not to determine how much water I apply to crops.

How would turnout-level measurement affect O&M activities?

Most of the districts interviewed believe that the greater number of measurement devices used, the more associated maintenance is required, as well as additional staff time to read the meters. All general managers interviewed said that increasing the number of measurement devices would increase (or has increased) the effort staff spends on O&M activities and would increase maintenance costs. Particular responses from other staff varied, primarily depending on district size.

Some field staff at the larger districts (Districts A, B, and C) believe that with additional measurement devices they would spend a substantial amount of time reading meters and cleaning out clogged meters rather than managing water, and that additional staff would be required to assist in these efforts. District A completed a study on turnout-level metering and concluded that capital investment and annual labor required for turnout-level metering would force rates to go up by 20 to 25 percent. Staff at District C speculated that additional measurement devices would require more routine maintenance activities, but if equipped with SCADA, overall field time could be reduced. Two ditch tenders did not believe that the number of measurement devices affected their maintenance effort.

District D, the smallest district interviewed, has implemented propeller meters for about 130 turnouts, and one additional full-time staff person was required to read and maintain the meters. The general manager and board members believe that the increase in labor is outweighed by the benefits of measuring at the turnout level. Benefits reported include water savings, spill prevention, and greater individual accountability.

Would grower irrigation practices change if turnout measurement was implemented? Would crop distribution be affected?

Interview participants did not think turnout measurement alone would influence irrigation practices. Turnout measurement coupled with a change to volume-based pricing could result in changes in practices or crops grown, but this response varied across districts.

If turnout measurement were implemented, growers might wish to modify their irrigation practices, but growers could still be restricted by when district staff could open and close turnout gates. For example, the district staff might not be available to shut off a grower's pump or close turnout gates in the middle of the night.

Districts A and B believe that if turnout measurement were implemented in conjunction with a change to volume-based pricing, this could influence crop distribution across the districts by promoting crops most suited to a given soil type. One general manager speculated that there could be a possible shift toward orchard crops or a more efficient irrigation method. However, District D did not experience a change in crop mix after changing to measuring water at the turnout. District C's crop distribution has not changed significantly since this district switched from volume-based pricing to acre-based pricing, but the district believes the pricing structure might have contributed to a small increase of relatively marginal lands being cultivated for rice production.

Do opinions about water measurement differ among farmers who grow rice, those who grow row crops, and those who have orchards?

Although responses across districts varied, in general, rice growers expressed the strongest views against measuring water at a turnout. Growers of row crops and orchards expressed a variety of opinions about water measurement, and trends could not be established.

Because rice growers focus on a rapid rate of flooding (in spring) and maintaining a constant water level (in summer), rice growers expressed less need for flow measurement than growers of other crops. Rice growers at Districts A and B also expressed concern that a measurement device would physically limit their ability to flood and drain rapidly, which is important for seed establishment, weed management, and vector control. Rice growers at

Districts C and D (who have measurement devices installed at their turnouts) did not express this concern.

Responses of row and orchard crop growers varied. Some growers who irrigate using siphons or drip systems expressed that they could use turnout measurement to best determine the number of siphons to use at a given time, or to verify that they received the flow they ordered from the district.

How has the change from volume-based pricing to acre-based pricing affected District C?

District C changed from volume-based pricing to acre-based pricing (by crop). There were several reasons for the change: the turnout measurement method that was used by the district was thought by some to be too inaccurate for billing; ditch tenders were blamed by growers and other staff for not being accurate with their readings; the district's board thought too many staff and resources were being spent on water measurement; and the district could not recover the costs through water rates.

According to those interviewed, the change to acre-based pricing has led to a number of changes in the district, including staff priorities, water use, and drain flows. Growers and staff expressed a variety of opinions about the change, but in general, rice growers were satisfied with the new system, and other growers and district staff were not. Summaries of key observations and viewpoints expressed by the interviewees follow:

- More water is delivered to growers under the new system. One district staff member estimates that between 25 and 50 percent more water is being delivered to crops now than under the former system, although the effect on Sacramento River diversions is not known. Although more water might be delivered, there is an incremental increase in water that is recaptured and returned to the water delivery system.
- Staff and growers notice more flows in the drains, and because the district must pump out drain flows, more money is spent to pump out the excess drainwater. Growers perceive this is because ditch tenders are not being attentive, whereas ditch tenders believe growers should pay more attention to water use and management.
- The change has not significantly affected the distribution of crops within the district, but the pricing structure might have contributed to a small increase of relatively marginal lands being cultivated for rice production.
- Staff stated that although the district continues to record deliveries to growers, the records are not as precise as those collected when the information was used for billing. Some ditch tenders acknowledged that they were more attentive to operations under the former system.
- Larger rice growers view the change in policy favorably, and smaller rice growers and those who grow row crops or orchards believe that measuring and billing by the turnout is a more equitable system. District staff believe that a flat-rate system works to the advantage of the larger rice growers, and that long-standing disputes associated with turnout measurement are resolved.

- Growers who farm primarily row crops or orchards believe that it is fairer to charge growers by how much water they use, despite owning or leasing land with different soil types, which the grower cannot control. These growers acknowledged they would use as little water as possible if charged volumetrically.
- In general, rice growers are satisfied with the new billing policy, because turnout measurement was not accurate enough to justify billing by volume under the previous policy. These growers were concerned that mistakes made by ditch tenders led to inaccurate billing.

How has the change from acre-based pricing to volume-based pricing affected District D?

District D changed from billing by acre to billing by actual metered water use with an additional flat charge for administration and overhead, as described previously. Under this system, the district's meters are read regularly, generally every 2 days. When growers were billed by acre, the district was regularly exceeding their contractual allotment and buying additional water at a much higher rate. The district was not recovering its costs, and there was a perception of a high degree of wasted water.

Under the new measurement system and pricing policy, district staff believe district-wide water use and drain flows are lower. (It should be noted that the analysis described in Section 4.2 of this report was unable to verify a complete water balance before and after the change in pricing policy.) Staff acknowledges it is more expensive and requires more maintenance, including an additional staff person. The propeller meters, although accurate, clog frequently. In general, the growers and staff interviewed are satisfied with the new system and feel it is more accountable. Summaries of key observations and viewpoints expressed by the interviewees follow:

- The district estimates that under the current system, it is using less than it did before the change in measurement and billing practices. The timing of diversions has not changed.
- Drain flows are considerably lower under the new system. The new policy has reduced wasted water, but the degree of savings varies by grower. Other factors might contribute to lower drain flows, including the implementation of an extensive recirculation system, which occurred in 1994.
- Most district staff believe the turnout meters are accurate to within 5 percent when installed correctly. All growers believe the meters are usually accurate when functioning correctly. Estimations are made when the meters are out of service. The propeller meters installed at the turnout have problems with pondweed, clogging, and damage by debris during flooding.
- The change has not affected the distribution of crops grown within the district.
- Under the new system, growers pay closer attention to the water they use. The measurement data help growers with daily operations and management, and help to lower the overall cost of water. Growers feel they recycle more water under the new system.
- The change has not affected the way field staff manage water deliveries; however, an additional full-time staff person was required to read and maintain turnout meters.

- Both staff and growers feel that the current measurement method and pricing policy is more costly, but more accurate and more accountable.
- The change in measurement and pricing policy has not occurred without contention, because some aspects of water use cannot be directly controlled by a grower. The upper part of the district has more porous soils, necessitating higher water use, and growers there are refunded less than the lower part of the district. Also, growers who farm adjacent to ditches with a high water level typically save water because of canal seepage.

How would growers and staff at District A and District B respond if the districts changed from pricing water by acre to pricing water by volume?

Staff at Districts A and B suspect that turnout measurement combined with volume-based pricing probably would change diversions from the Sacramento River and the timing of those diversions. They suspect that drain flows would also be reduced, resulting in less water returned to the Sacramento River and less being available for downstream water users that rely on their outflows. Most district staff do not think that the amount of water applied to crops would change, but that turnout measurement combined with volume-based pricing might affect how growers control tailwater, which impacts the total volume of water through a turnout. The greatest effect would be seen in the amount of water applied to rice, because rice is irrigated by a continuous-flow system. Although tailwater could be reduced, growers must drain enough to flush salts that could impact crop yields.

General managers at these districts expressed concern about how to distribute operating costs of the district if billing by volume. They believe that if water use decreased but maintenance costs increased as a result of turnout metering, rates would go up substantially to cover operating costs.

Growers at Districts A and B emphasized that they have no reason to apply more water than a crop needs. Most growers said that price does not influence how they irrigate.

4.3.4 Summary of Findings

The interviews conducted for the Cooperative Study yielded valuable information about the variety of water measurement practices and perceptions in the Sacramento Valley. Summaries of perceptions drawn from all interview responses follow:

- A wide range of measurement methods are used in the Sacramento Valley. Districts generally select measurement methods that allow efficient day-to-day system management, early detection of maintenance issues, seasonal water accounting, and evaluation of water use efficiency. Measurement methods and intensity (field-level, lateral-level, and district-level) are influenced by a combination of district-specific factors including crop mix, district infrastructure, operating budget, and management need.
- Water measurement combined with staff experience plays a significant role in water management at all levels of district operations. District staff use water measurement data to the extent that it assists them with their particular management responsibilities. All districts indicated changes involving improved or more accurate measurement are made if they are economically justified. The point at which improvements in

measurement might be economically justifiable depends on the financial situation, operations, crop distribution, and size of each individual irrigation district.

- Growers typically rely on experience and knowledge of their land and associated crop needs to determine how best to irrigate. Growers value flexibility. Growers desire the ability to apply water on an as-needed basis, and they want the freedom to manage irrigation practices the way that they think is best for the crop and meets pesticide or herbicide best management practices.
- The majority of rice growers in districts that do not measure by turnout are not in favor of measuring water at the turnout level because they do not believe it would help them manage water. Some rice growers who do not currently have turnout measurement are concerned that malfunctioning or clogged turnout measurement devices, particularly propeller meters, will inhibit water flow through their turnouts during flood-up, resulting in a slower flood-up, a less productive crop, and possible financial loss. Rice growers at Districts C and D who have measurement devices installed did not express this concern, although the manager at District C speculated his growers might be likely to complain if they had propeller meters rather than rated checkboxes that are typically used for measuring his deliveries.
- Growers of orchard and row crops have a variety of attitudes and opinions about turnout measurement. Some think that turnout measurement data would help them manage their water, and other growers expressed opinions that it would neither help them nor change the way they irrigate.
- Experienced and educated ditch tenders are critical to water operations throughout the systems. Growers might rely on ditch tenders to track their irrigation events, to maintain their turnout gates, and to know about how much water flow they will need. Ditch tenders often must interpret growers' orders for water into specific flow rates, and understand how much to open a gate or how many inches over a weir will convey the ordered amount. Many ditch tenders know approximately how much flow is needed at each turnout and are often responsible for ensuring proper flow and quantity at each turnout. Some growers believe that it is most important to have ditch tenders who understand individual grower preferences and fields, rather than growers knowing exactly how much water they are being delivered.
- Some believe control of field tailwater is an effective water management tool and could be an alternative to monitoring the amount of water flowing through individual turnouts, particularly for rice growers, depending on the specific location and conditions. Many rice growers who use notched weir boards to monitor drain flows from each field understand the relationship between water flowing into their fields and the water running out of their fields and into drains. General managers from Districts A, B, and C also believe that controlling spills is of equal or greater importance than controlling flows through a turnout. Potential effects to users "downstream" that use tailwater was also identified as an issue needing to be considered with respect to overall water demands within or even across water districts.

- Some expressed that measuring water at the turnout and linking volumetric measurement to water pricing and district billing practices might change the water irrigation practices of some growers and field staff.
- The accuracy of measurement equipment is critically important to growers, and is the source of greatest controversy among growers (district customers) and the district if water is priced volumetrically. General managers and field staff believe that turnout meters are expensive to install and maintain, but some believe that measurement at the lateral level coupled with proper field staff training might yield similar and more cost-effective measurement.
- Large districts do not consider the capital and maintenance costs associated with turnout measurement to be economically justified. The capital expenditure of buying and installing one meter or measurement device for every turnout (more than 800 at one district interviewed), maintaining, and reading each device might exceed the operating budgets for these districts, which depend primarily on revenues from water rates to operate their systems.

Section 5 Benefits and Costs

This section identifies the potential benefits and costs of water measurement in accordance with the objectives previously identified in Section 1.4:

- Evaluate the potential benefits derived from measurement at turnout, lateral, and district levels.
- Estimate potential costs associated with a measurement program at the district, lateral, and turnout levels.

The findings of the Cooperative Study in terms of potential benefits and costs of measurement are largely consistent with the findings articulated by the CALFED Independent Panel on Appropriate Measurement of Agricultural Water Use (2003). The CALFED Independent Panel was a cooperative effort to determine the appropriate level of water measurement as part of the CALFED WUE. The panel noted that measurement data might help water districts distribute water to users and assist districts in making informed operational decisions and facility improvements. The panel also noted that water measurement allows districts to charge for water as they deem appropriate. In addition, water measurement information may be used to support district and regional water resources planning and water rights objectives, and can allow growers to demonstrate the effects of efficiency practices.

The panel recognized that it was unreasonable and speculative to estimate in a comprehensive manner the costs and benefits of future conservation or management projects that would be enabled by improved measurement. The panel expressed caution to agencies supporting costly measurement improvements when the benefits are uncertain.

As described in Section 4.1, numerous issues affected the accuracy of data collected in the field study at RD 108; and thus, the specific benefits of added measurement were determined to most appropriately be identified in qualitative terms. The discussion below summarizes the potential benefits of various levels of water measurement identified as part of the Cooperative Study through the field study, the water management and measurement interviews, and input from the study participants. Cost information was compiled from the equipment purchase, installation, calibration, and maintenance costs associated with the field study conducted in RD 108 during 2006 and 2007, and relevant cost information obtained from RD 1004, GCID, and Reclamation. Example conceptual measurement programs are also presented to demonstrate the order of magnitude of costs.

5.1 Benefits

This section and Table 5-1 summarize potential benefits of measurement at turnout, lateral, and district levels in qualitative terms as observed in the Cooperative Study. (Table 5-1 is located at the end of this section.) In addition to these levels of measurement, benefits of measurement at the sub-basin level, as well as measuring field drains, are discussed given the high degree of reuse that occurs within and across the Sacramento Valley.

5.1.1 Turnout Level

Turnout-level measurement may be an effective management tool; however, the accuracy and feasibility of turnout-level measurement is dependent on the system configuration, district/company policies, and other factors such as crop type. Therefore, turnout-level measurement was generally not found to be used within most of the study area that is dominated by flood-irrigated rice.

Where turnout-level measurement is feasible, such as for irrigation of row or tree crops, access to field delivery data can assist growers in scheduling water deliveries and in meeting outflow targets. This potential benefit is dependent on the crop and whether the given district has the policies and facilities in place to consistently provide a flexible delivery schedule.

An accurate and equitable measurement program acceptable to growers is necessary if a district/company chooses to implement a pricing-by-volume policy.

5.1.2 Lateral Level

Significant operational benefits can be realized with lateral-level measurement. Currently, districts use lateral-level measurement to make water delivery system operation decisions multiple times every day. All SRSCs that participated in the Cooperative Study use some form of lateral-level measurement (e.g., water level, flow rate). Water level and flow rate measurement provide operational tools that help the districts maintain appropriate pumping flow rates or head in laterals.

Approaches to lateral-level measurement currently used by those districts that participated in the Cooperative Study include rated check structures, long-crested weirs, rated canal sections, and staff gages for monitoring water levels. "Higher tech" devices such as acoustic Doppler meters are not commonly used among SRSCs, but they do have the potential to be useful for flow rate, water level, and volumetric measurement, especially if they are installed in conjunction with a remote sensing or SCADA. As with any measurement device, they must be properly installed, calibrated, and maintained by personnel trained in the use of the particular device to ensure accurate data. The acoustic Doppler meters installed at RD 108 in Year 2 of the Cooperative Study were intended to assist in evaluating the benefits of lateral-level measurement; however, insufficient calibration within the range of flows experienced at both meters resulted in unreliable data, as discussed in Section 4.1. Doppler and other electronic meters are relatively new technologies in the agricultural field. These higher tech devices have generally been developed for measuring flow in pipes and pressurized systems. Using these devices for open-channel measurement presents challenges. Sediment deposits and weed growth, especially in unlined canals, which are prevalent within the SRSC service areas, can result in changing cross sections during an irrigation season. These changes must be monitored and accounted for to assure accurate data are being collected.

Existing lateral-level measurement devices used by the SRSCs such as rated sections, staff gages, and long-crested weirs play an important role in daily water control operations and equitable deliveries among many growers on a particular lateral. In many cases, these facilities are not currently used for volumetric measurement.

Measurement at the lateral level can provide information leading to coordination among growers along a lateral and sub-basin efficiency improvements. Better understanding of lateral flows can allow a district to optimize its reuse operations and to evaluate facility improvements or identify the need for facility improvements. Districts might realize additional operational benefits if real-time access to lateral-level data is available through remote sensing.

5.1.3 District Level

Volumetric measurement of river diversions is required for each of the SRSCs for compliance with their long-term contracts with Reclamation as well as their water rights. The river diversion measurement program is carried out by Reclamation, and records of these diversions are provided monthly to the districts. Flow rate measurement can provide an important operational tool to assist in managing deliveries on a daily or hourly basis to meet respective district-wide demands. Real-time access to existing measurement information could result in more efficient operation at the district or company level.

Because of the level of reuse within the Sacramento Valley, outflow measurement can be an important aspect of district-level and sub-basin-level measurement programs. Outflow measurement, at the district and sub-basin-level, was not included in the scope of the Cooperative Study; however, outflow measurement at the sub-basin level was identified in the *Sacramento River Basinwide Water Management Plan, Sub-basin-level Water Measurement Study* (SRSCs, 2003a) as having the potential to provide the following benefits:

- Improved understanding of sub-basin outflow to evaluate opportunities for improved water management
- Coordinated management of sub-basin outflow
- Maximized benefits from other regional actions
- Possible integration with future sub-basin-level water quality monitoring program

In general, some level of district-level and sub-basin-level outflow measurement is already occurring in the service areas of the SRSCs.

5.1.4 Field Drains

Volumetric measurement of field drains (i.e., measuring outflow where possible at the field or lateral level) would increase understanding of water balances and associated water demands and reuse. Field-level drain measurement would help facilitate the quantification of water conservation practices implemented by growers at the field level.

Using notched weir boards to control outflow from rice fields provides growers with a better understanding of the relationship between water flowing into and out of individual fields than traditional check boards. Some general managers believe that controlling outflow from rice fields may be of equal or greater importance in managing available water supplies at the field level than controlling flow through individual turnouts. This concept may be particularly important in areas where recapture/recycle systems are not integrated into the irrigation operations and where excess drainwater is pumped out of the service area at high or additional pumping cost.

5.2 Costs

To demonstrate the order-of-magnitude costs of implementing a measurement program for varied levels of measurement, three conceptual models are presented. The conceptual models are for the a district-wide turnout-level program at RD 108, a range of lateral-level programs at RD 108, and an estimate of an existing district-level measurement program at RD 108. Detailed cost breakdowns of the conceptual models are provided in Appendix E.

5.2.1 Conceptual Turnout-level Measurement Program Costs

To demonstrate costs of an "entry-level" district-wide turnout-level measurement program, costs were estimated for a conceptual program at RD 108. The RD 108 program is considered entry level because no consideration is given for system reconfiguration. Measurement devices are installed at all delivery turnouts, telemetry equipment and software are not included, and sedimentation issues and low-flow velocity issues associated with mid-season maintenance flows for rice below the accurate velocity range of meters described in the Field Measurement Study are not explicitly addressed. Equipment costs are based on replacement meter purchases in 2008 by another SRSC. The meters purchased in 2008 are electronic propeller meters with digital readouts compatible with a 24-inch-diameter turnout. For the purposes of this estimate at RD 108, it is assumed that all turnouts are the 24-inch-diameter size. Installation costs are based on actual installation costs for similar meters using district personnel at RD 108 in 2006 and 2007 for the Field Measurement Study. Annual O&M costs, including field checks (debris checks and removal), data reading, data management, routine purchase of replacement parts, and an additional annual cost for data quality control is estimated. The labor rate for data quality control is based on an average labor rate for a ditch tender or field technician.

The installation costs provided in the estimate are based on installation costs observed during the Field Measurement Study. If a district-wide turnout-level measurement program were to be implemented at RD 108, it is likely that the district would need to hire an outside contractor because of the number of installations required. On the basis of conversations with some of the SRSC participants, it is likely that installation costs would be double those observed during the Field Measurement Study, considering contractor markups and the use of labor with prevailing wage requirements. Appendix E provides the cost summary for the conceptual turnout-level measurement program. The annualized cost for the conceptual turnout-level program at RD 108 would be approximately $30 per acre.

5.2.2 Conceptual Lateral-level Measurement Program Costs

As another point of reference for relative costs of potential measurement programs, costs for two hypothetical lateral-level programs were estimated for implementation at RD 108. By using input from RD 108, assumptions were made on how many lateral-level measurement sites are necessary. Equipment purchase, site civil work, device installation, and calibration costs are based on actual recent lateral-level measurement site installations at RD 108, GCID, and other sources. The "high-range" lateral-level measurement site includes an acoustic Doppler measurement device that records water level, flow, and volume. For the "low-range" cost estimate, existing flumes or similar in-channel structures would be coupled with level measurement from which flow and volume can be calculated and stored. These assumed devices are assumed to be SCADA compatible, but telemetry and SCADA costs are not included. By using recent annual costs at RD 108 for similar measurement sites, it is assumed that O&M costs are approximately 20 percent of the initial capital cost for the flume measurement sites. The labor rate for data quality control on the flume sites is based on an average labor rate for a ditch tender or field technician. For sites with acoustic Doppler devices, annual O&M costs are estimated as 30 percent of the initial capital costs. Because of the higher level of expertise required for data quality control for the acoustic Doppler devices, the labor rate is based on an average labor rate for an engineer or engineering technician. Summaries of costs for the range of conceptual lateral-level programs at RD 108 are provided in Appendix E. The annualized cost for the low range is approximately $5 per acre and for the high range is approximately $12 per acre.

5.2.3 Estimated District-level Supply Measurement Program Costs

As noted previously in this section, Reclamation measures all SRSCs' Sacramento River diversions for contract compliance purposes. An order-of-magnitude cost estimate for this district-level supply measurement is provided as an additional reference point with respect to the cost of varied levels of water measurement. The estimate provided in Appendix E is based on actual measurement devices in place or planned for installation by Reclamation. To provide a similar per-acre comparison to the turnout-level measurement and lateral-level measurement programs, it is assumed that all devices have yet to be installed. The devices are assumed to have a 7-year life. It is assumed that O&M costs are approximately 30 percent of the initial capital cost for the river diversion sites. The labor rate for data quality control is based on an average labor rate for an engineer or engineering technician. Appendix E provides a range of necessary measurement sites to measure all river diversions at RD 108, which is a typical larger SRSC. Costs would vary by SRSC, but this provides a data point for comparison to turnout-level and lateral-level measurement programs at RD 108. The annualized cost for district-level supply measurement is estimated at approximately $1.50 per acre.

5.3 Summary of Benefits and Costs

The benefits and estimated costs of conceptual programs for turnout-, lateral-, and district-level measurement were presented above. Table 5-1 provides a summary of the costs and associated benefits together with the potential beneficiaries and issues or considerations associated with each of the measurement programs. For this comparison, no SCADA costs are included, and all measurement would be capable of flow and level measurement as well as total volume. The turnout-level program estimated for RD 108 for annualized capital and O&M costs are on the order of $30 per acre. The annualized per-acre cost of a conceptual lateral-level measurement program ranges from $5 to $12 per acre. Lastly, the estimate of the existing district-level measurement is significantly less costly on a per-acre-served basis than the conceptual turnout-level or lateral-level programs at approximately $1.50 per acre.

For cost perspective, the conceptual annualized per-acre costs for the range of water measurement level could be considered in the overall water cost to the grower. For one major SRSC, the water rate for rice growers is currently $64 per acre. As discussed previously, district-level measurement is already in place. Adding lateral-level measurement and turnout-level measurement where it does not exist could increase the water cost $35 to $42 per acre. This equates to a 55 to 66 percent increase in water cost to the grower, which is likely to be infeasible – especially if the added measurement has beneficiaries beyond the grower. Therefore, it is important to distinguish not only what the benefits are, but who benefits from water measurement in order to equitably pay for capital and O&M costs. As previously acknowledged, additional study is required to quantify benefits, and identification of beneficiaries is equally important.

A summary of costs, potential benefits, beneficiaries, and potential issues for the turnout-, lateral-, and district-level measurement programs is presented in Table 5-1.

TABLE 5-1
Summary of Measurement Benefits and Costs
Cooperative Water Measurement Study Report

Measurement Level	Estimated Annualized Cost per Acre	Potential Benefits	Potential Beneficiary	Identified Issues/ Considerations
Turnout Level	**$30**	• For districts choosing to implement metered delivery pricing policies, acceptable turnout measurement is necessary for equitable implementation of that policy. • Turnout-level measurement can assist growers in managing water deliveries to meet outflow targets, assuming the field and/or crop type will allow for feasible measurement at the turnout level.	• District • Grower	• High cost for initial installation and annual O&M • Inaccurate for rice lands because of extreme flow range • Installation of meters does not result in less water use • Field-level conservation measures can negatively impact district or basin reuse or conjunctive use operations • Dependent on lateral-level management
Lateral Level	**$5 to $12**	• Additional data at the lateral level would assist districts in making daily operational decisions. Remote access to real-time lateral-level flow and level data could improve operational efficiencies. • Additional data at the lateral level would be useful for planning purposes (e.g., operational studies and infrastructure planning). • Lateral-level measurement would provide information regarding sub-basin efficiency improvements and coordination among growers. • Lateral-level measurement would optimize district reuse operations. • Lateral-level measurement would allow for better evaluation of facility improvements.	• District • District • District, growers • District • District	• Conservation measures such as reducing lateral-level spill can negatively impact district-wide or basinwide reuse or conjunctive use operations

TABLE 5-1
Summary of Measurement Benefits and Costs
Cooperative Water Measurement Study Report

Measurement Level	Estimated Annualized Cost per Acre	Potential Benefits	Potential Beneficiary	Identified Issues/ Considerations
District Level	**$1.50**	• District-level measurement provides an operational tool to manage deliveries on a daily or hourly basis to meet district-wide demands. Improved access to existing measurement information on a real-time basis could result in more efficient operation at the district or company level. • District-level measurement is required for compliance with water rights and contract provisions. • Improving outflow measurement at the district level would assist in understanding district-level water balances and may assist with regional coordinated management among sub-basins.	• District, state • District, region, state • Region, state	• Successful program already implemented and maintained by Reclamation for SRSCs • District-level outflow measurement is not currently implemented but has been identified as a potentially useful management tool with regional benefits; the annualized district-level measurement cost do not include outflow measurement

section 6

Study Conclusions and Recommendations

This section summarizes the conclusions of the Cooperative Study and provides recommendations and areas for further study that are considered applicable for many or all of the participating SRSCs.

Although some recommendations can be applied to the majority of the districts, the uniqueness of each SRSC service area with respect to existing facilities, operational needs, physical characteristics, cropping pattern, and district policies does not lend itself to a "one-size-fits-all" water measurement approach. General conclusions are drawn where appropriate.

As described previously, the development and implementation of the Cooperative Study was an outgrowth of the BWMP completed in 2004. Among the outcomes of the BWMP was the development of information and understanding "for the ongoing management of the water resources of the Sacramento Valley on a basinwide basis." The BWMP evaluated a wide range of water management and supply options, including increased groundwater use, drainwater reuse, system automation, incentive pricing, and water transfers (see BWMP Technical Memorandum No. 5, *Water Management and Supply Options*). Each of these options was evaluated at district and sub-basin levels as to their application and benefit. Among the options evaluated was water measurement, which was considered a district-level option. As presented in Table 5 of the BWMP Technical Memorandum No. 5, the following factors were identified as needing to be considered in determining the most effective or appropriate water measurement method:

- Purpose of measurement
- Accuracy requirements
- Cost
- Legal constraints
- Range of flow rates
- Head loss
- Site conditions
- Type of measurement needed
- Debris and sediment
- Maintenance requirements
- Vandalism potential
- Crop types

In addition to technical investigations that examined these factors relating to appropriate levels of water measurement, the Cooperative Study also documented wide-ranging observed and potential benefits of water measurement. Benefits were identified at several operating levels based on current practices within the SRSCs service areas or technical work carried out as part of this study. Accurate and timely water measurement data and information can be used to provide the following potential benefits, depending on the access to the measurement data:

- Contract and water right compliance
- Facilitating daily or hourly system operations
- Equitable apportionment of flow between water users
- Equitable apportionment and quantifying of applied water to different crops and uses
- Projection for supplying and allocating of total available water for the service area
- Implementation of district or company pricing policies
- Assist with water delivery scheduling
- Quantifying conservation and water use efficiency projects
- For drainage measurement, facilitates assessment of how conservation measures impact outflow
- Water transfers

Subsequent to the completion of the BWMP, the SRSCs and Reclamation agreed to pursue a regional approach rather than a typical district-specific water management plan as provided for in the SRSCs' renewed CVP water contracts. The resulting Regional Plan, completed in 2007 (as well as each SRSC CVP water contract), references the Cooperative Study as being an ongoing evaluation to develop a mutually agreeable water measurement approach. Completion of the Cooperative Study and the development of a mutually agreeable measurement approach by district or for the group was selected as an alternative to individual turnout-level measurement identified in each of the participating SRSC CVP water contracts.

The SRSCs and Reclamation agreed that the development of the Work Plan and subsequent study implementation required third-party reviewers be involved in the study design and approach to ensure objectivity and to promote stakeholder acceptance. Accordingly, nationally recognized experts in irrigation and agricultural water measurement assisted with the development of the Work Plan and reviewed aspects of study implementation, including this conclusions development. Additional details regarding the third-party reviewers and the review process are provided in Section 2.

6.1 Study Conclusions

As stated in Section 1, Study Goals and Objectives, the purpose and goal of the Cooperative Study is to assist in determining the appropriate level of agricultural water measurement in a cooperative manner between the SRSCs and Reclamation. The study conclusions are presented below with the specific study objectives.

As described in this report, four primary objectives were identified by the SRSCs and Reclamation in the Work Plan development process and were carried forward into study implementation. The study conclusions are organized according to the objectives, which are listed below.

1. Identify cost-effective, feasible measurement methods appropriate for the individual SRSC service areas.
2. Identify and evaluate the potential benefits derived from measurement at turnout, lateral, and district levels.
3. Identify and evaluate potential water use issues and benefits of pricing water by volume measured at the turnout or customer level.
4. Estimate potential costs associated with measurement programs at district, lateral, and turnout levels.

With respect to these specific objectives and the limited scope of the study, the following key conclusions were drawn from the Cooperative Measurement Study. A summary of conclusions from other measurement studies is provided in Appendix F to provide a comparison to other relevant measurement studies.

6.1.1 Objective 1: Identify Cost-effective, Feasible Measurement Methods Appropriate for the Individual Sacramento River Settlement Contractors' Service Areas.

The primary Cooperative Study conclusion is that the use of many metering devices for turnout-level measurement and management of deliveries to rice fields appears to be generally ineffective. The reasons for this as determined in this study are as follows:

- In general, irrigation practices for rice require high, early season flows to flood fields (basins) quickly to a certain level, followed by much lower flows to account for ETc, evaporation, and other losses, and maintain water levels over the course of the irrigation season. Visual monitoring of field outflow does not require the capital investment of turnout measurement and may be a more useful tool for growers in their water supplies than accurately quantifying the inflow to the field. Although some amount of flow through the fields is important to maintain crop yields, excessive outflow may result in higher operational or fertilizer costs.
- The technical complexity of measuring turnout deliveries for rice fields is a major consideration. Irrigation practices require extreme range of flow rates, very high flows during flood-up, and much lower maintenance flows for the majority of the growing season. The lower maintenance flows are often outside the accurate calibrated flow range of measurement devices sized for flood-up flows. Sediment deposits and buildup further complicate measurement in the low-lying basins in which rice is typically grown. As evidenced in this study, sediment buildup can clog propeller meters and can alter the pipe cross section, thereby affecting accurate flow measurement. Because the pipes are submerged throughout the irrigation season, sediment issues may be undetectable to operators or growers until the fields are drained in the fall.

The Cooperative Study provides additional technical information regarding different levels of water measurement for the SRSCs and reinforced the premise that the measurement approach must be evaluated on the basis of the specific characteristics of a

given service area. This study concludes that measurement approaches need to be tailored to each service area rather than attempting to develop and implement a single definitive measurement program for all SRSCs. Additionally, the approach or method must be tailored to the purpose for the intended measurement.

District-level water measurement is already occurring for all SRSCs. Measurement of diversions from the Sacramento River is required pursuant to the SRSCs' contracts with Reclamation as well as the terms and conditions of the SRSCs' state-issued water rights. These diversions are currently measured for all SRSCs by Reclamation. The measurements include both flow rate and volumetric measurement by ultrasonic or propeller meters, although flow rates are not continuously monitored or recorded for all SRSCs. In addition to monitoring and reporting district-level diversions and use, these measurements may be used for operational purposes.

Lateral-level water measurement is an appropriate level of measurement for operational purposes. Currently, all districts use some form of lateral-level measurement at least at key locations to assist in daily operations. Typically, these measurements may include flow rates or water levels. The Cooperative Study found broad support and practice of lateral-level measurement evident among the SRSCs for real-time water operations. This study indicates that there is opportunity for the improved accuracy and extent of lateral-level measurement within district operations. The accuracy of devices typically used for lateral-level measurement is being improved as the technology and funding are available.

Lateral-level water measurement may assist in the equitable distribution of water supplies and for billing. The Cooperative Study attempted to compare water deliveries measured at the lateral level and at the turnout level. As discussed in Chapter 4, because of questions relative to the accuracy of the turnout measurement data collected, a useful comparison of the two measurement levels was not possible. Lateral-level measurement may be useful for equitable distribution and billing purposes in districts that do not measure field-level deliveries. Additional study should be conducted to assess the potential benefits of lateral-level measurement for distribution and billing purposes.

Turnout-level measurement can be used for volumetric pricing for districts choosing such a pricing policy and if water users have accepted the level of measurement accuracy. The Cooperative Study found that accurate measurement acceptable to growers is critical to the implementation of volumetric measurement programs. The study also found that accurate measurement of deliveries through individual turnouts to rice fields can be difficult and costly. It is noted that RD 1004 uses propeller meters in their predominantly rice service area to measure turnout-level deliveries for operational and billing purposes. RD 1004 has a staff person dedicated to regular field checks of meters, and has established procedures to estimate flows during periods when the meters may be affected by debris or sediment. No adjustments are made to the recorded meter data during periods when the maintenance flows are outside of the rated accuracy range of the meters. However, because all turnouts are treated the same, the metered delivery data provide for equitable and accepted billing among RD 1004's growers.

Turnout-level measurement may not be the best water management tool available for many service areas. Accuracy of turnout-level measurement is highly dependent on crop type, irrigation system infrastructure, and irrigation operations.

System reconfiguration would be required for accurate turnout-level water measurement within many SRSC service areas. Accurate turnout-level measurement is dependent on sufficient head drop through the turnout, which maintains velocities within the rated range of the device and is high enough to minimize sediment accumulation. Much of the land used to grow rice within the service areas participating in the Cooperative Study is located in low-lying areas of districts (e.g., RD 108). Improving measurement accuracy would, in many areas, require costly reconfiguration of the delivery system to provide sufficient head, and in most cases is economically or logistically infeasible.

Current measurement methods and intensity are influenced by a combination of factors unique to each district, including crop mix, district infrastructure, topography, operating budget, and management need. Each SRSC participating in this Cooperative Study uses a generally unique method of water measurement that they feel is best suited to meet their needs, although it is noted that all SRSCs have measurement and data collection devices at all Sacramento River diversions (i.e., district-level inflow measurement). One key theme derived from the Cooperative Study is that SRSCs currently implement system changes such as installation of more intensive, improved, or more accurate measurement equipment when it is economically justified. Economic justification might include reducing pumping costs by controlling spill, reducing labor costs, or avoiding financial liability. An example of cost-justified measurement improvement is replacing aged propeller meters at Sacramento River diversions or lateral control points with ultrasonic devices to reduce maintenance costs. In addition, telemetry equipment is installed with the ultrasonic meters, which allows real-time access to the measurement data. Real-time to flow and water level data has the potential to improve district operations by reducing operational spills and increasing system efficiency.

6.1.2 Objective 2: Evaluate Benefits Derived from Measurement at Turnout, Lateral, and District Levels.

The Cooperative Study documented the potential benefits of various levels of water measurement, and these are summarized in Table 6-1.

6.1.3 Objective 3: Identify and Evaluate Potential Water Use Issues and Benefits of Pricing Water by Volume Measured at the Turnout or Customer Level.

The analysis of historical delivery data at SMWC was inconclusive regarding the influence of pricing policy on field-level deliveries. The delivery data analysis described in Section 4.2 was designed to provide insights into the potential water delivery effects of changing irrigation water pricing policies. An array of factors influenced field deliveries during the study period, making it difficult to isolate the effect of pricing alone; however, the Cooperative Study did not find a statistically significant correlation between the change in pricing policy and a change in field deliveries within SMWC.

In the interview portion of the study, pricing policy was noted by some growers and managers as a possible tool for improving water management; however, a wide range of perceptions on pricing by volume was evident. Measuring water at the turnout and linking volumetric measurement to water pricing and district billing practices was generally thought to have the potential to change the water management practices of some growers and field staff. Measurement at the turnout without coupling the practice with volumetric billing practices is expected to have little effect on the water management practices according to the Cooperative Study's interviews. Accuracy of measurement equipment is critically important to growers and is the source of greatest controversy between growers and the district where water is priced volumetrically. Some growers who farm primarily row crops or orchards believe that it is more equitable to charge growers by how much water they use, despite owning land on different soil types, which the grower cannot control. These growers acknowledged they would use as little water as possible if charged volumetrically. Major rice growers viewed the flat-rate pricing favorably, but smaller rice growers and those who grow row crops or orchards believe that measuring and billing by volume delivered is a more equitable system. Much of the policy regarding water delivery pricing depends on the role certain cropping plays in maintaining the financial sustainability of individual district operations and existence. Also, district pricing policy is largely influenced by the largest growers and the relative make-up of their farming and cropping characteristics.

TABLE 6-1
Potential Benefits of Various Water Measurement Levels
Cooperative Water Measurement Study Report

Measurement Level	Potential Benefits
Turnout Level	• For districts choosing to implement metered delivery pricing policies, acceptable turnout measurement is necessary for equitable implementation of that policy. • Turnout-level measurement can assist growers in managing water deliveries to meet outflow targets, assuming the field and/or crop type will allow for feasible measurement at the turnout level.
Lateral Level	• Additional data at the lateral level would assist districts in making daily operational decisions. Remote access to real-time lateral-level flow and level data could improve operational efficiencies. • Additional data at the lateral level would be useful for planning purposes (e.g., operational studies and infrastructure planning). • Lateral-level measurement would provide information regarding sub-basin efficiency improvements and coordination among growers. • Lateral-level measurement would optimize district reuse operations. • Lateral-level measurement would allow for better evaluation of facility improvements.
District Level	• District-level measurement provides an operational tool to manage deliveries on a daily or hourly basis to meet district-wide demands. Improved access to existing measurement information on a real-time basis could result in more efficient operation at the district or company level. • District-level measurement is required for compliance with water rights and contract provisions. • Improving outflow measurement at the district level would assist in understanding district-level water balances and may assist with regional coordinated management among sub-basins.

6.1.4 Objective 4: Estimate Potential Costs Associated with a Measurement Program at the District, Lateral, and Turnout Levels.

Turnout-level measurement equipment can be relatively expensive, especially when the cost of installation, maintenance, calibration, administration, and data management is considered. The Cooperative Study documented the cost of measuring at the turnout level for a small percentage of SRSC service acreage farmed to rice. Considering purchase, installation, routine maintenance, and data management, the average cost of a single turnout propeller meter for the first year of operation is typically over $5,000, with annual costs approximately $1,300 per meter thereafter. Some SRSCs have over 3,000 turnouts, which would make district-wide turnout-level measurement a major cost. Additionally, fields may vary significantly in size, resulting in a wide range of cost when viewed on a per-acre basis. Such a significant investment would require more analysis of quantifiable benefits and beneficiaries, particularly in terms of benefit to the Sacramento River. Although it is generally costly to install and maintain propeller meters at every turnout, other less costly methods such as rated checkboxes might be implemented depending on turnout configurations, the purpose for the measurement, and the desired level of accuracy.

To demonstrate the range of costs and relative differences in cost for various levels of water measurement, the cost of the field study and turnout-level measurement program at RD 1004 were documented. Conceptual lateral-level measurement programs were estimated for application at RD 108. Lastly, an estimate of the existing district-level measurement program at RD 108 for diversion of the Sacramento River was developed. The summary of annualized costs on a per-acre basis over the expected life of a measurement site (including total initial capital cost and expected annual costs for measurement site O&M and data management) is provided in Table 6-2. To put these conceptual measurement costs into perspective, a typical large SRSC charges its rice growers $64 per acre for water deliveries. Adding lateral-level and turnout-level measurement costs to the water rates could increase their rates by 55 to 66 percent. Whether or not growers should bear the additional measurement costs should be dependent on whether the benefits are quantified and whether the grower is the beneficiary.

TABLE 6-2
Summary of Measurement Costs
Cooperative Water Measurement Study Report

Measurement Level	Estimated Annualized Costs per Acre
District Level	$1.50
Lateral Level	$5 to $12
Turnout Level[a]	$30

[a]Turnout level costs do not address system reconfiguration

6.2 Recommendations and Areas for Further Study

Improvements in water management and measurement can be achieved through a variety of methods. Water management techniques vary among crops, growers, and districts within the SRSC service areas evaluated. Use of water measurement devices at turnout and lateral levels was found to have certain benefits and drawbacks depending on the application and purpose for measuring. In general, it was concluded that "one size does not fit all," even among water districts/companies dominated by a single crop such as rice. Given the number of turnouts and crop types, economic considerations are also a major factor in each district's opinion of appropriate measurement approach. Also, as identified previously, controlling spills/tailwater was identified as a potential effective water management practice. In closed basins, reducing spills can also reduce energy costs for pumping drainwater out. However, given the amount of water reuse that occurs within districts, as well as the fact that tailwater from a field or district is often a source of supply for downstream users, reducing spills needs to be evaluated in the context of overall water use (SRSCs, 2004).

6.2.1 Recommendations

It is recommended that districts develop and maintain programs to continually ensure that all measurement devices are properly installed, maintained, and accurately calibrated. Additionally, adequate staffing levels need to be maintained throughout the irrigation season.

It is recommended that districts provide continued and ongoing training for field operators. Training for field staff in proper operation, maintenance, and calibration of measurement devices is crucial for obtaining accurate measurement data. Field staff should be provided the most up-to-date and appropriate training to ensure accurate measurement. Training should be provided for new equipment and technologies as well as existing equipment.

It is recommended that districts develop and implement quality assurance/quality control programs to ensure that all measurement data are accurately recorded, documented, and archived. Measurement data at any level are useful only if the accuracy and quality of the data can be assured. Additionally, the quality assurance/quality control program should ensure the data are appropriately archived and available for future review and use.

It is recommended that the results of this Cooperative Study be used to inform DWR regarding the implementation of recently passed Senate Bill SBX7 7, Water Conservation – Agricultural Measurement Requirement. DWR is expected to initiate a process to adopt regulations that provide for a range of options for agricultural water suppliers to comply with the measurement requirement. The costs, benefits, and issues of water measurement documented through the Cooperative Study could provide useful input to DWR's forthcoming implementation process.

6.2.2 Areas for Further Study

As noted previously, the focused nature of the Cooperative Study limited the broader applicability of study results. On the basis of information developed through the Cooperative Study, several areas outside of the study's scope are recommended for future study to assist in identifying appropriate levels of agricultural water measurement for the SRSCs. The following is a summary of the areas identified for further study.

Water management options other than turnout-level water measurement should be identified and evaluated. Other water management tools might be more effective in meeting the goal of reduced Sacramento River diversions, particularly for rice. Other tools such as incentivized drainwater management, minimizing rice basin outflow, and district-level reuse may provide quantifiable benefits. It is recommended that the SRSCs identify and analyze other water management practices that could have benefits that are more quantifiable than water measurement.

The sub-basin-level measurement program should be revisited and evaluated, and coupled with a sub-basin-level water balance analysis. The sub-basin-level measurement program was identified in the BWMP and the concept was studied through a DWR WUE grant in 2003. A first step could be to measure drain flow at key locations to understand and quantify the maximum possible benefit. Additionally, analysis of the sub-basin-level water balance would provide valuable information about data gaps and, ultimately, could provide information about benefits of additional measurement on a broader scale.

Additional investigation of different levels of water measurement for crops other than rice, particularly at the turnout level, should be undertaken. The field measurement portion of the Cooperative Study was limited to studying deliveries to rice fields. This narrowed focus was deemed appropriate given the predominance of rice within the SRSC service areas. It is acknowledged that many other crops are grown within SRSC service areas and the measurement requirements or issues for these crops may be different. Measurement of deliveries to crops other than rice should be studied. RD 108's voluntary turnout-level measurement program for row crop growers, which was initiated in 2010, may provide an opportunity for this type of study. The study should include an evaluation of measurement that can assist in reducing applied water requirements and energy usage, and, if so, the effects of reductions in applied water on crop yields and quality.

section 7

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Appendix A
Field Study Analysis

APPENDIX A

Field Study Analysis

This Appendix A provides the analysis of the data collected during the Field Measurement Study. The analysis includes comparisons of total deliveries, drainage, and net deliveries measured at lateral, sub-lateral, and field levels for both years of the study.

Year 1 Data Analysis

Average monthly and seasonal delivery and drainage per acre were used to compare the various levels of measurement. Figures A-1 and A-2 summarize the average monthly deliveries and drainage measured in Year 1, respectively. The figures show that in Year 1, the average per-acre recorded deliveries to the Field-level Site were greater than the recorded per-acre deliveries to the Lateral-level Site, and, except for August, the average per-acre drainage recorded for the Field-level Site was less than was recorded for the Lateral-level Site.

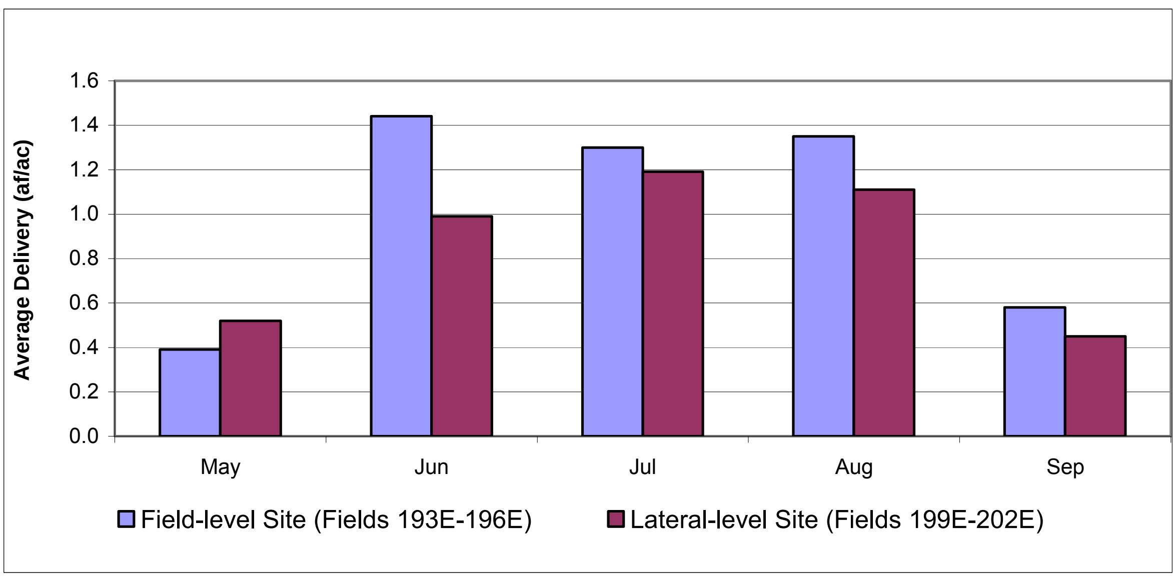

FIGURE A-1
COMPARISON OF YEAR 1 MEASURED MONTHLY LATERAL-LEVEL DELIVERIES

Note:
af/ac = acre-feet per acre

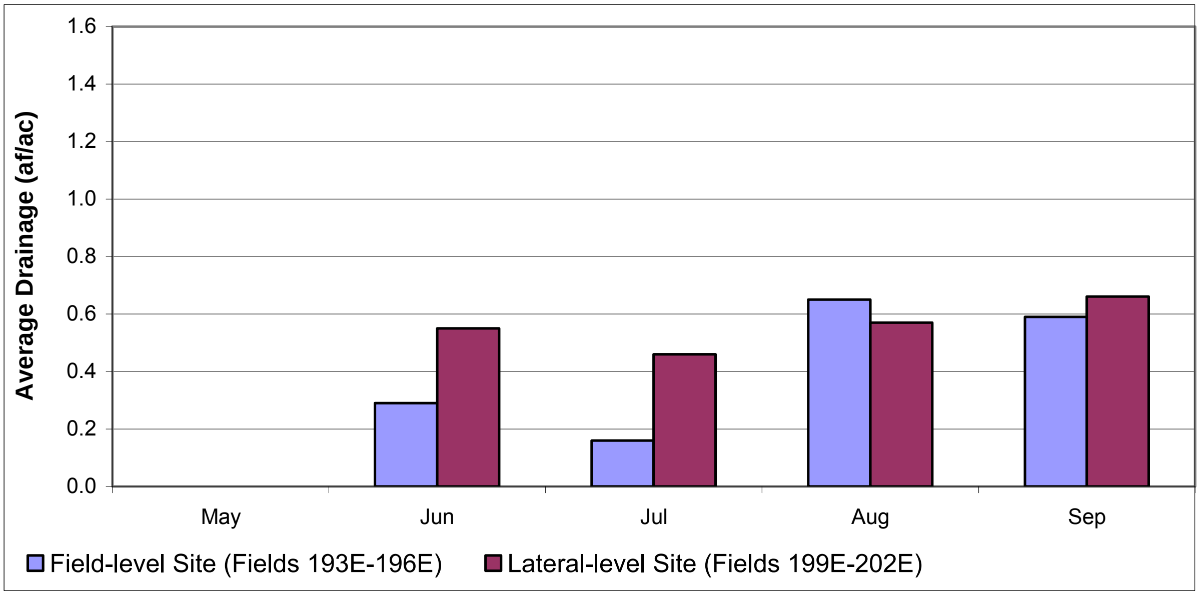

FIGURE A-2
COMPARISON OF YEAR 1 MEASURED MONTHLY LATERAL-LEVEL DRAINAGE

On the basis of data collected during Year 1, the average delivery within the Field-level Site was approximately 5.1 af/ac. The data indicate the average delivery to the Lateral-level Site was approximately 4.3 af/ac. Deliveries for rice varieties grown and the soil types found within Reclamation District 108 (RD 108) typically range between 5 and 6 af/ac.

Conditions encountered in Year 1 that affected the accuracy of the measured deliveries and drainage within the study sites are as follows:

- Estimates of deliveries through unmeasured gates at S13, S14, S15, S17, and S18
- Unmeasured inflow to the drain above the meter at D4 resulting from a malfunctioning water level sensor
- Drain meters observed at times to be only partially submerged
- Debris and weeds observed to be interfering with the operation of propeller meters

The technical team worked with RD 108 staff to identify these issues and to develop ways to minimize similar conditions in Year 2.

Year 2 Data Analysis

Study Site Measurement

For Year 2, average per-acre delivery and drainage measured at the lateral level were compared to the Field-level Site and the Lateral-level Site. Figures A-3 and A-4 summarize the average monthly unit deliveries and drainage by using these measurements for Year 2.

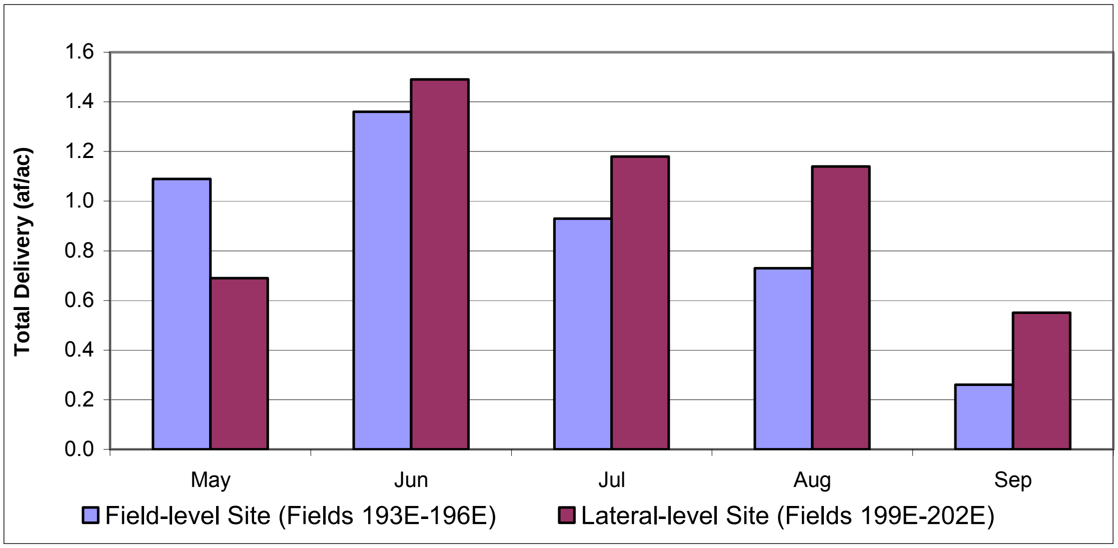

FIGURE A-3
COMPARISON OF YEAR 2 MEASURED MONTHLY LATERAL-LEVEL DELIVERIES

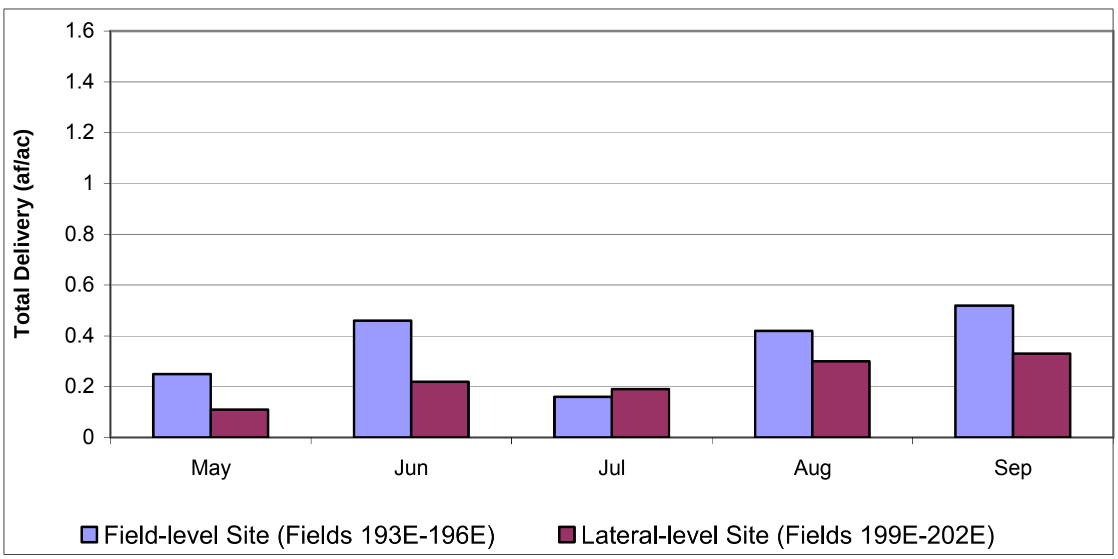

FIGURE A-4
COMPARISON OF YEAR 2 MEASURED MONTHLY LATERAL-LEVEL DRAINAGE

In Year 2, except for May, monthly deliveries measured at the lateral level to the Lateral-level Site were higher than the measured deliveries to the Field-level Site. Conversely, the drainage measured from the Lateral-level Site was lower than was measured from the Field-level Site each month except for July.

Figures A-5, A-6, and A-7 compare the average irrigation season deliveries, drainage, and the net deliveries measured at the lateral level for both study sites in Year 2.

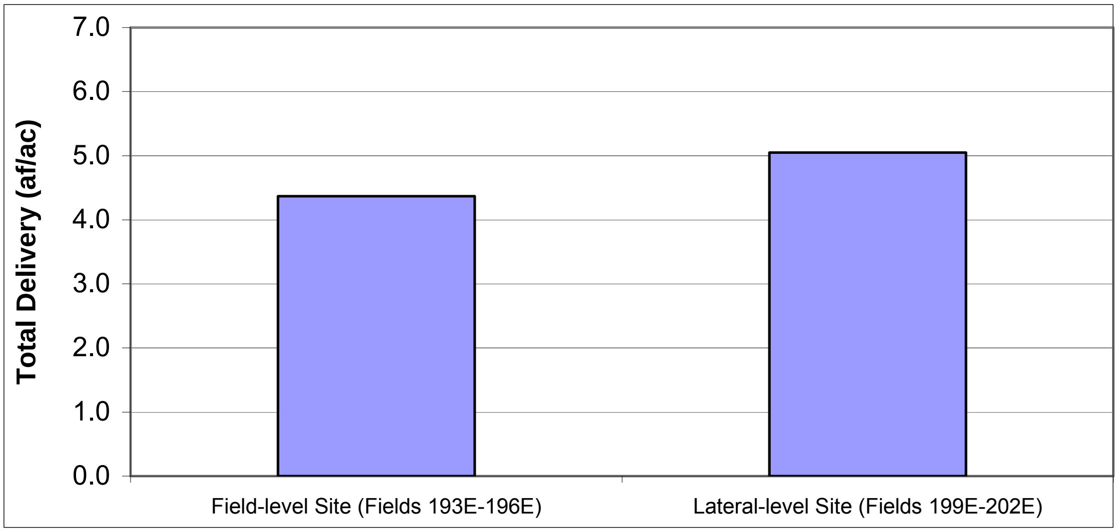

FIGURE A-5
COMPARISON OF YEAR 2 AVERAGE SEASONAL LATERAL-LEVEL DELIVERIES

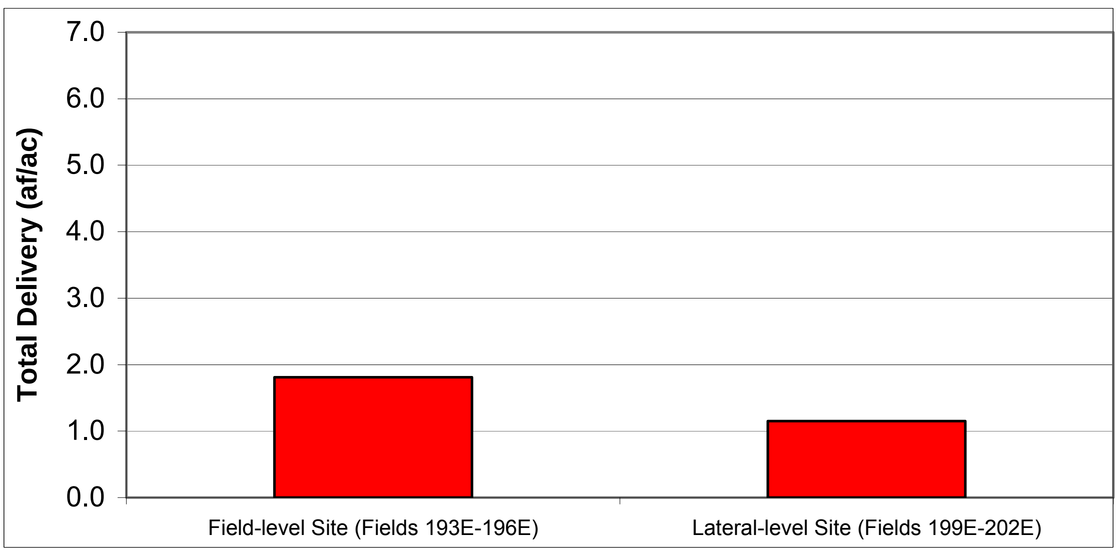

FIGURE A-6
COMPARISON OF YEAR 2 AVERAGE SEASONAL LATERAL-LEVEL DRAINAGE

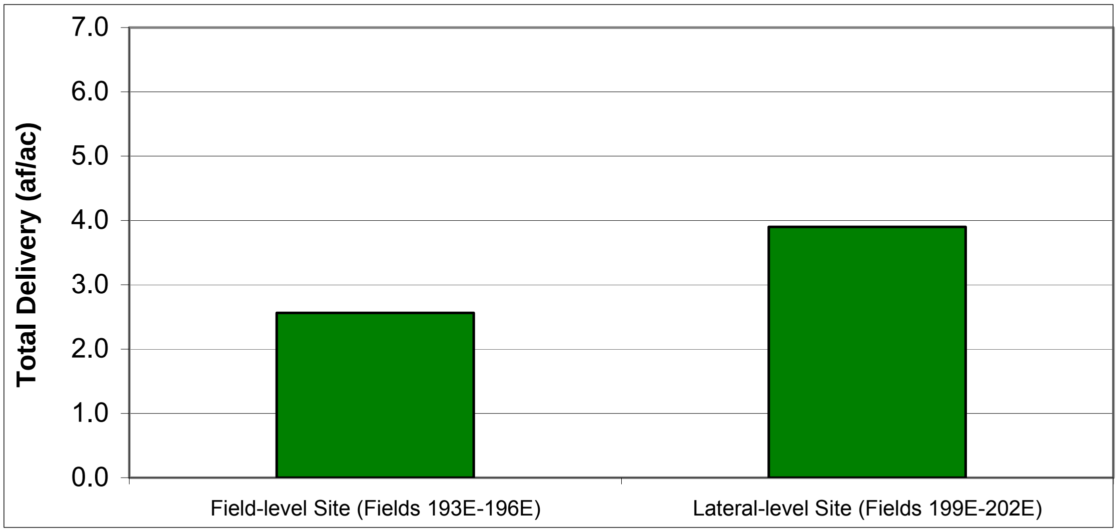

FIGURE A-7
COMPARISON OF YEAR 2 AVERAGE NET DELIVERIES

Comparison of Year 1 and Year 2 Measurement

Figures A-8, A-9, and A-10 provide a side-by-side comparison of the average measured deliveries, drainage, and net delivery to the Field-level Site and the Lateral-level Site for each year of the study.

FIGURE A-8
COMPARISON OF YEAR 1 AND YEAR 2 AVERAGE DELIVERIES

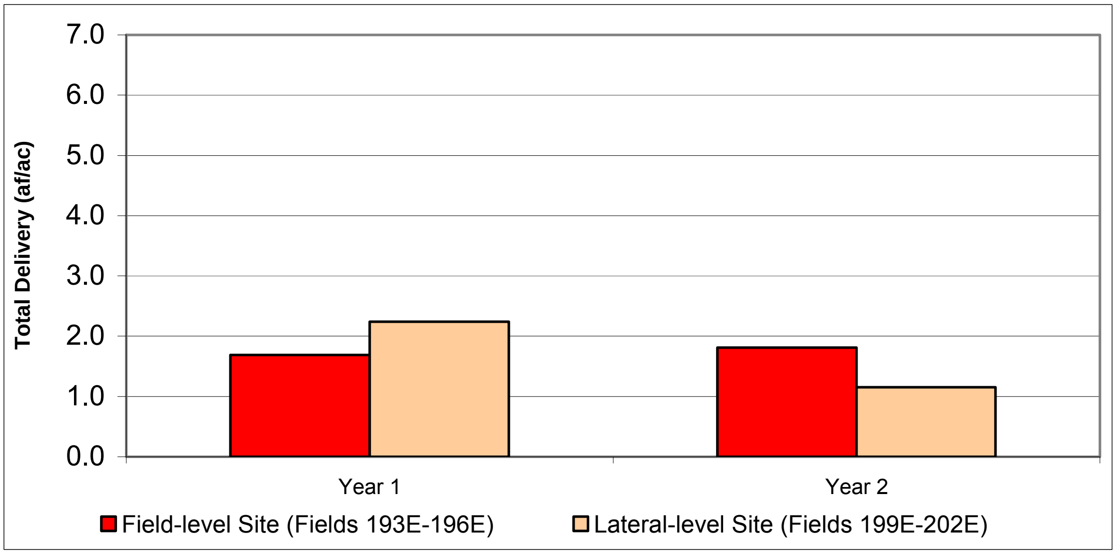

FIGURE A-9
COMPARISON OF YEAR 1 AND YEAR 2 AVERAGE DRAINAGE

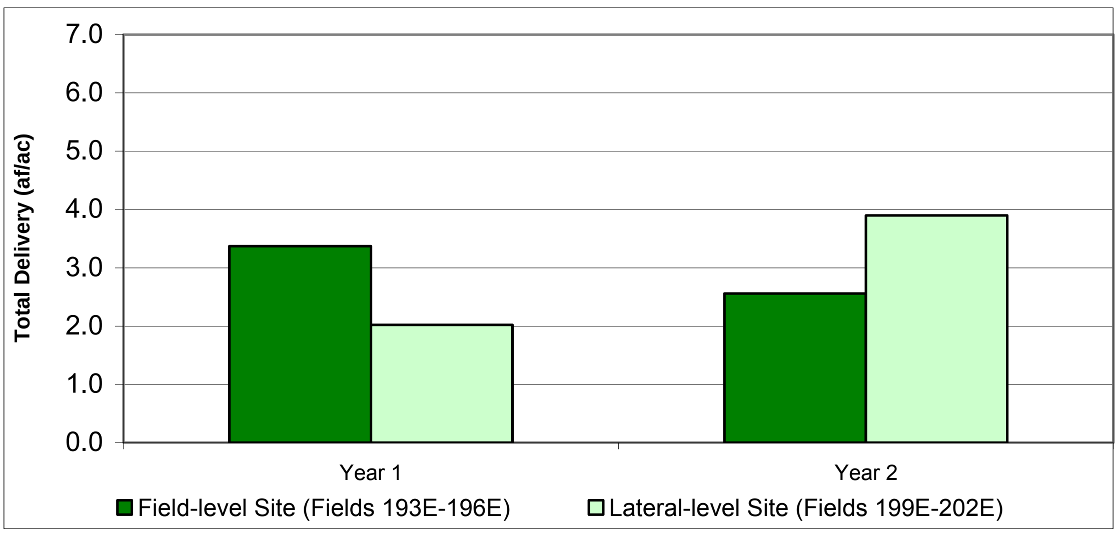

FIGURE A-10
COMPARISON OF YEAR 1 AND YEAR 2 AVERAGE NET DELIVERIES

As shown on Figure A-8, the average total deliveries measured for the Field-level Site were higher in Year 1 and lower in Year 2 than were measured for the Lateral-level Site. Figure A-9 shows that the average drainage measured was just the opposite, lower for the Field-level Site in Year 1 and higher in Year 2.

Sub-lateral-level Measurement

Measured deliveries from Lateral 14B to Sub-lateral 1B3 were compared with the turnout deliveries to the fields from the sub-lateral at Gates S2, S3, S4, S10, and S12. Figure A-11 shows the monthly deliveries to the fields supplied by Sub-lateral 1B3 measured at the lateral level and at the turnout level.

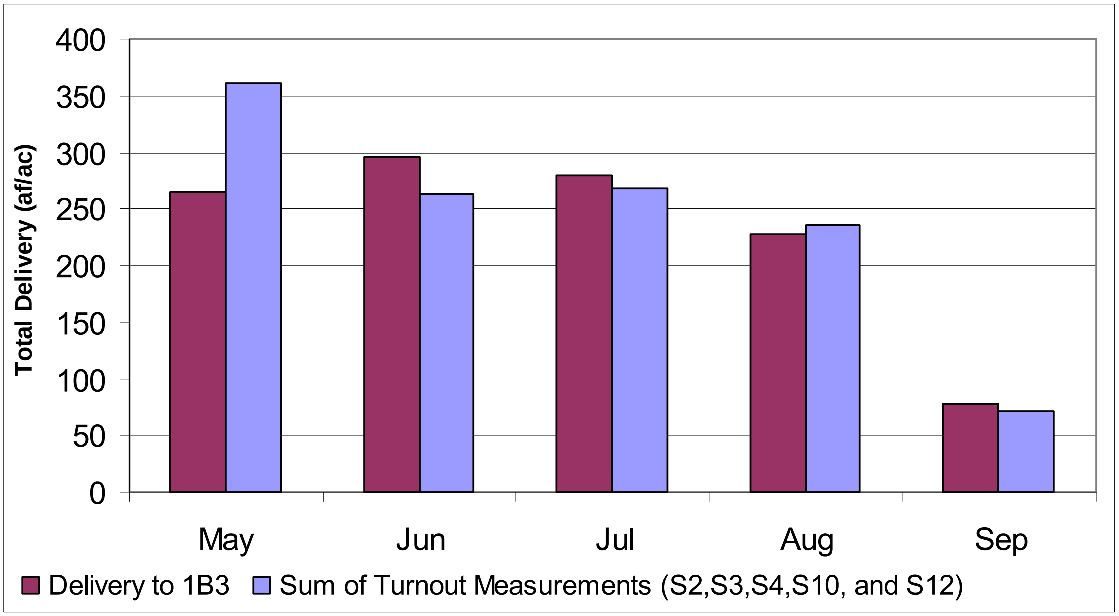

FIGURE A-11
COMPARISON OF SUB-LATERAL-LEVEL AND TURNOUT-LEVEL MEASUREMENTS ON SUB-LATERAL 1B3

As shown on Figure A-11, with the exception of May deliveries, the monthly deliveries from Sub-lateral 1B3 measured at the sub-lateral and turnout level are comparable. The differences in monthly diversions may be attributed to several factors including, but not limited to, seepage losses and timing. Deliveries in May measured at the turnout level were approximately 26 percent higher than were measured at the sub-lateral level. The measured deliveries in July and August are within 4 percent of each other. The large discrepancy in May might be because the downstream ends of the delivery pipes where the meters were located were not fully submerged when water was initially turned into the fields. This condition results in an overestimate of the volume actually delivered through the meters during the flood-up of the rice fields.

Field-level Measurement

Average monthly deliveries and drainage measured at the field level are shown on Figures A-12 and A-13.

As shown on Figures A-12 and A-13, the deliveries and drainage measured at the field level varied significantly from one field to another. Additionally, the pattern of deliveries and drainage appear to be different than the pattern indicated by the lateral-level measurement in both Year 1 and Year 2.

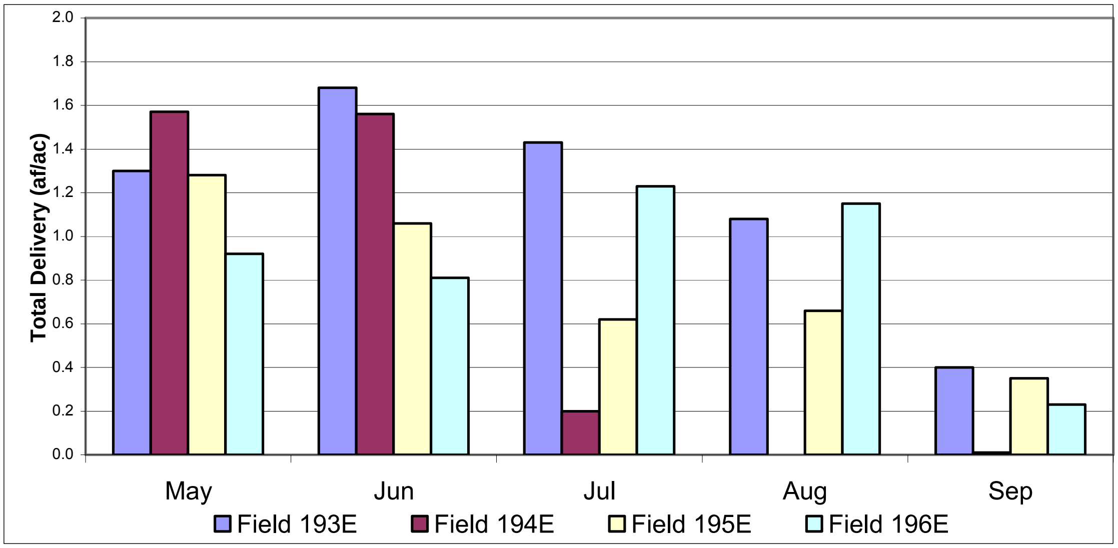

FIGURE A-12
YEAR 2 AVERAGE MONTHLY DELIVERIES MEASURED AT THE FIELD LEVEL

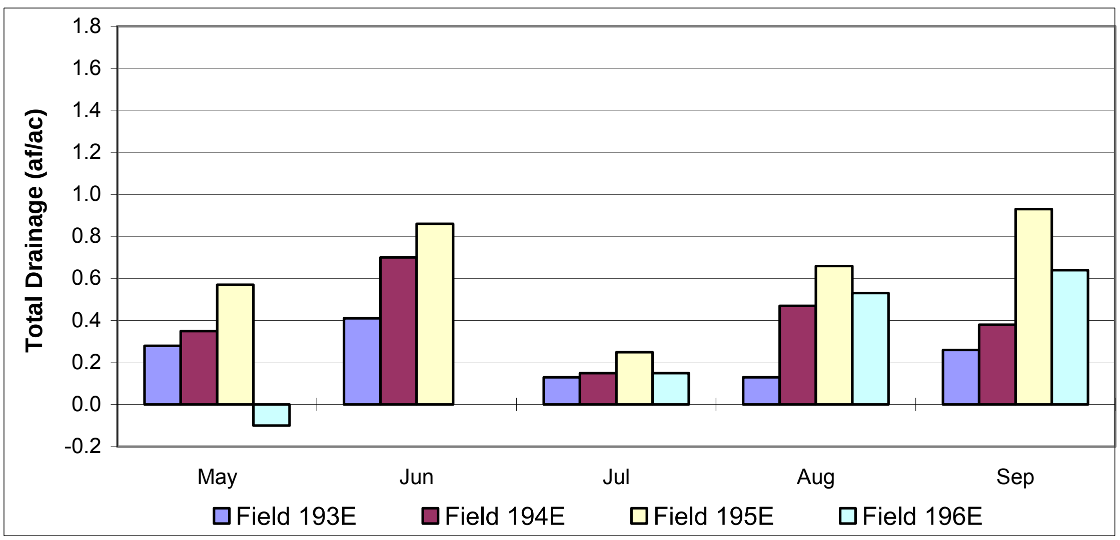

FIGURE A-13
YEAR 2 AVERAGE MONTHLY DRAINAGE MEASURED AT THE FIELD LEVEL

Figures A-14 through A-16 identify the average seasonal deliveries, drainage, and net deliveries measured at the field level in Year 2 of the study, respectively. As with the monthly measurements, these figures show significant variance in the measured flows to and from each field.

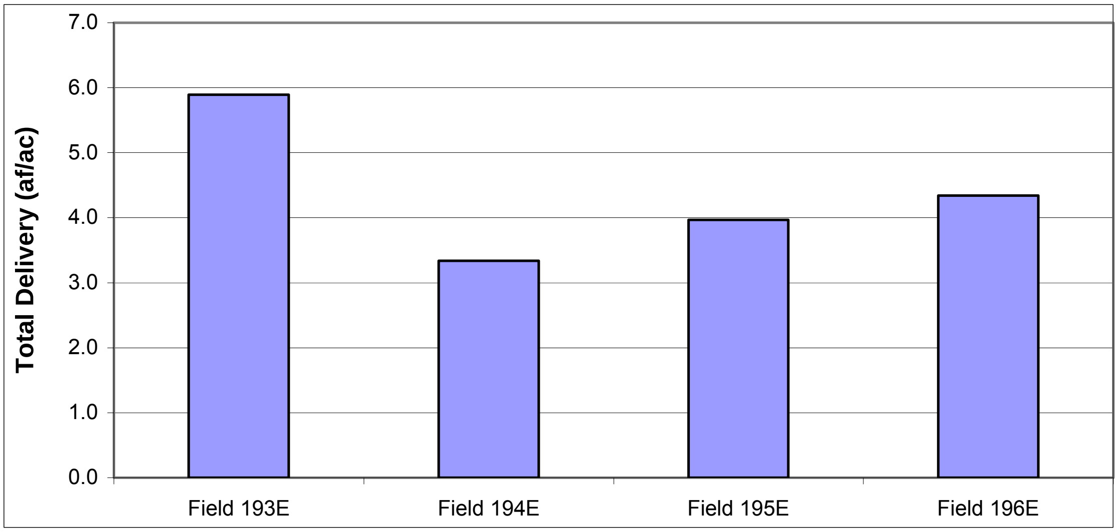

FIGURE A-14
AVERAGE SEASONAL DELIVERIES MEASURED IN YEAR 2 AT THE FIELD LEVEL

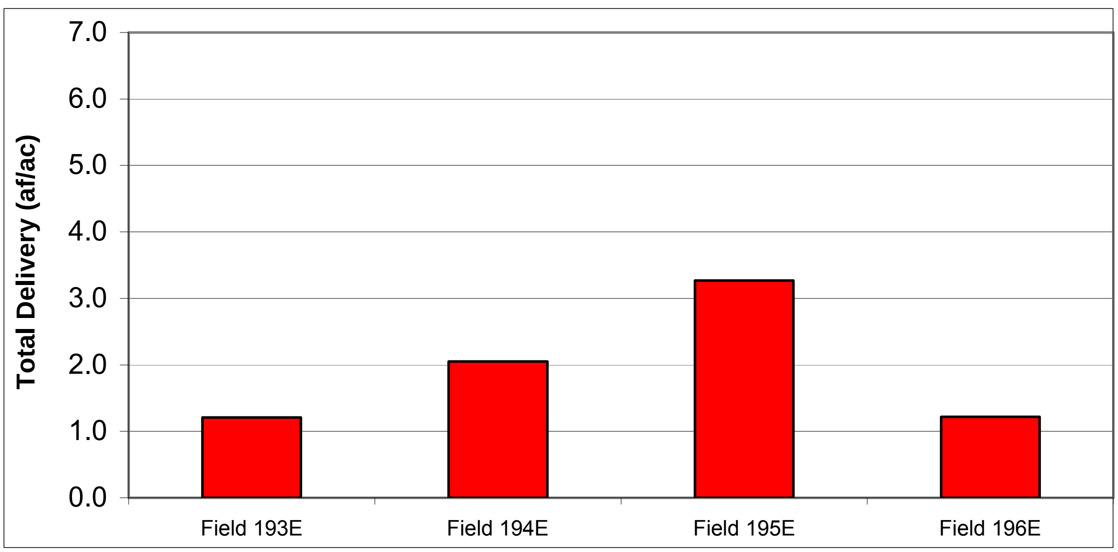

FIGURE A-15
AVERAGE SEASONAL DRAINAGE MEASURED IN YEAR 2 AT THE FIELD LEVEL

As shown on Figure A-14, the total recorded deliveries to the individual fields within the Field-level Site ranged from a high of approximately 5.9 af/ac in Field 193 to a low of approximately 3.3 af/ac in Field 194. Average deliveries recorded for Fields 195 and 196 were approximately 4.0 af/ac and 4.4 af/ac, respectively. Velocities observed during the rice flow maintenance period after flood-up were at times below the rated range of the meters. The accuracy of the data collected during these periods is unknown. After the fields were drained, the meter installations were inspected; and some meters were found to be affected by sediment deposits (see Figure A-16).

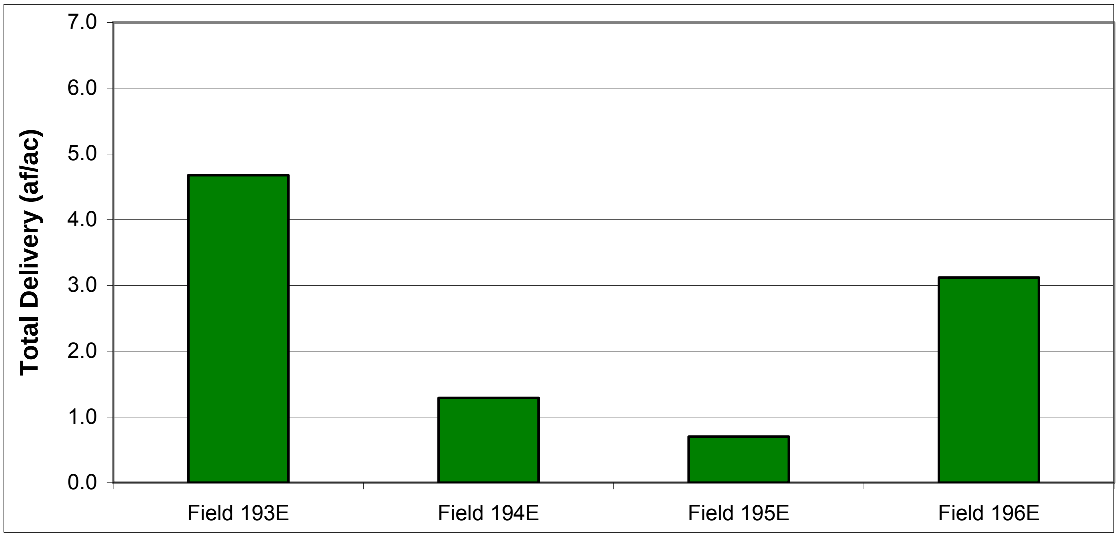

FIGURE A-16
AVERAGE NET SEASONAL DELIVERY MEASURED IN YEAR 2 AT THE FIELD LEVEL

According to the meter data, average drainage from the fields within the Field-level Site ranged from 1.2 to 3.3 af/ac. As previously identified, weed growth and debris interfered, at times, with the operation of the meters located within the drains. Velocities observed at the drain meters were at times below the rated range of the meters. Additionally, at times, the drainage meters were not fully submerged. RD 108 staff attempted to maintain water levels to keep the meters functional by building small dams in the drain downstream from some of the meters. The propeller meter at D1 was observed on several occasions either to be partially submerged or not registering flow when drain flow and velocity was low, during the flood-up and maintenance periods. Therefore, the totalized volume from the meter overestimates the actual drain flow at this location. This overestimation of volume for D1 accounts for the negative drain flow for Field 194, shown on Figure A-13, and might also result in recording lower than actual drain flow in other months.

Conclusions

Conditions affecting meter performance and measurement accuracy were experienced at all measurement levels and with all types of equipment used in the study. The deliveries and drainage measured at the lateral level resulted in net deliveries to the Field-level Site in Year 1 and to the Lateral-level Site in Year 2 insufficient to meet the consumptive use requirements for rice. This is also true of the net deliveries to Fields 194 and 195 measured in Year 2. In fact, total deliveries to Field 194 measured in Year 2 were approximately equal to the consumptive use requirements. Unit deliveries according to the data collected varied widely from year to year and site to site, as well as between levels of measurement.

Gated pipes used for delivery to rice fields must be sized to quickly flood the field. These same pipes are used to deliver much smaller maintenance flows. Although propeller meters were used in this study, conditions that affected the performance and accuracy of the meters such as sediment buildup and the inability to accurately measure flows over a wide velocity range would also have been experienced with more sophisticated devices such as Doppler or ultrasonic devices. These sophisticated devices might provide reasonably accurate measurement in laterals where volumes and velocities are more constant. However, they require regular operation and maintenance; strict calibration procedures; and skilled, knowledgeable operators to provide accurate and useful information. Accuracy of other measurement devices such as rated or meter gates may also be affected by sediment and weed growth. Overflow structures such as weirs and check boards may be less affected by these conditions. However, all devices require a sufficient amount of head loss to provide reasonably accurate measurement.

Because of the issues identified above, drawing conclusions as to the appropriate level at which to measure water deliveries to rice fields on the basis of the data collected in this study is not possible.

Appendix B
SonTek Data Collection Summary

APPENDIX B

SonTek Data Collection Summary

As described in Section 4.1 of the *Cooperative Water Measurement Study Report*, the technical team identified the potential opportunity to measure deliveries within the study area at a main lateral level, as well as sub-lateral and field levels. As a result, the Bureau of Reclamation (Reclamation) obtained, installed, and maintained two SonTek/YSI Argonaut SL 3000 (SonTek) side-looking Doppler flow meters. In Year 2, one of these Doppler meters was installed upstream of Lateral 1B3, and the second was installed downstream of Lateral 1B1. This Appendix B describes the installation and intended purpose of the SonTeks, some issues encountered, and provides a summary of the data they provided.

The two side-looking Argonaut SL 3000 meters were installed on sliding tracks to allow the meters to be properly placed within the flow column and to allow them to be easily accessed for cleaning and servicing. Each of the SL 3000 meters was connected by cable to solar power supplies located nearby, and equipped with data loggers. The SonTek measures velocities and water depths using Doppler technology. Flow volumes are calculated depending on the average velocity measured by the Doppler meter and the cross sectional area at the meter location. Doppler sensors cannot "see" and, therefore, cannot measure the velocity of all of the water particles within the cross section. Therefore, the Doppler meters are calibrated using a velocity index rating and channel cross section. The velocity index rating is developed by making discharge measurements at various flow rates over the expected range to be measured, and observing the average velocity recorded by the Doppler meter. One factor that can affect the velocity index rating is changes in channel cross section. This is true of both lined and unlined canals. Maintenance operations during the non-irrigation season typically result in irrigation canals that are relatively clean and weed free when deliveries begin. However, over the irrigation season, sediment, algae, and aquatic weed growth can change the cross section and flow characteristics. To obtain accurate data, Doppler meters such as the SonTek must be calibrated over the full range of flows and conditions being measured using proper indexing procedures.

The SonTek meters were installed by Reclamation on April 20, 2007. During the installation, cross sections were taken to be used by the device to calculate average flow rates during the specified intervals. The cross sections for both measurement sites were obtained with a SonTek RiverCat using Doppler technology at both sites. No additional cross section information was obtained at either location to account for changes in the cross sectional area due to sediment deposits or aquatic weed growth during the irrigation season. The upstream SonTek meter was calibrated on four occasions between August 7 and August 28, 2007. These calibrations occurred at flows ranging between 94 and 109 cubic feet per second (cfs). The downstream SonTek meter was calibrated on three occasions between August 10 and August 28, 2007, at flows ranging between 80 and 91 cfs. Depth and velocity data were recorded at 15-minute intervals. Data were downloaded by Reclamation each time the meter was calibrated and after the end of the irrigation season.

Data provided to the technical team by Reclamation included both raw data and an index equation used to calibrate and process the data at each location. Review of the data indicates both meters, at times, recorded negative velocities, indicating possible inconsistencies within the meters that might be attributed to errors in the cross sectional area or the development of the index equation. Positive flows recorded at the upstream SonTek meter ranged from 2 to 223 cfs and at the downstream SonTek meter from 0.5 to 191 cfs. Flows at both SonTek meters ranged well outside of the calibrated range. Table B-1 summarizes the monthly flows recorded by the Argonaut SL 3000 meters according to the data, cross section information, and indexing equations provided by Reclamation for the period May 18 through September 14, the period when water was being delivered to the study sites.

TABLE B-1
Year 2 – Lateral 14B Flow Measured by Doppler Meters (acre-feet)
Cooperative Water Measurement Study Report

Doppler Meter Location	Month					Total
	May 18–31	June	July	August	September 1–14	
Upstream	4,474	8,282	7,989	6,413	1,482	28,640
Downstream	3,757	6,745	6,680	4,937	735	22,854
Difference	717	1,537	1,309	1,476	747	5,786

Table B-2 provides a comparison of the deliveries to Lateral 14B based on the SonTek meter data with the deliveries to Sub-laterals 1B1 and 1B3 at Gates S11 and S16.

TABLE B-2
Year 2 – Comparison of Lateral 14B Flows (acre-feet)
Cooperative Water Measurement Study Report

Month	SonTek			Metered Delivery to 1B1 and 1B3			SonTek Minus (S11+S16)	Percent Difference
	Upstream	Downstream	Difference	S11	S16	Total		
May 18–31	4,474	3,757	717	266	365	631	86	12
June	8,282	6,745	1,537	297	763	1,060	477	31
July	7,989	6,680	1,309	319	606	925	384	29
August	6,413	4,937	1,476	227	585	812	664	45
September 1–14	1,482	735	747	78	282	360	387	52
Total	**28,640**	**22,854**	**5,786**	**1,187**	**2,601**	**3,788**	**1,998**	**35**

The metered deliveries to Sub-laterals 1B1 and 1B3 at Gates S11 and S16 account for the only diversions from Lateral 14B between the SonTek meters during Year 2. Therefore, the total flow measured at these locations was expected to be similar to that measured using the SonTek meters. As shown in Table B-2, the difference between the measurement methods is significant, and the relative difference increased over time. The discrepancy is much higher than would be explained by seepage losses, and might be partially due to changes in the cross sections at the SonTek measurement sites over the course of the season or the development of the indexing equations used for calibration of the SonTek meters.

Appendix C
Delivery Data Study Analysis

APPENDIX C

Delivery Data Study Analysis

This appendix provides additional analysis relative to the delivery data collected for Sutter Mutual Water Company (SMWC) and Reclamation District 1004 (RD 1004). This analysis includes estimated crop evapotranspiration (ETc) during the study period along with an evaluation of hydrologic conditions, cropping patterns, varietal shift, and commodity process during 2000 through 2006. A more detailed summary of the statistical analysis comparing changes in unit deliveries within SMWC and RD 1004 is also included.

Crop Evapotranspiration

Estimates of ETc were developed and compared with diversions and deliveries within SMWC for the study period. Three Sacramento Valley California Irrigation Management Information System (CIMIS) stations were used to provide estimated ETc requirements for the major crops grown within SMWC. The six major crops within SMWC include beans, corn, melons, rice, tomatoes, and sunflower, which comprise 87 to 94 percent of the irrigated acreage within SMWC.

SMWC is located between the Colusa, Nicholas, and Zamora Gage Stations (Stations 32, 30, and 27, respectively). Each CIMIS station calculates the reference evapotranspiration (ETo) by using several factors previously described in the Data Collection portion of the report. An average ETo value for SMWC was estimated using the ETo calculated by the three gage stations. The ETo is multiplied by the crop coefficient as defined in the *FAO Irrigation and Drainage Paper 56: Crop Evapotranspiration, Guidelines for Computing Crop Water Requirements*, to estimate the ETc requirement. The ETc is an estimate of the crop consumptive use which is then multiplied by the crop acreage to provide a company-wide estimate of individual and major crop consumptive use within SMWC. The crop coefficient approach for estimating crop consumptive use does not account for cultural practices for crop cultivation or system losses.

Figure C-1 compares the estimated crop water need within SMWC based on the ETc requirements within SMWC to the measured deliveries and diversions from the Sacramento River. The estimated consumptive use based on the ETc generally follows the diversion and delivery trends within SMWC. During times when the CIMIS gage stations were non-operational, CIMIS-defined regional and historical estimates of ETo were used to estimate ETc requirement. The regional and historical estimates of ETo do not take into account above-average temperatures recorded during any given year. During the 2006 irrigation season, above-average temperatures were experienced in the Sacramento Valley. Also for 2006, the Colusa and Zamora Gage Stations were non-operational. Therefore, regional and historical estimates as previously described were used to estimate the 2006 ETc within SMWC. The use of regional and historical ETo values to calculate ETc may account for the disproportional increase in consumptive use estimated for 2006, as compared to the Sacramento River diversions and deliveries. The difference between deliveries, diversions, and the estimated ETc may be attributed to several factors including, but not limited to, cultivation practices, conveyance loss, and evaporation. In addition, the ETc was generated using the six major crops grown within SMWC; and therefore, does not include estimated consumptive use for approximately 6 to 13 percent of the acreage planted to miscellaneous other crops during the study period. In addition, rice is the predominant crop within SMWC, and cultivation practice requires additional applied water for seed germination, as well as weed and pest control. The applied water for rice cultivation not consumptively used is either recirculated within SMWC or returned to the Sacramento River downstream of SMWC. A combination of all of the aforementioned factors accounts for the difference between the estimated ETc and deliveries and diversions within SMWC. The general trend in ETc is consistent with the recorded deliveries and diversions within SMWC during the study period.

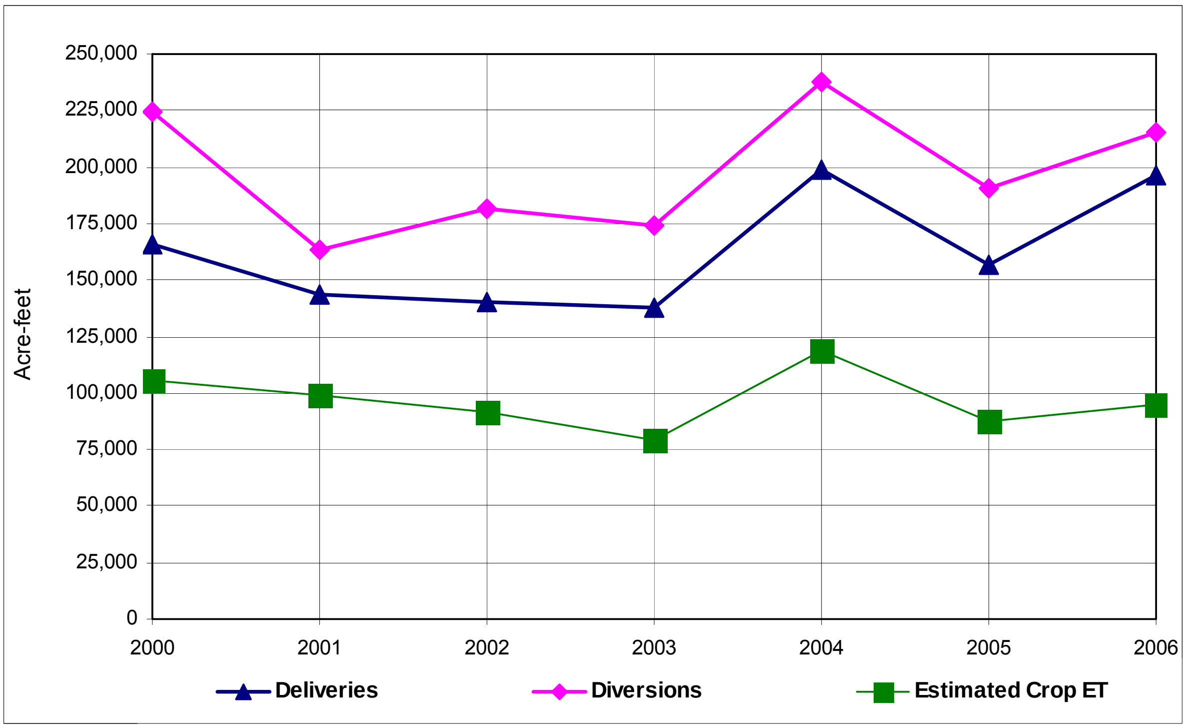

FIGURE C-1
DELIVERIES, DIVERSION, AND ESTIMATED CROP CONSUMPTIVE USE WITHIN SUTTER MUTUAL WATER COMPANY

Crop Patterns, Varietals, and Commodity Prices

The total irrigated acres during the study period varied from a low of approximately 30,100 in 2003 to a high of approximately 43,200 in 2004. As previously identified, the 2001, 2003, and 2005 transfer programs contributed to the lower irrigated acreage, deliveries, and diversions as compared to the year immediately preceding the transfer. The 2000 through 2006 study period shows a slight decreasing trend in the total irrigated acreage within SMWC, as seen on Figure C-2.

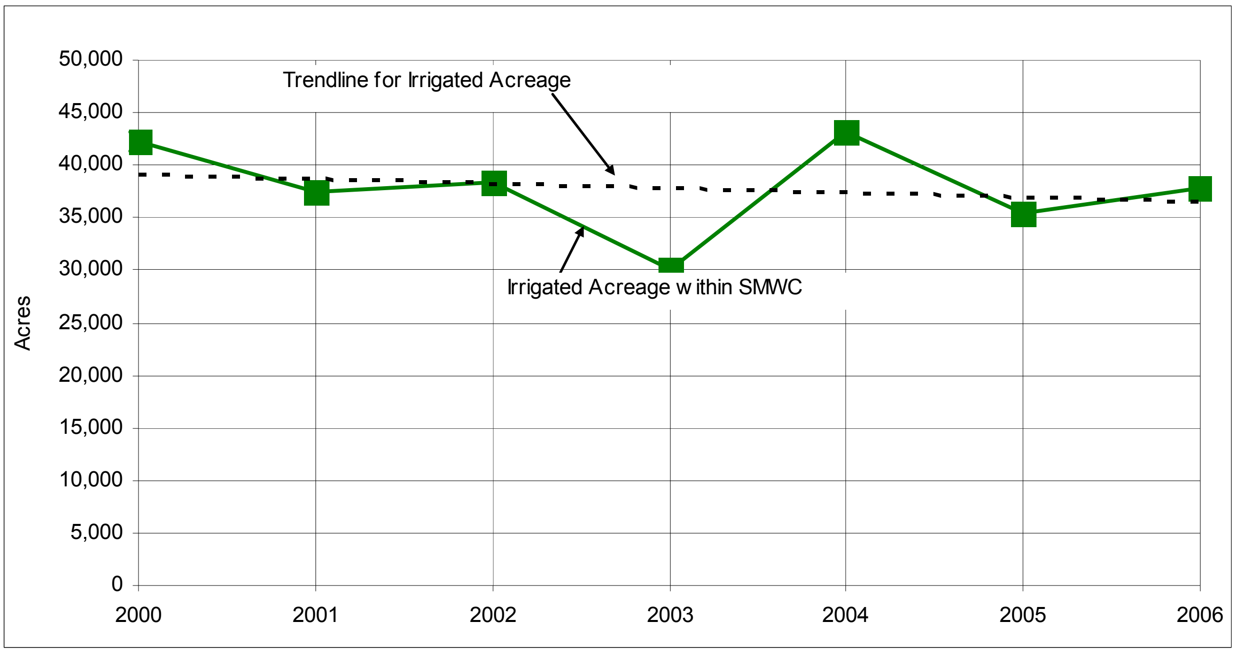

FIGURE C-2
IRRIGATED ACRES WITHIN SUTTER MUTUAL WATER COMPANY

Other crop-related factors were identified and analyzed to evaluate their potential effect on SMWC's diversions and deliveries. These factors include changes in cropping patterns, crop varieties, irrigation methods, and commodity prices. Cropping patterns within SMWC are identified on Figure C-3.

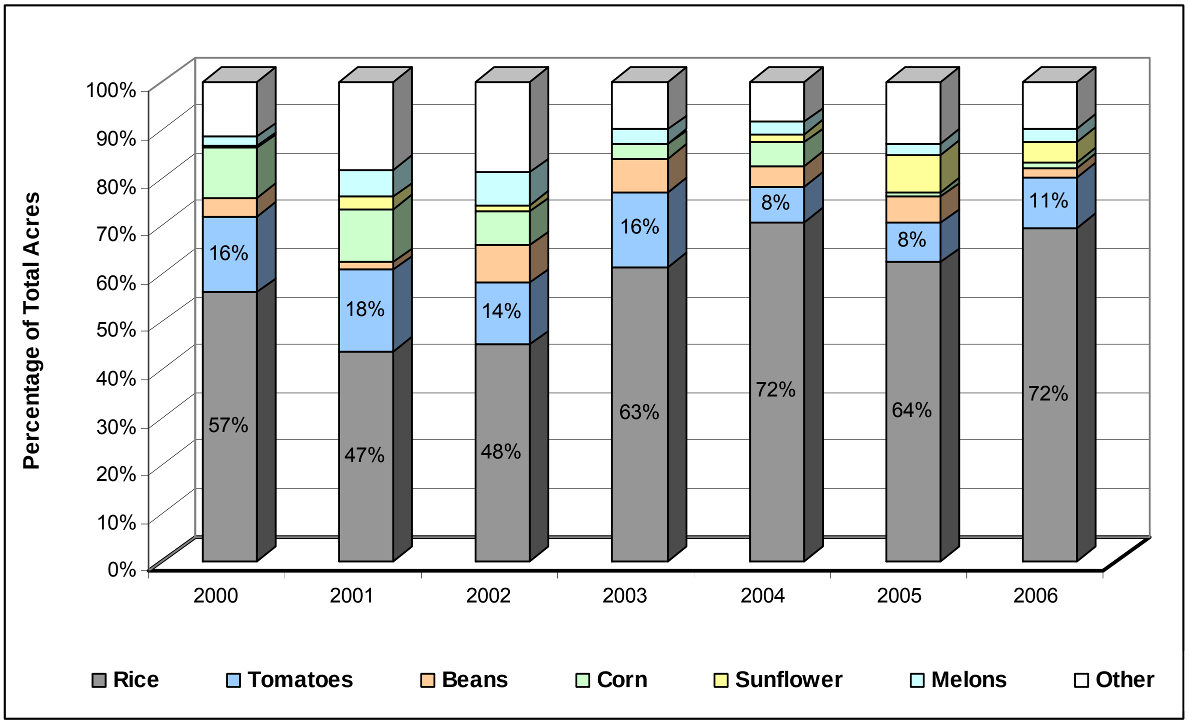

FIGURE C-3
SUTTER MUTUAL WATER COMPANY
CROPPING PATTERN

As Table C-1 indicates, the number of irrigated crops grown within SMWC has decreased during the study period. Shifts in commodity prices and the closures or relocation of processing facilities may account for the reduction in the number of crops grown within the service area. The result is a cropping pattern with less diversity and more acreage devoted to higher production value crops. Major crops within SMWC include rice, tomatoes, beans, corn, melons, and sunflower. These six crops comprise 87 to 94 percent of the total irrigated acres during the study period.

TABLE C-1
Sutter Mutual Water Company Summary of Delivery Data Analysis
Cooperative Water Measurement Study Report

Year	Total Irrigated Acres	Acre-feet of Water Delivered	Acre-feet of Water Diverted	Number of Crops Irrigated	Three Largest Irrigated Crops	Percentage of Acres planted to Rice
2000	42,200	165,700	224,800	15	Rice, tomatoes, corn	57
2001	37,500	143,500	163,500	15	Rice, tomatoes, corn	47
2002	38,300	140,300	181,500	14	Rice, tomatoes, beans	48
2003	30,100	137,400	174,500	13	Rice, tomatoes, beans	63
2004	43,200	199,200	237,500	11	Rice, tomatoes, melons	72
2005	35,500	156,600	190,900	13	Rice, tomatoes, sunflowers	64
2006	37,800	196,100	215,300	13	Rice, tomatoes, sunflowers	72

As shown on Figure C-3, rice is the predominant crop within SMWC. The figure also shows that the acreage planted to rice increased significantly following the 2002 irrigation season. The substantial increase in the price per cwt (100 pounds), as shown on Figure C-4, resulted in a significant increase in rice production within SMWC. The influence in cropping pattern as a result of commodity prices is further described below. Figure C-4 shows the statewide rice and tomato commodity prices for the study period. The figure identifies a substantial increase in the statewide commodity price for rice, approximately 155 percent, and the relatively consistent commodity price associated with tomatoes during the study period. As previously identified, as rice prices increased during the study period, fewer acres were planted to other crops with a relatively lower commodity price.

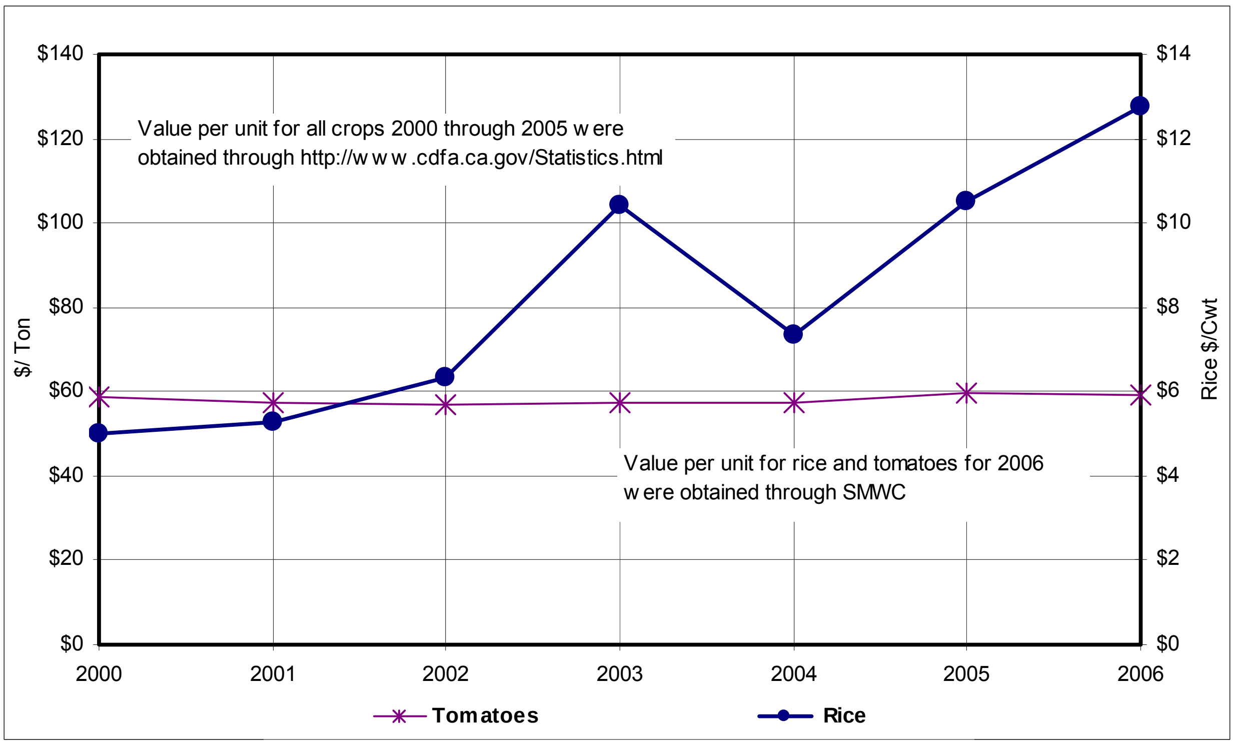

FIGURE C-4
STATEWIDE COMMODITY PRICES FOR RICE AND TOMATOES

Rice

Rice is the predominant crop in SMWC, comprising 47 to 72 percent of the production acreage during the study period. As shown on Figure C-4, the commodity prices for rice have steadily increased since 2000. In 2004, because of an overall increase in rice production, the crop experienced a slight decrease in value ($7.34/100 pounds); however, in 2005, the price jumped 43 percent from the prior year, resulting in a significant increase in production value[1]; and subsequently, more acreage was planted for rice production. Statewide cropping trends were reviewed to evaluate whether rice production within SMWC may have been influenced by the change in pricing structure or whether the trends were consistent with statewide rice production and may have been driven by the market value. As shown on Figure C-5, changes in rice production acreage within SMWC are consistent

[1] California Agriculture Resource Directory, 2006, http://www.cdfa.ca.gov/files/pdf/card/ResDir06_FieldFlowerProd.pdf

with statewide trends; and therefore, the significant increase in rice production is more likely attributable to the increased commodity price of rice.

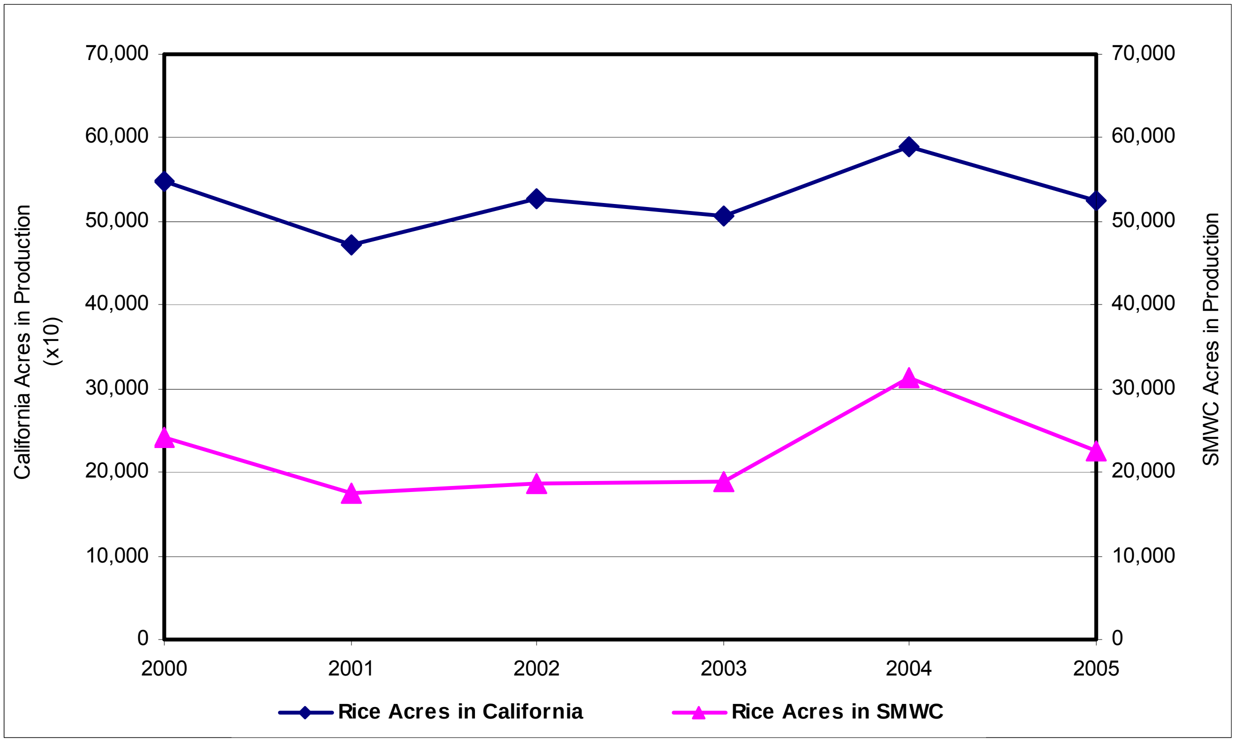

FIGURE C-5
COMPARISON OF CALIFORNIA RICE PRODUCTION WITH SUTTER MUTUAL WATER COMPANY

Of the crops grown within SMWC, rice has the highest delivery requirement; and therefore, accounts for the majority of diversions and deliveries of surface water. Figure C-6 shows the changes in the delivery and diversion patterns, which correlate to the changes in the number of acres planted to rice within SMWC. As shown on Figure C-6, the rice production within SMWC closely follows the general trends in SMWC diversions and deliveries. According to discussions with SMWC's general manager, irrigation methods used for rice cultivation changed slightly over the study period, with an increase in the use of the Leathers Method. Traditionally, rice fields are flooded and seeded, and water levels are maintained throughout the growing season. The Leathers Method involves initially flooding the field and seeding the flooded field. After the seed is established, the field is drained and then re-flooded after the rice plant begins to stand. Use of the Leathers Method results in a change in the timing of water delivery compared with traditional methods; however, the total quantity delivered to the field and used by the crop is essentially the same. According to SMWC's general manager, the increase in the use of the Leathers Method is assumed to be consistent with the increase in rice acreage. Irrigation practices for other commodities grown within the SMWC remained relatively consistent. Additionally, SMWC's general manager indicated that changes in some rice herbicide application and cultural techniques may account for some increase in applied water within SMWC.

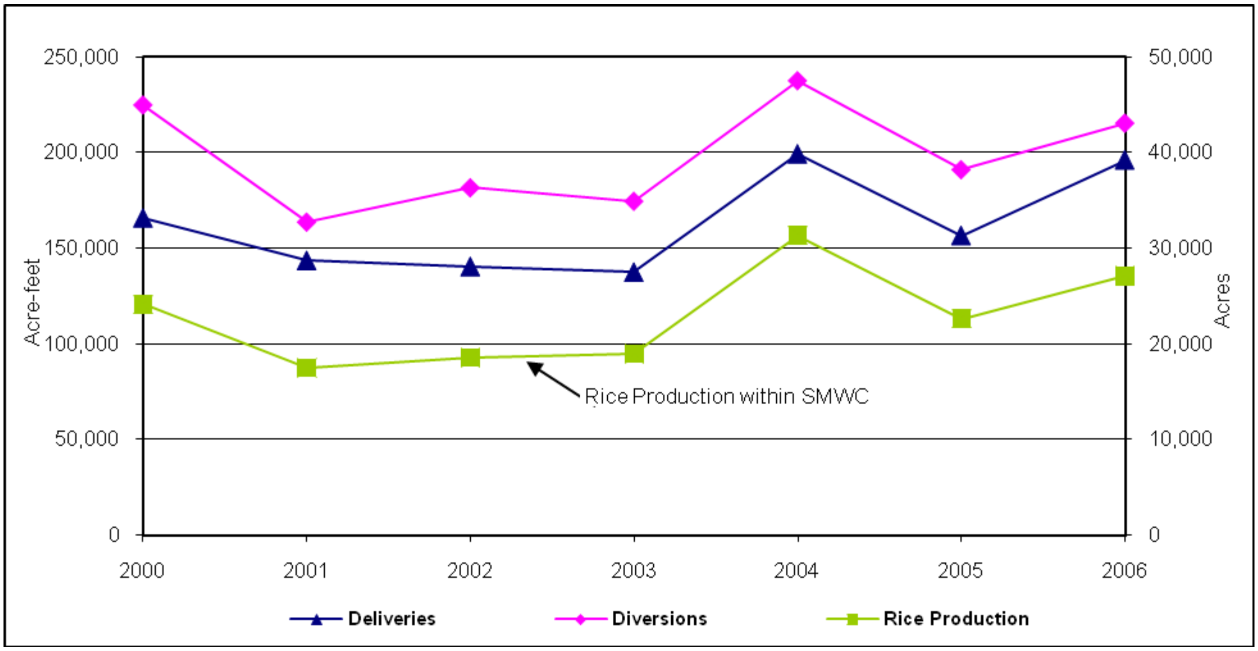

FIGURE C-6
COMPARISON OF DELIVERIES AND DIVERSIONS WITH RICE PRODUCTION ACREAGE WITHIN SUTTER MUTUAL WATER COMPANY

Tomatoes

Tomatoes are the second largest single crop grown within SMWC. As shown on Figure C-7, the percentage of lands devoted to tomato production has decreased during the study period from 18 percent to approximately 8 percent of the total irrigated acreage within SMWC. Following the 2003 growing season, the contracted tomato acreage throughout the state decreased because of changes in cannery operations and cannery closures. The decrease in tomato production acreage within SMWC may also be linked to a decrease in tomato processing contracts in Northern California, with many more contracts being awarded to growers in the San Joaquin Valley. In 2006, the contracted acreage for canning tomatoes in California increased 10 percent over the previous year, which might account for the slight increase in tomato production within SMWC during that year[2]. A review of regional and state tomato production trends indicates that tomato production is driven by commodity prices and regional contracts. Tomato production within SMWC is consistent with statewide and regional production trends, and does not appear to be linked to the change in SMWC's pricing structure.

[2] California League of Food Processors, http://www.clfp.com/tomato/ContractIntentions/May2006_2.pdf

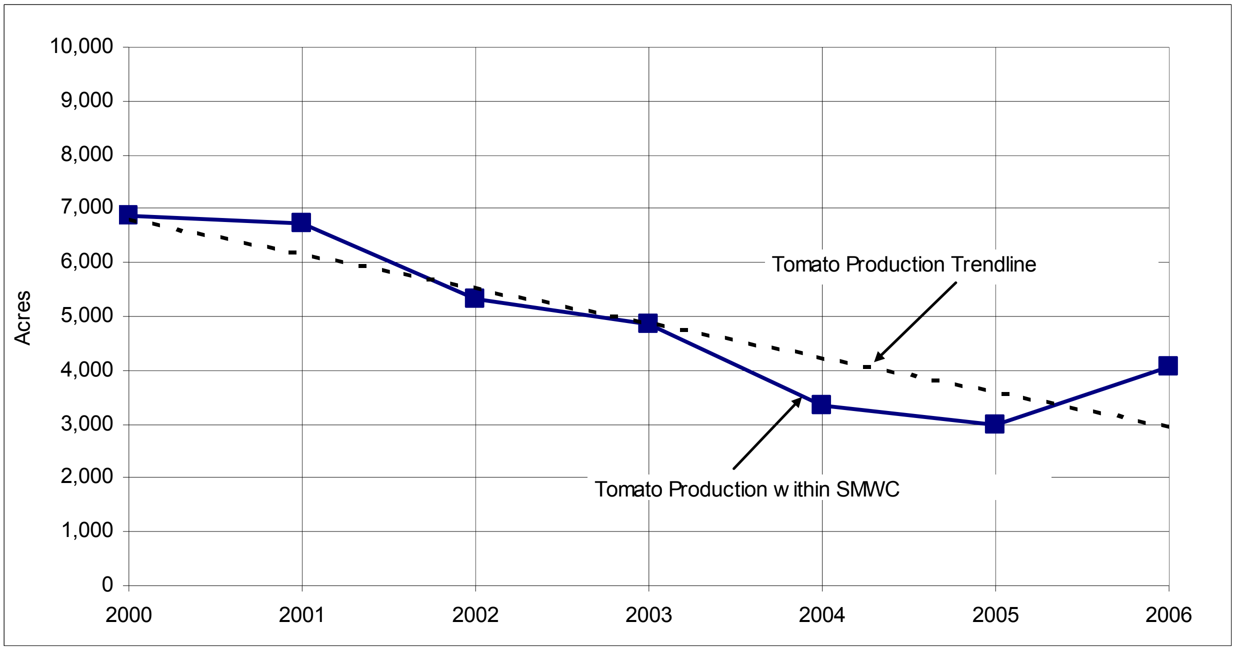

FIGURE C-7
TOMATO PRODUCTION WITHIN SUTTER MUTUAL WATER COMPANY

Other Crops

Within SMWC, crops other than rice and tomatoes account for relatively small percentages of the overall cropping pattern. Figure C-8 shows the planted acreage for the next four largest crops, by acreage, grown within SMWC. As the figure shows, with the exception of sunflower, these crops show a decreasing trend in acreage during the study period. This decrease in acreage can be accounted for by the general increase in rice acreage. Table C-2 identifies the value per unit for the other major crops irrigated within SMWC. The 2006 value per unit has not been published by the United States Department of Agriculture; and therefore, is unavailable for beans, corn, and melons. Commodity prices for beans, corn, and sunflower increased during the study period, and the price for melons has generally decreased, as shown in Table C-2. As shown on Figure C-8, overall production acreage for beans, corn, and melons decreased during the study period. Sunflower showed an increase in production during the same period, which is likely due to the increase in the commodity price for this crop, as shown in Table C-2. The water needs of sunflowers are generally only supplemented with irrigation water within SMWC; therefore, changes in production acreage would not cause a significant change in diversions or deliveries. In general, irrigated crops besides rice and tomatoes within SMWC do not account for a significant amount of diversions and deliveries. Cropping patterns of other crops grown within SMWC are driven by market value and follow the same trends of regional and state production.

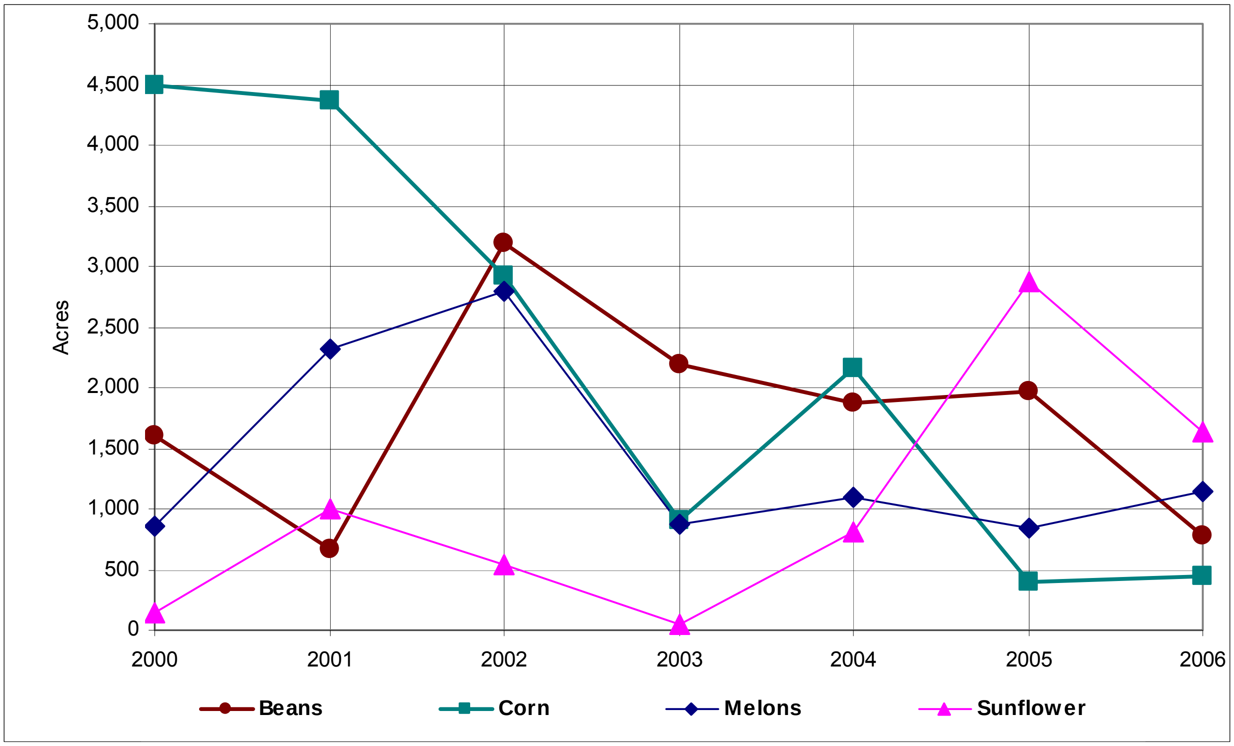

FIGURE C-8
OTHER MAJOR IRRIGATED CROP ACREAGES WITHIN SUTTER MUTUAL WATER COMPANY

TABLE C-2
Value per Unit of Irrigated Crops Grown within Sutter Mutual Water Company
Cooperative Water Measurement Study Report

	Value per Unit			
Year	Beans ($/100 pounds)	Corn ($/ton)	Melons ($/100 pounds)	Sunflower Oil ($/pound)
2000	26.80	17.09	18.60	15.89
2001	31.20	21.75	19.70	23.25
2002	33.30	21.95	16.80	33.11
2003	35.30	21.70	17.50	33.41
2004	36.90	24.31	17.70	43.71
2005	40.40	26.85	13.00	40.64
2006				58.03

As previously mentioned, the increase in commodity prices for rice resulted in more acreage being planted for rice cultivation, which partially explains the decreasing trend in acreage for the other irrigated crops within SMWC. Because of cultivation practices that limit irrigation frequency and volume for these crops and their relatively small percentage of production acreage, these other crops do not significantly affect total deliveries and annual diversions by SMWC. Rice commodity prices, and as a result, cropping patterns within SMWC, are believed to have the greatest potential effect on diversions and deliveries within SMWC.

Hydrologic Conditions and Weather Data

Table C-3 identifies the year type for each year of the study period according to the Sacramento Valley Water Year Type Index (40-30-30 Index).

TABLE C-3
Sacramento Valley Water Year Type Index
Cooperative Water Measurement Study Report

Year	Sacramento Valley Water Year Type Index (40-30-30)	SMWC Contract Supply (acre-feet)
2000	Wet	267,900
2001	Dry	267,900
2002	Dry	267,900
2003	Above normal	267,900
2004	Below normal	267,900
2005	Below normal	226,000
2006	Dry	226,000

SMWC received a full supply under its contract with the Bureau of Reclamation (Reclamation) in each year of the study period. However, as indicated in Table C-3, the supply available to SMWC under its contract changed beginning in 2005. As with all Sacramento River Settlement Contractors (SRSC), SMWC's contract with Reclamation was renewed in March 2005. During the renewal process, the Central Project Water portion of the contract supply was reduced by 41,900 acre-feet. This, coupled with an increase in rice acreage, has resulted in greater recirculation of tailwater within SMWC.

Precipitation in the Sacramento Valley during 2000 through 2006 remained within the normal range, with the highest rainfall occurring in 2000 and 2005. Figure C-9 identifies annual and irrigation-season precipitation during the study period. Late spring rains in 2003 may account for the slight decrease in deliveries during that year. Overall, the annual rainfall near SMWC did not vary significantly.

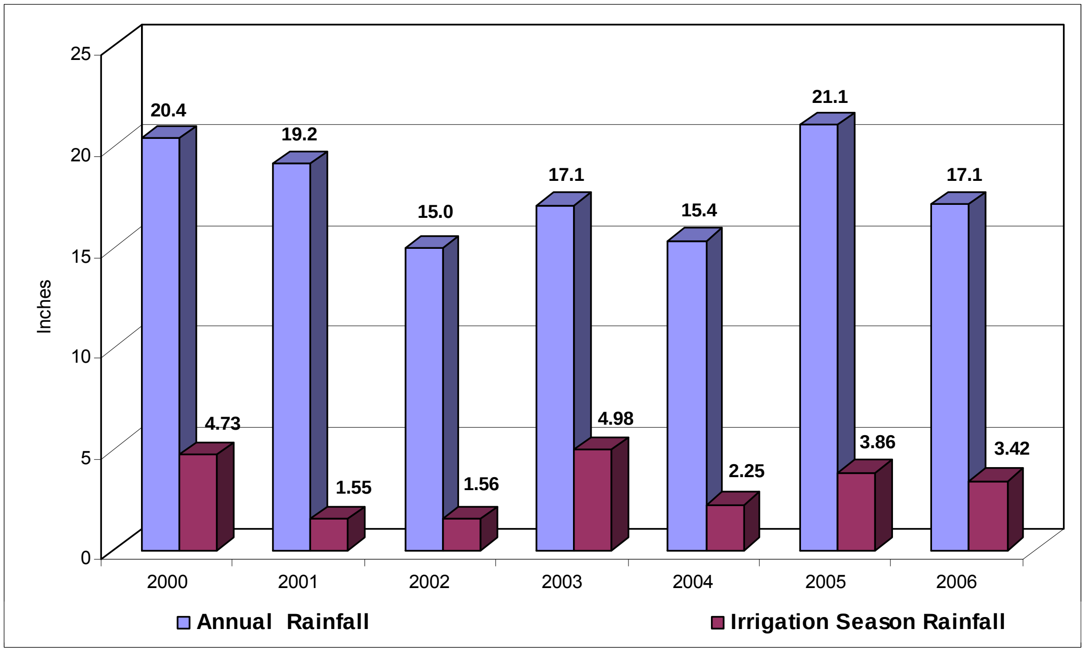

FIGURE C-9
AVERAGE ANNUAL AND IRRIGATION-SEASON (APRIL – OCTOBER) PRECIPITATION AT THE NICHOLAS GAGE STATION (STATION #30)

Temperatures for the region were generally within the normal range. However, the Sacramento Valley experienced above-average maximum temperatures during July and August 2001 and 2006, as shown on Figure C-10. In addition, 2006 experienced a higher number of consecutive days where the maximum temperature exceeded 100 degrees Fahrenheit. The above-average and consecutive number of days where temperatures exceeded 100 degrees Fahrenheit during the irrigation season may partially explain the increase in deliveries during the 2006 irrigation season.

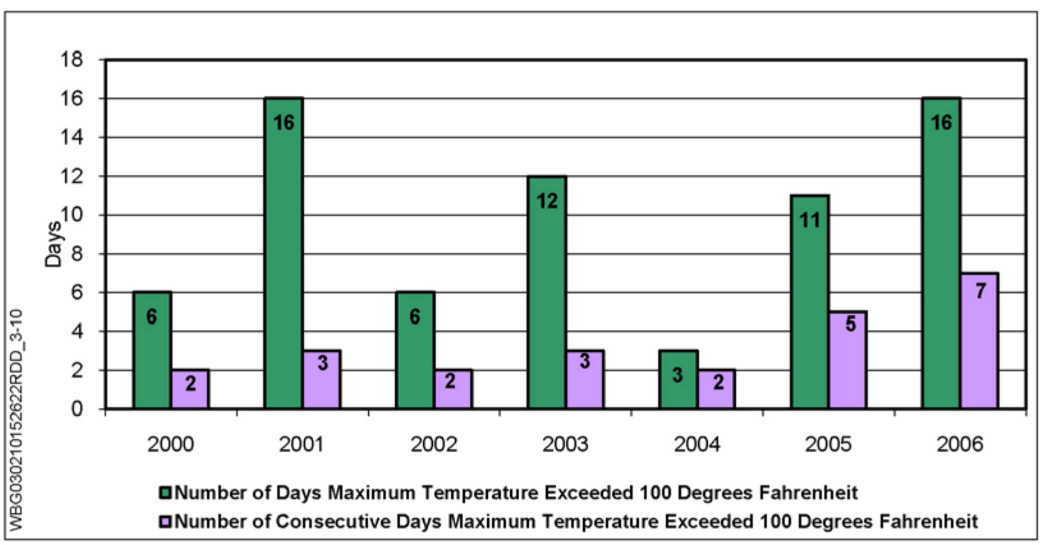

FIGURE C-10
AVERAGE DAILY TEMPERATURE DURING THE STUDY PERIOD

Statistical Analysis

A statistical analysis was performed to determine the variances in individual field unit deliveries within SMWC and RD 1004. Field-level unit delivery data for both RD 1004 and SMWC were analyzed. Outliers to account for the discrepancies in data as described below were determined using the crop consumptive use requirements for rice and SRSC district manager and study team input. The average consumptive use requirement for rice within the Sacramento Valley is approximately 3.3 acre-feet per acre (af/ac). Because this is an average value, and because the consumptive use requirement does not account for cultivation practices associated with rice, the study team used a conservative value of 3.5 af/ac as the lower limit for determining outliers. The upper limit was determined by analyzing the number of outliers and variance of the data set values. The study team identified 12 af/ac, approximately twice the quantity typically delivered to meet the applied water requirements for rice, as the upper limit for outlier selection. The analysis was conducted using several different limits for outlier selection. The results of the various scenarios showed little or no change in average or median unit deliveries within the two districts. Therefore, the selection of 3.5 af/ac and 12.0 af/ac as the upper and lower limits, respectively, was determined to be reasonable by the study team.

To perform a statistical analysis, the data sets were analyzed using box and whisker plots to verify the assumption of normal distribution. Figures C-11 and C-12 show the distribution of the field-level unit deliveries for rice in SMWC and RD 1004, respectively. The two data sets are robust and generally indicate normal distribution.

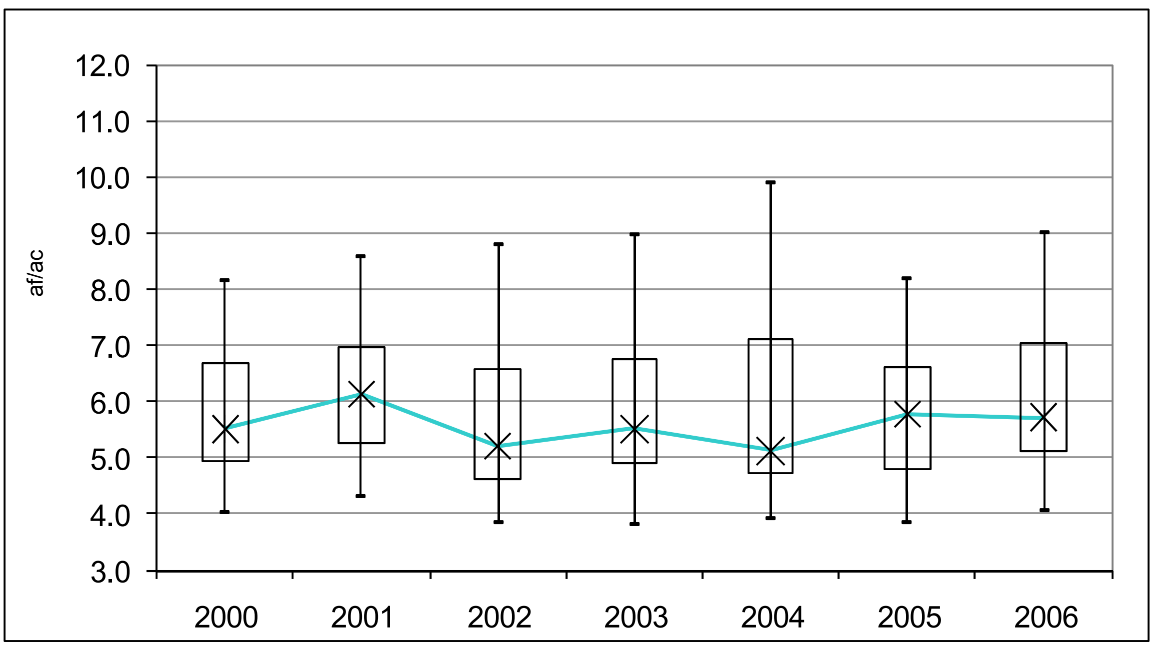

FIGURE C-11
BOX AND WHISKER PLOT OF SUTTER MUTUAL WATER COMPANY
FIELD-LEVEL UNIT RICE DELIVERY

A comparison of Figures C-11 and C-12 indicates a greater variance in the median field-level unit rice deliveries associated with RD 1004.

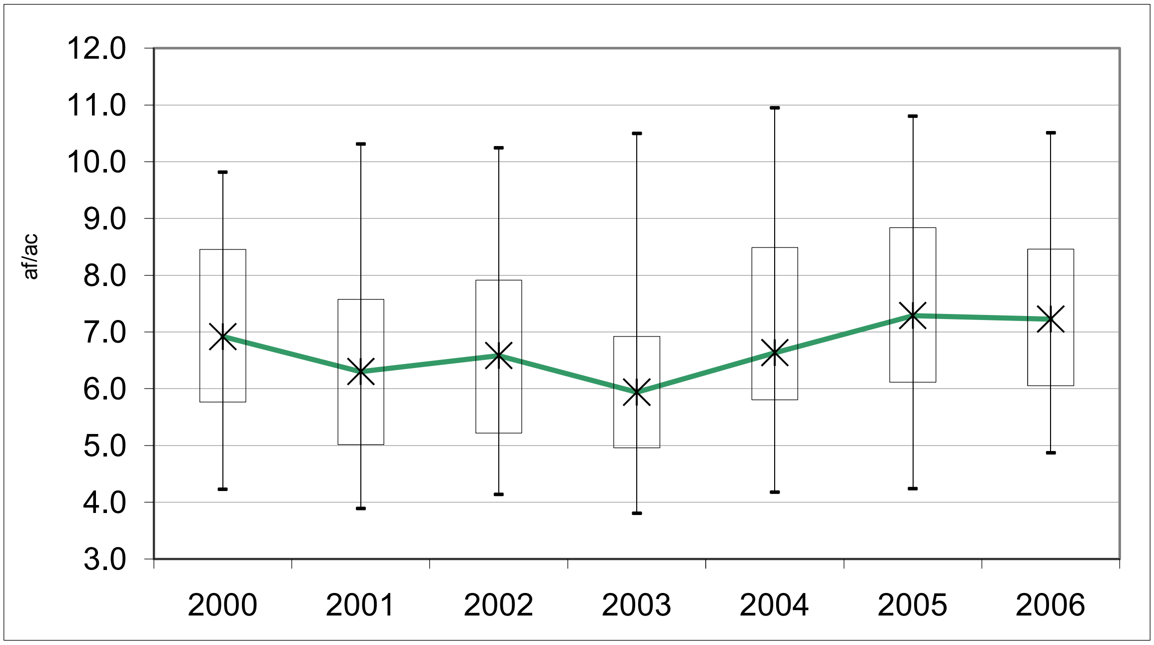

FIGURE C-12
BOX AND WHISKER PLOT OF RECLAMATION DISTRICT 1004
FIELD-LEVEL UNIT RICE DELIVERY

Descriptive statistics were calculated and used to compare field-level unit deliveries within SMWC and RD 1004. Tables C-4 and C-5 show the population size (number of fields), number of outliers within the data sets, the percentage of outliers within the given data set, and the average field size within each service area. As shown on Figures C-13 and C-14, there appears to be no statistically significant difference in the mean and median of the two sample populations/districts, which further indicates normal distribution of the data set.

A comparison of the average field size for each year of the study indicates that the fields within both service areas are similar in size, with an approximate 10 percent larger average field size within RD 1004 compared to SMWC in all years, except 2000. Although there is some variation from year to year, the overall percentage of outliers within each data set during the study period is also similar.

T-Test

A two-tailed, pooled-variance t-test was performed to determine whether there is a significant difference between the means of two populations for three scenarios further described below (see Table C-6). The null hypothesis (H_o) for each test scenario hypothesizes that the mean difference between the two populations does not significantly differ. For a given level of significance, in a two-tailed test, the H_o is rejected, identifying a statistically significant difference between the data sets, if the computed t-test statistic exceeds the upper tailed critical value or falls below the lower tailed critical value from the t distribution. In addition, the H_o is rejected if the determined p-value is less than the determined level of significance.

TABLE C-4
Sutter Mutual Water Company Unit Rice Delivery Descriptive Statistics
Cooperative Water Measurement Study Report

Year	Standard Deviation	Mean	Median	Maximum	Minimum	Population Size	Number of Outliers within Population	Percentage of Outliers within Population	Average Field Size within SMWC (acres)
2000	1.4	5.9	5.5	11.2	3.5	152	25	16	152
2001	1.4	6.3	6.1	11.6	3.7	114	12	11	150
2002	1.5	5.7	5.2	11.6	3.6	129	16	12	143
2003	1.6	5.9	5.5	10.6	3.5	138	11	8	133
2004	1.8	6.1	5.1	12.0	3.5	201	37	18	147
2005	1.5	5.9	5.8	11.9	3.5	146	23	16	146
2006	1.6	6.2	5.7	11.8	3.6	188	15	8	138

TABLE C-5
Reclamation District 1004 Unit Rice Delivery Descriptive Statistics
Cooperative Water Measurement Study Report

Year	Standard Deviation	Mean	Median	Maximum	Minimum	Population Size	Number of Outliers within Population	Percentage of Outliers within the Population	Average Field Size within RD 1004 (acres)
2000	1.8	7.0	6.9	10.1	3.6	73	5	7	153
2001	2.0	6.6	6.3	11.7	3.7	67	10	15	164
2002	2.0	6.8	6.6	11.7	3.6	66	11	17	167
2003	1.9	6.3	5.9	11.5	3.5	68	9	13	158
2004	2.0	7.1	6.6	11.4	3.6	70	6	9	156
2005	2.0	7.4	7.3	11.7	3.6	64	9	14	167
2006	1.7	7.3	7.2	11.3	4.2	67	10	15	162

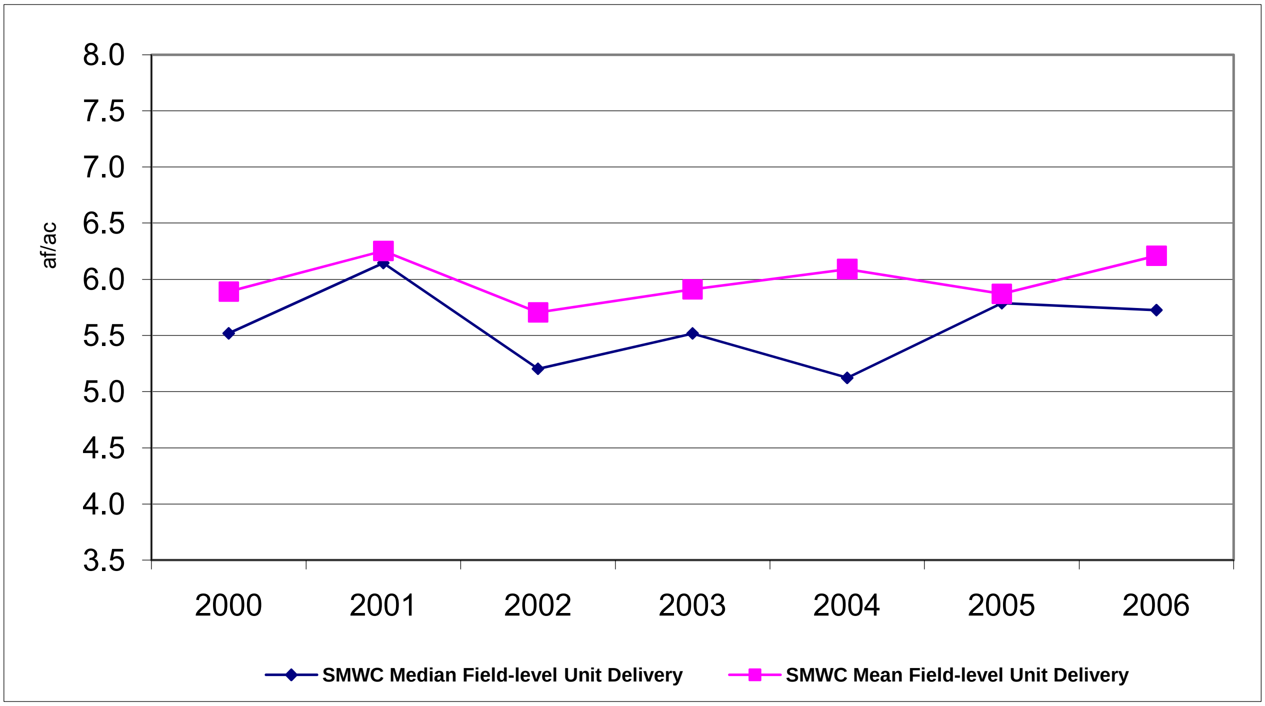

FIGURE C-13
DISTRICT-WIDE UNIT RICE DELIVERY MEAN AND MEDIAN COMPARISON
OF SUTTER MUTUAL WATER COMPANY

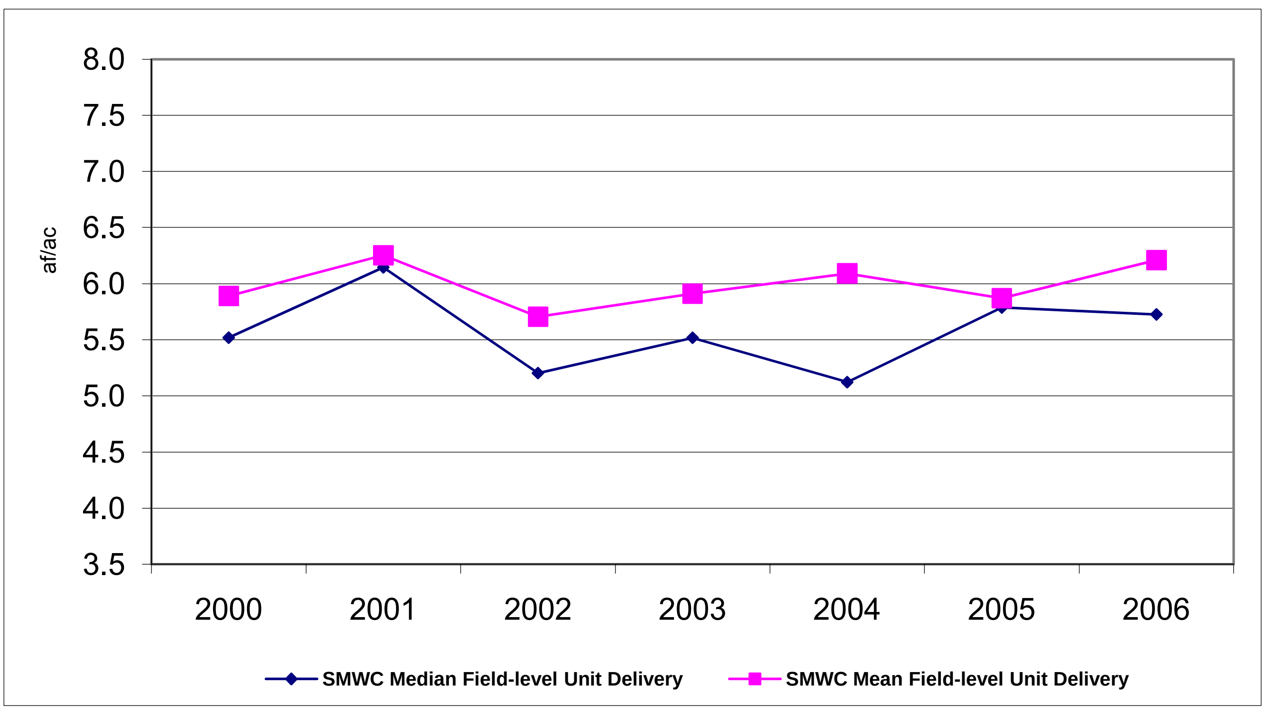

FIGURE C-14
DISTRICT-WIDE UNIT RICE DELIVERY MEAN AND MEDIAN COMPARISON
OF RECLAMATION DISTRICT 1004

In Scenario 1, the two population samples were defined as SMWC's unit rice deliveries for the period 2000 through 2002 (the period prior to the pricing structure change) and unit rice deliveries for the period 2003 through 2006 (the period after the change in pricing structure).

TABLE C-6
Scenario 1 – Mean Difference Comparison between the Pre- and Post-billing Structure Change within SMWC
Cooperative Water Measurement Study Report

	Variable 1	**Variable 2**
Mean	5.94	6.04
Variance	2.16	2.70
Observations	395	673
Pooled Variance	2.50	
Hypothesized Mean Difference	0.00	
Df	1,066	
t Stat	-1.04	
P(T≤t) One-tail	0.15	
t Critical One-tail	1.65	
P(T≤t) Two-tail	0.30	
t Critical Two-tail	1.96	

As identified in Table C-6, at a 0.05 level of significance, Scenario 1 indicates that H_o is not rejected because the computed t statistic (t Stat = -1.04) falls between the upper tailed and lower tailed statistic (t critical for two-tailed test = ± 1.96), within the region of non-rejection, and the p-value (p = 0.30) exceeds the level of significance. The results of the t-test (see Table C-6) performed for Scenario 1 indicated there is no statistically significant difference in the unit rice deliveries to the fields within SMWC resulting from the change in pricing structure.

Additional t-tests, similar to Scenario 1, were performed comparing the unit rice deliveries within SMWC and RD 1004. Scenario 2 (see Table C-7) compared the unit rice deliveries within the two service areas for the years 2000 through 2002, the 3-year period prior to the change in pricing structure. Scenario 3 (see Table C-8) compared the unit deliveries for the 4-year period after the pricing structure change, 2003 through 2006. As shown in Tables C-7 and B-8, the results of these analyses indicate a statistically significant difference in the unit deliveries within the two service areas. However, the analysis does not provide insight as to the impact on unit rice deliveries within SMWC as a result of the change in pricing structure.

TABLE C-7
Scenario 2 – Pre-billing Structure Mean Difference Comparison between Sutter Mutual Water Company and Reclamation District 1004
Cooperative Water Measurement Study Report

	Variable 1	Variable 2
Mean	5.94	6.81
Variance	2.16	3.67
Observations	395	206
Pooled Variance	2.67	
Hypothesized Mean Difference	0	
Df	599	
t Stat	-6.24	
P(T≤t) One-tail	0.00	
t Critical One-tail	1.65	
P(T≤t) Two-tail	0.00	
t Critical Two-tail	1.96	

TABLE C-8
Scenario 3 – Post-billing Structure Mean Difference Comparison between Sutter Mutual Water Company and Reclamation District 1004
Cooperative Water Measurement Study Report

	Variable 1	Variable 2
Mean	6.04	7.03
Variance	2.70	3.82
Observations	673	269
Pooled Variance	3.02	
Hypothesized Mean Difference	0	
Df	940	
t Stat	-7.87	
P(T≤t) One-tail	0.00	
t Critical One-tail	1.65	
P(T≤t) Two-tail	0.00	
t Critical Two-tail	1.96	

Figure C-15 shows the mean field-level unit deliveries for the two sample populations during the study period. As indicated in the t-test comparison, the mean unit delivery values are significantly different; however, field-level unit rice deliveries for both are within the typical range of the rice cultivation unit delivery requirements. The figure shows a generally increasing trend in the mean unit rice delivery trends within both the SMWC and RD 1004 service areas. Figure C-15 also indicates the average unit rice delivery within RD 1004 is slightly higher in all study years and has a greater increasing trend in unit rice deliveries than within SMWC.

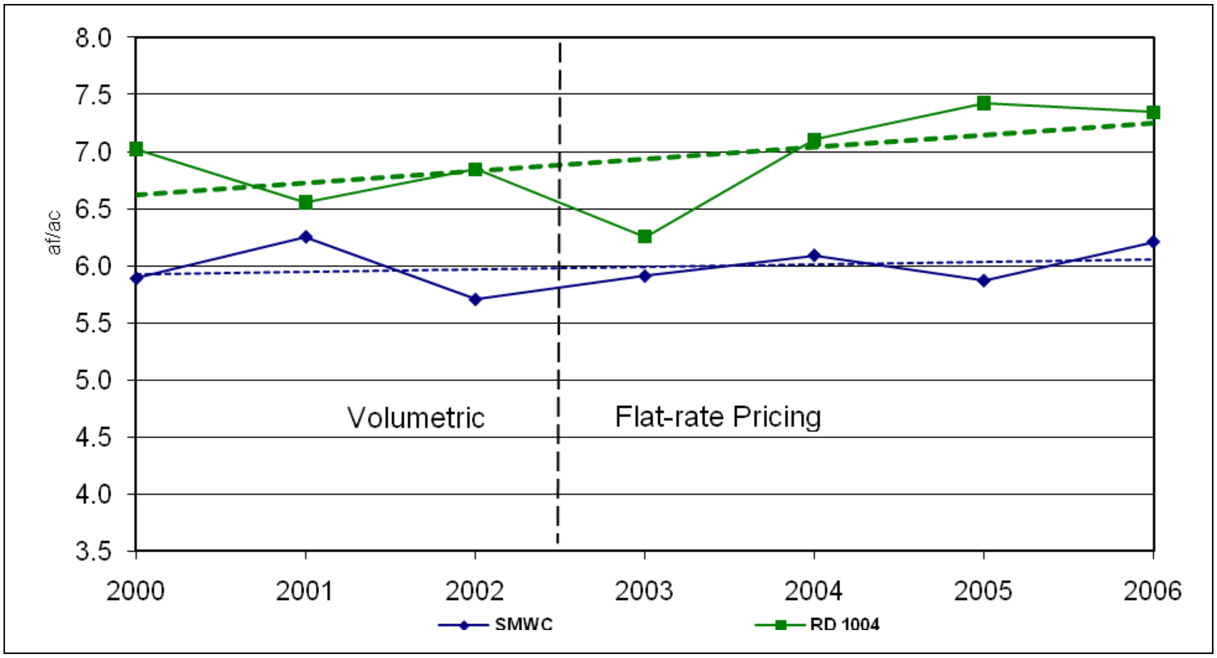

FIGURE C-15
FIELD-LEVEL AVERAGE UNIT RICE DELIVERY COMPARISON

Appendix D
Interview Questions

GENERAL MANAGERS

Focus: Policy issues affecting water deliveries and diversions, grower opinions from their perspective

Subject	Q's for Districts that Do *Not* Price Water by Volume	Q's for Districts that Price Water by Volume (turnout measured)
Current Practices	How do you currently measure water in your district? At what points? Is there a reason for choosing that particular method and location? What incentive would have you consider an alternative method (or would you?)	(same)
	Do you record measurement information? If so, what do you use it for? If not, can you envision uses for measurement information, if it was available?	(same)
	How is water ordered? Does this depend on the time of year or conditions? Describe the process from the time water is ordered to the time water is delivered. How much time usually passes between the time you receive the order and the time it is delivered?	(same)
	Do growers receive a statement describing their water use? How often? Is a grower's water use information readily available to them? How is this information made available?	(same)
	Is there a formal written policy on delivery allocations, water operations, and shortage criteria? How was that policy developed?	(same)
Pricing and Policy	How do you price water? How do you decide on a particular price? What drives changes to water pricing? How do you bill your customers for water?	(same)
	Has your pricing and measurement policy changed? When did it change and why?	(same)
	How do you manage operational spills? For example, if a grower orders water but does not take it, what happens to that water? Is the grower charged for the water?	(same)
Appropriate Level of Water Measurement	What is your experience with water measurement? Do you have experience with measurement in other districts? If so, how has that knowledge been useful in your district?	(same)
	Would turnout-level measurement help you manage your district on a day-to-day basis? How would you use this information?	Does turnout-level measurement help you manage your district on a day-to-day basis? How?
	How does the number of measurement devices in your system affect the effort your staff puts into O&M activities? What O&M activities are affected?	How have turnout water measurement devices affected the effort your staff puts into O&M activities? What O&M activities are affected?

GENERAL MANAGERS

Focus: Policy issues affecting water deliveries and diversions, grower opinions from their perspective

Subject	Q's for Districts that Do *Not* Price Water by Volume	Q's for Districts that Price Water by Volume (turnout measured)
	Do you think that measuring water at a turnout level would influence the types of crops grown in the district? If so, what would change?	Do you think that the level of water measurement has influenced the types of crops grown in your district? Have related changes in water price influenced the crops grown?
	How would changing to a different level of measurement (lateral, sub-lateral, turnout, etc.) affect your district's operations? Do you think it would change the total diversions from the river? How would the timing of diversions be different? How would drain flows be affected? Would you expect O&M costs to be affected? Can your current rates pay for it?	*(If recently changed to turnout level measurement)* Since you've changed to measuring water at the turnout level, how has that affected your district's operations? Has it changed the total diversions from the river, or the timing of those diversions? Have there been any changes to your drain flow? Have O&M costs been affected? Has anything else changed?
	Regardless of budget, is there measurement equipment that you'd like to see installed in the district? Is there alternative equipment to what you currently use that you might prefer?	(same)
Training	Would you provide water measurement/management training for your field staff it was available?	(same)

FIELD SUPERINTENDENT/OPERATIONS MANAGER

Focus: District-level operations and coordination between the district and ditch tenders, grower opinions from their perspective

Subject	Q's for Districts that Do *Not* Price Water by Volume	Q's for Districts that Price Water by Volume (turnout measured)
Current Practices	Describe your daily activities involving water management. Can you briefly take us through a typical day/week? How do you manage water on a daily basis?	(same)
	How is water ordered? Does this depend on the time of year or conditions? Describe the process from the time water is ordered to the time water is delivered. How much time usually passes between the time you receive the order and the time it is delivered? What is your role in this process?	(same)
	How do you use water measurement data in your daily activities? What types of decisions are made based on these findings?	(same)
	How is water apportioned for simultaneous orders along a lateral below the last point of measurement?	How is water apportioned for simultaneous orders along a lateral?
	What are the biggest challenges in delivering water?	(same)
Appropriate Level of Water Measurement	What is your experience with water measurement? Do you have experience with measurement in other districts? If so, how has that knowledge been useful in your district?	(same)
	Would a different level of measurement (lateral, turnout, etc.) assist you in your daily operations? What level of measurement would be the most helpful? How?	(same)
	If measurement devices were installed on each turnout, would you use these to help with your duties? How would you use this information? Would measurement at a different level be more helpful?	How has turnout measurement affected your daily activities? Does turnout-level measurement help you manage your district on a day-to-day basis? How?
	How has the number of measurement devices in your system affected the effort your staff puts into O&M activities? What O&M activities are affected?	How have water measurement devices at each turnout affected the effort your staff puts into O&M activities? What O&M activities are affected?
	How do you think that growers would respond to a different level of water measurement? Do you think it would change their operations or the way they irrigate?	How do you think that growers have responded to measuring water at the turnout level? From your perspective, did it change their operations? Do you think they paid closer attention to the water they used?

FIELD SUPERINTENDENT/OPERATIONS MANAGER

Focus: District-level operations and coordination between the district and ditch tenders, grower opinions from their perspective

Subject	Q's for Districts that Do *Not* Price Water by Volume	Q's for Districts that Price Water by Volume (turnout measured)
	Regardless of budget, is there measurement equipment that you'd like to see installed in the district? Is there alternative equipment to what you currently use that you might prefer?	(same)
Training	What type of training (if any) would you like to see made available for your staff?	(same)

DITCH TENDER

Focus: Daily canal, lateral, and turnout operation; coordination and communication with the district, other ditch tenders, and growers

Subject	Q's for Districts that Do *Not* Price Water by Volume	Q's for Districts that Price Water by Volume (turnout measured)
Current Practices	Describe your daily activities involving water management. How do you manage water on a daily basis?	(same)
	How is water ordered? Does this depend on the time of year or conditions? Describe the process from the time water is ordered to the time water is delivered. How much time usually passes between the time you receive the order and the time it is delivered? What is your role in this process?	(same)
	Who is responsible for opening/closing/adjusting turnout gates? Does the grower every change the turnout on their own?	(same)
	How is water measured? How do you determine how much water is flowing in a canal? A turnout? How often is this information recorded? Can the grower monitor his/her own water use?	(same)
	Do you use water measurement data in your daily activities? What data do you use and how do you use it?	(same)
	How is water apportioned for simultaneous orders along a lateral below the last point of measurement?	How is water apportioned for simultaneous orders along a lateral?
	What are the three biggest challenges in delivering water?	(same)
Appropriate Level of Water Measurement	What is your experience with water measurement? Do you have experience with measurement in other districts? If so, how has that knowledge been useful in your district?	(same)
	Would a different level of measurement (lateral, turnout, etc.) assist you in your daily operations? What level of measurement would be the most helpful?	(same)
	If measurement devices were installed on each turnout, would you use these to help with your duties? How would you use this information? Would measurement at a different level be more helpful?	How has turnout measurement affected your daily activities? Does turnout-level measurement help you manage your district on a day-to-day basis? How?
	How has the number of measurement devices in your system affected the effort your staff puts into O&M activities? What O&M activities are affected?	How have water measurement devices at each turnout affected the effort you put into O&M activities? What O&M activities are affected?

DITCH TENDER

Focus: Daily canal, lateral, and turnout operation; coordination and communication with the district, other ditch tenders, and growers

Subject	Q's for Districts that Do *Not* Price Water by Volume	Q's for Districts that Price Water by Volume (turnout measured)
	How do you think that growers would respond to a different level of water measurement? Do you think it would change their operations or the way they irrigate?	How do you think that growers have responded to measuring water at the turnout level? From your perspective, did it change their operations? Do you think they paid closer attention to the water they use?
	Regardless of budget, is there measurement equipment that you'd like to see installed in the district? Is there alternative equipment to what you currently use that you might prefer?	(same)
	How do you manage operational spills? For example, if a grower orders water but does not take it, what happens to the water? Is the grower charged for that water?	(same)
Training	What additional training in water measurement or operations would be helpful?	(same)

GROWERS

Focus: Grower perspective on measurement and pricing policies and operations

Subject	Q's for Districts that Do *Not* Price Water by Volume	Q's for Districts that Price Water by Volume (turnout measured)
Current Practices	What do you grow? How many seasons have you grown this crop?	(same)
	How often to you change the crops you grow? What has influenced these changes in the past?	(same)
	How do you order water? What is the process? Do you order water by acreage, acre-feet, as a flow rate (cfs), etc.?	(same)
	How much time do you need to allow from the time you submit the order to the time you want to receive it? Is on-time delivery of this water reliable? Does it depend on the season? Time of year? Which is the best/worst?	(same)
	Do you or the district make adjustments to the turnout gates?	(same)
	How do you determine the amount of water to order? How do you estimate the amount of water you need to apply to your fields? How do you determine how frequently to irrigate? Are you decisions impacted by irrigation service schedules or response time?	(same)
	How do you pay for water? Does the cost of water in any way determine how much water you order? When do you pay for water?	(same)
	Name two problems you encounter in your water delivery.	(same)
	Do you grow crops in more than one district or service area? Are there policy or procedural differences? If so, do they affect your practices?	(same)
Water Measurement	Do you measure water coming into your land? If yes, how is it measured? How often is it recorded? Do you measure water draining from your land? If yes, how is it measured? How often is it recorded?	(same)
	About how much water do you use in a year? *(Any unit of measure, range is ok. Note that this question is more to understand whether or not they know how much water they use, not so we can record the actual value.)*	(same)
	Do you think there is there a more appropriate point or level to measure water than what your district currently practices? Is there a more appropriate way to price water?	(same)

GROWERS

Focus: Grower perspective on measurement and pricing policies and operations

Subject	Q's for Districts that Do *Not* Price Water by Volume	Q's for Districts that Price Water by Volume (turnout measured)
	What is your experience with water measurement devices? If you had a measurement device installed on your turnout(s), would you use it to manage your water use? If so, how would it be helpful to you?	What is your experience with water measurement devices? Since measurement devices have been installed on your turnouts, have you used this information to help with your operations? If so, in what way has it been helpful for you?
	Have you ever farmed in a district that uses measurement for delivery or billing? What was your experience?	N/A
	Regardless of budget, is there measurement equipment that you'd like to see installed in the district or on your land? Is there alternative equipment to what you currently use that you might prefer?	(same)
	How do you think you or other growers would respond to a different level of water measurement? Would it change irrigation practices?	How do you think that growers have responded to measuring water at the turnout level? Does it change irrigation practices at all? Have you noticed a change in the amount of water you use since the change was made to charging for water by the acre-foot?
	Do you receive water use records from the district? If so, how often do you receive a statement? Would more frequent statements assist you in managing your water?	(same)
	What factors limit your ability to manage your irrigation system as you would like to?	(same)

Appendix E
Cost Data

APPENDIX E

Cost Data

Tables E-1 through E-4 summarize the cost data used to develop annualized per-acre costs that were presented in Section 5, Table 5-1.

TABLE E-1
Summary of Potential Reclamation District 108 Turnout-level Measurement Program Costs
Cooperative Water Measurement Study

Description	Unit Cost ($)	Quantity	Subtotal ($)	Annualized Cost[a] ($)
Capital Improvement Costs				
Propeller Meters	2,500[b]	606 meters[c]	1,515,000	271,400
Installation Cost	3,000[d]	600 turnouts	1,800,000	322,400
Capital Improvement Subtotal	*NA*	*NA*	*3,315,000*	*593,800*
Annual Operation and Maintenance Costs				
Meter Reading and Maintenance[e]	980	600 turnouts	NA	588,000
Data Quality Assurance/Quality Control[f]	360	600 turnouts	NA	216,000
Operation and Maintenance Subtotal	*NA*	*NA*	*NA*	*804,000*
Total Costs				
Total Annualized Cost	***NA***	***NA***	***NA***	***1,397,800***
Annualized Cost Per Turnout	1,397,800	600 turnouts	***NA***	***2,330***
Annualized Cost Per Acre	1,397,800	47,000 acres	***NA***	***29.74***

[a]Annualized costs are in 2010 dollars. Annualized capital improvement costs are based on a 7-year life at a 6 percent rate.

[b]The estimated equipment unit cost is for a 24-inch-diameter propeller meter with a digital readout that is based on an actual purchase in 2008, with a cost adjustment for 2010 dollars.

[c]There is one propeller meter each for 600 turnouts, plus it is assumed that six spare propeller meters will be kept on hand for mid-season malfunctions.

[d]This unit cost was derived from the Reclamation District 108 Field Measurement Study installation costs and multiplied by a factor of 2 to reflect anticipated installation by a private contractor rather than district staff.

[e]Assumed 1 hour/week/meter for 26 weeks (for meter maintenance, field checks, and data management) at an average labor rate of $30/hour (ditchtender/field technician rate) plus vehicle allowance/depreciation of $100/season plus miscellaneous parts/tools at $100/season.

[f]Assumed 12 hours/year/meter for data quality assurance/quality control using an average labor rate of $30/hour (ditchtender/field technician rate).

Note:

NA = not applicable

TABLE E-2
Summary of Potential Reclamation District 108 Lateral-level Measurement Program Costs (Low-range Costs)
Cooperative Water Measurement Study

Description	Unit Cost ($)	Quantity	Subtotal ($)	Annualized Cost[a] ($)
Capital Improvement Costs				
Flow Measurement Installation and Calibration	25,000[b]	25 sites	625,000	112,000
Capital Improvement Subtotal	*NA*	*NA*	*625,000*	*112,000*
Annual Operation and Maintenance Costs				
Meter Reading and Maintenance[c]	5,000	25 sites	NA	125,000
Data Quality Assurance/Quality Control[d]	360	25 sites	NA	9,000
Operation and Maintenance Subtotal	*NA*	*NA*	*NA*	*134,000*
Total Costs				
Total Annualized Cost	***NA***	***NA***	***NA***	***246,000***
Annualized Cost Per Site	246,000	25 sites	***NA***	***9,840***
Annualized Cost Per Acre	246,000	47,000 acres	***NA***	***5.23***

[a]Annualized costs are in 2010 dollars. Annualized capital improvement costs are based on a 7-year life at a 6 percent rate.

[b]Unit cost is based on recent actual costs for a variety of installations on Sacramento River Settlement Contractor laterals. Includes use of existing structure with minimal or no cross section improvements and installation of a rated weir/orifice with level recording device. Does not include acoustic Doppler flow meter or supervisory control and data acquisition.

[c]It was assumed that the unit cost for meter reading and maintenance was 20 percent of the initial capital improvement cost. This line item includes purchasing replacement parts, collecting data, and checking meters during the irrigation season.

[d]Assumed 12 hours/year/meter for data processing and quality assurance/quality control using an average labor rate of $30/hour (ditchtender/field technician rate).

TABLE E-3
Summary of Potential Reclamation District 108 Lateral-level Measurement Program Costs (High-range Costs)
Cooperative Water Measurement Study

Description	Unit Cost ($)	Quantity	Subtotal ($)	Annualized Cost[a] ($)
Capital Improvement Costs				
Acoustic Doppler Flow Meter Installation and Calibration	25,000[b]	25 sites	625,000	112,000
Channel Improvements	25,000	25 sites	625,000	54,500
Capital Improvement Subtotal	*NA*	*NA*	*1,250,000*	*166,500*
Annual Operation and Maintenance Costs				
Meter Reading and Maintenance[c]	15,000	25 sites	NA	375,000
Data Quality Assurance/Quality Control[d]	640	25 sites	NA	16,000
Operation and Maintenance Subtotal	*NA*	*NA*	*NA*	*391,000*
Total Costs				
Total Annualized Cost	***NA***	***NA***	***NA***	***557,500***
Annualized Cost Per Site	557,500	25 sites	***NA***	***22,300***
Annualized Cost Per Acre	557,500	47,000 acres	***NA***	***11.86***

[a]Annualized costs are in 2010 dollars. Annualized capital improvement costs are based on a 7-year life at a 6 percent rate; except channel improvements are based on a 20-year life at a 6 percent rate.

[b]Unit cost is based on recent actual costs for a variety of installations on Sacramento River Settlement Contractor laterals. Includes acoustic Doppler flow meter procurement, installation, and initial calibration. Does not include supervisory control and data acquisition.

[c]It was assumed that the unit cost for meter reading and maintenance was 30 percent of the initial capital improvement cost (this is a higher percentage for acoustic Doppler flow meter installation). This line item includes purchasing replacement meters, collecting data, and checking meters during the irrigation season.

[d]Assumed 16 hours/year/meter for data processing and quality assurance/quality control using an average labor rate of $40/hour (junior engineer/engineering technician rate).

TABLE E-4
Summary of Potential Reclamation District 108 District-level Measurement Program Costs
Cooperative Water Measurement Study

Description	Unit Cost ($)	Quantity	Subtotal ($)	Annualized Cost[a] ($)
Capital Improvement Costs				
Large Pumping Plant				
Acoustic Doppler Flow Meter	8,000[b]	1	8,000	1,400
Installation and Calibration	10,000	1	10,000	1,800
Cross Section Improvements	30,000	1	30,000	2,600
Subtotal	*NA*	*NA*	*48,000*	*5,800*
Mid-sized Pumping Plant				
Acoustic Doppler Flow Meter	8,000[b]	2	16,000	2,900
Installation and Calibration	10,000	2	20,000	3,600
Cross Section Improvements	10,000	2	20,000	1,700
Subtotal	*NA*	*NA*	*56,000*	*8,200*
Small Pumping Plant I				
Acoustic Doppler Flow Meter	8,000[b]	1	8,000	1,400
Installation and Calibration	10,000	1	10,000	1,800
Cross Section Improvements	10,000	1	10,000	900
Subtotal	*NA*	*NA*	*28,000*	*4,100*
Small Pumping Plant II				
Ultrasonic Flow Meter	4,000	2	8,000	1,400
Installation and Calibration	5,000	2	10,000	1,800
Subtotal	*NA*	*NA*	*18,000*	*3,200*
Capital Improvement Subtotal	*NA*	*NA*	*150,000*	*21,300*
Annual Operation and Maintenance Costs				
Meter Reading and Maintenance[c]	NA	NA	NA	45,000
Data Quality Assurance/Quality Control[d]	960	6 meters	NA	5,760
Operation and Maintenance Subtotal	*NA*	*NA*	*NA*	*50,760*
Total Costs				
Total Annualized Cost	***NA***	***NA***	***NA***	***72,060***
Annualized Cost Per Meter	72,060	6 meters	***NA***	***12,010***
Annualized Cost Per Acre	72,060	47,000 acres	***NA***	***1.53***

[a]Annualized costs are in 2010 dollars. Annualized capital improvement costs are based on a 7-year life at a 6 percent rate; except channel improvements are based on a 20-year life at a 6 percent rate.

[b]Estimated cost for a SonTek Side-Looker.

[c]It was assumed that the unit cost for meter reading and maintenance was 30 percent of the initial capital improvement cost. This line item includes purchasing replacement parts, collecting data, checking calibration, and checking meters during the irrigation season.

[d]Assumed 24 hours/year/meter for data processing and quality assurance/quality control using an average labor rate of $40/hour (junior engineer/engineering technician rate).

Appendix F
Summary of Conclusions from Other Measurement Studies

APPENDIX F

Summary of Conclusions from Other Measurement Studies

Technical information developed through this Cooperative Water Measurement Study (Cooperative Study) provides support for conclusions reached in other forums or studies and is generally consistent with their respective findings. Three such recent examples are efforts conducted by the California Bay-Delta Authority, the California Polytechnic State University Irrigation Training and Resource Center, and previously by the Basinwide Water Management Program participants.

Independent Panel on Appropriate Measurement of Agricultural Water Use, California Bay-Delta Authority, 2003

In 2003, the California Bay-Delta Authority completed the Independent Panel on Appropriate Measurement of Agricultural Water Use, which is the most comprehensive recent investigation of agricultural water measurement on a statewide level. Some key recommendations of that report regarding measurement issues important to the Sacramento River Settlement Contractors (SRSC) are as follows:

- "It is appropriate to measure all major surface water diversions at the highest technically practical level – in other words, using flow-totaling devices and, if necessary, date loggers and telemetry. It is also appropriate for data to be managed locally and reported to the State.
- "Although more accurate farm-gate delivery measurement can be an important component of local water management strategies, changes in farm-gate measurement alone will not likely result in significant water management improvements.
- "…given current and physical and institutional conditions, it is not necessary to require flows at farm-gates to be more rigorously or accurately measured at this time.
- "…the costs associated with changing those farm gates at the basic level (measured or estimated flows at +/-15%) outweigh the benefits."

The Cooperative Study developed information that supports all of these key conclusions of the Independent Panel on Appropriate Measurement of Agricultural Water Use. Regarding major surface water diversions, the SRSCs are measuring their Sacramento River diversions at the highest technically practicable level with reporting to the Bureau of Reclamation for compliance and operational purposes.

Sycamore Family Trust Site Visit Report, California Polytechnic State University Irrigation Training and Resource Center, 2006

In 2006, the California Polytechnic State University Irrigation Training and Research Center investigated water measurement options for the Sycamore Family Trust Farm, which includes about 9,000 acres of irrigated land. The predominant crop is rice. The investigation was performed under contract with the Bureau of Reclamation. The farm did not have volumetric measurement beyond the pump station diversions at the Sacramento River. The site visit report included the following conclusions or recommendations:

- Turnout-level measurement is highly sensitive to these factors: trash in supply lateral, head requirements, construction methods, and durability of electronic components. The site visit report emphasized the importance of equipment maintenance, silt control or management, and continued calibration of equipment.
- The site visit report investigated the range of equipment available for turnout-level measurement. For the 30 sites, the initial capital cost of turnout-level measurement would range from $150,000 to $360,000. This cost does not include annual maintenance, calibration, or anticipated future equipment replacement.
- The site visit report identified that the purpose of measurement and the appropriate unit or level of measurement needs to be determined prior to the implementation of a measurement plan. To determine what level of measurement is necessary, external indicators may be analyzed or specific internal processes may be analyzed that may result in a positive external result. For example, a project might want to determine the total volume consumed (an external indicator) within a district service area; therefore, internal flow measurement might not be necessary if the total volume diverted is the focus.
- The *Sycamore Family Trust Site Visit Report* emphasized the need to determine the purpose and appropriate level of measurement and associated cost with increased measurement at a turnout level when taking into account system configuration, cropping pattern, and measurement sensitivity to uncontrollable factors. Similar to the *Sycamore Family Trust Site Visit Report*, the Cooperative Water Measurement Study concluded that turnout-level measurement should be evaluated on a service area or district basis to determine whether it is economically justified.

Sacramento River Basinwide Water Measurement Plan Sub-basin-level Water Measurement Study, Sacramento River Settlement Contractors, 2003

As an extension of the Basinwide Water Management Program, participating SRSCs initiated and received grant funding for the Sub-basin-level Water Measurement Study. The study investigated the feasibility of improving water measurement at key sub-basin outflow locations in the Colusa, Butte, Sutter, and Natomas Sub-basins, which includes the service areas of the SRSCs. The study concluded that implementation of the sub-basin-level measurement program would provide an improved understanding of sub-basin outflow, which, in turn, would assist in water balance analyses. In addition, the outflow information was identified as leading to the following potential benefits:

- Improved understanding of sub-basin outflow to evaluate opportunities for improved water management
- Coordinated management of sub-basin outflow
- Maximized benefits from other regional actions
- Possible integration with future sub-basin-level water quality monitoring program