Managing Irrigation Systems in Today's Environment

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Preface

The papers included in these Proceedings were presented during the **USCID Water Management Conference**, held November 13-16, 2012, in Reno, Nevada. The Theme of the Conference was ***Managing Irrigation Systems in Today's Environment***. An accompanying book presents abstracts of each paper.

The diversity and complexity of issues facing irrigation districts today presents challenges for district managers and staff. Many districts, established solely to deliver irrigation water to farmers, now operate in a far different environment — one that requires continuing development of the tools, knowledge and skills necessary for enhanced decision-making capabilities. The Conference focused on contemporary issues and the experiences of irrigation districts in the western U.S.

For many districts, some more than 100 years old, rebuilding and modernizing their aging infrastructure is a key challenge. Even newer districts must ensure the integrity of their distribution systems, protecting them against losses due to seepage, corrosion, etc. Most districts are facing legal challenges to their water rights or water supply contracts, dealing with changing, ever-tightening water quality regulations, and wrestling with environmental issues. The need for district managers and staff to understand and implement new technologies is paramount, as districts work to operate more efficiently in order to cut costs and accomplish more with less.

The authors of papers presented in these Proceedings are professionals from academia; international, federal, state and local government agencies; water and irrigation districts; and the private sector.

USCID and the Conference Co-Chair express gratitude to the authors, session moderators and participants for their contributions.

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CREATIVE, ACCURATE AND COST-EFFECTIVE FARM-GATE DELIVERY MEASUREMENT APPROACHES

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ABSTRACT

Among California's agricultural water suppliers, those dominated by rice cropping will be most strongly affected by the newly adopted Agricultural Water Measurement regulation or California Water Code Section 597 (CWC §597 or regulation). Rice is fundamentally different from other crops from a water management perspective. Water measurement plays a different role as compared to other crops and measurement generally has not evolved in the same manner for rice water suppliers as it has with non-rice water suppliers. Additionally, the flows and conditions under which water is delivered to rice provide technical challenges to accurate, cost-effective water measurement.

In this paper, we summarize the requirements of CWC §597 and discuss the special considerations associated with rice water management and related water measurement challenges. We then describe an innovative technology and new measurement device that was conceived to overcome certain measurement challenges and enable rice water suppliers to comply with the accuracy standard in a cost-effective manner. The results of pilot testing this new device during the 2012 irrigation season are included. Although developed specifically for rice water delivery measurement, the device is applicable to non-rice water delivery also, and integrates with automated water billing processes.

INTRODUCTION

As directed by legislative action, the California Department of Water Resources (DWR) developed regulations comprising California Water Code Section 597 (CWC §597) that define a "sufficient" level of water measurement accuracy for the purposes of (1) adopting a water pricing structure based at least in part on the volume of water delivered and (2) reporting aggregated water deliveries to users. The regulation requires that each and every device used to measure customer water deliveries meets certain accuracy standards. All agricultural water suppliers measure water in a manner that suits their respective operations; however, there is a broad range of device types currently in use

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and a broad range of associated measurement accuracies. Thus, there is wide variance among suppliers with regards to the "gap" between existing measurement practices and the level of measurement accuracy needed to comply with the regulation. Also, some suppliers do not charge for water on a volumetric basis. For these suppliers, in addition to complying with the accuracy standard, effort will be needed to create an administrative process to track delivered water volumes and prepare water bills.

Among California's agricultural water suppliers, those dominated by rice cropping will be most strongly affected by the regulation. This is because rice is fundamentally different from other crops from a water management perspective leading to a different role for measurement. As a result, water measurement generally has not evolved in the same manner for rice water suppliers as it has with non-rice water suppliers. Additionally, the flows and conditions under which water is delivered to rice provide technical challenges to accurate, cost-effective water measurement.

CALIFORNIA WATER CODE SECTION 597 (CWC §597)

General

California Water Code §10608.48(b) requires that on or before July 31, 2012 agricultural water suppliers shall measure the volume of water delivered to customers with sufficient accuracy to:

- Adopt a pricing structure for water customers based at least in part on quantity delivered

- Submit an annual report to the Department of Water Resources that summarizes aggregated farm-gate water delivery data on a monthly or bi-monthly basis

Under the authority included in California Water Code §10608.48(b), the California Department of Water Resources has adopted the regulations summarized below pertaining to Agricultural Water Measurement or California Water Code Section 597 (CWC §597 or Regulation). These requirements apply unconditionally to agricultural suppliers serving more than 25,000 acres and to suppliers serving between 10,000 acres and 25,000 acres if funding is provided.

The Regulation requires measurement at individual customer delivery points with an allowance for measurement at points serving multiple customers subject to certain conditions. The requirements summarized below pertain to individual measurement points only. The permanent regulation was approved by the Office of Administrative Law on July 11th, 2012.

Measurement Accuracy

Existing measurement devices shall be certified to be accurate to within ±12 percent by volume. New or replacement measurement devices shall be certified to be accurate to within:

- ±5 percent by volume in the laboratory if using a laboratory certification;
- ±10 percent by volume in the field if using a non-laboratory certification

Accuracy Certification, Records Retention, Device Performance and Reporting

Initial Certification. Existing measurement devices shall be initially certified by trained individuals and documented in a report certified by an engineer by either:

- Field-testing of a random and statistically representative sample of existing devices

  OR

- Field-inspections and analysis completed for every device.

New or replacement measurement devices shall be initially certified and documented by either:

- Laboratory certification prior to installation following industry-established protocols. Documentation shall include the manufacturer's literature or the results of laboratory testing.

  OR

- Non-laboratory certification after installation documented by either:
  - An affidavit approved by an engineer submitted to the supplier of either (1) the design and installation of an individual device at a specified location or (2) the standardized design and installation for a group of measurement devices for each type of device installed at specified locations

    OR

  - Field testing as described above.

Protocols for Field-Testing and Field Inspection and Analysis. Field-testing will be performed on a sample of 10 percent of the existing devices for each device type, with a minimum of 5 and a maximum of 100 individual devices (recommended). Alternatively, a suppler may develop its own sampling plan using accepted statistical methodology. If more than one-quarter of the sample devices do not meet the accuracy criteria, the supplier shall provide in its Agricultural Water Management Plan a plan to test an additional 10 percent of its existing devices (not less than 5 and not more than 100). This second round of field-testing and corrective actions shall be completed within three years of the initial field-testing.

Field-inspections and analysis protocols shall be performed and the results shall be approved by an engineer for every existing measurement device.

Records Retention. Records shall be retained by the supplier for ten years or two Agricultural Water Management Plan cycles.

Performance Requirements. All measurement devices shall be correctly installed, maintained, operated, inspected and monitored as described by the manufacturer, the laboratory or the Registered Professional Engineer that has signed and stamped the certification. If an installed device fails to meet the accuracy requirements for either initial certification or during operations and maintenance, the supplier shall take appropriate corrective action to achieve the accuracy requirement.

Reporting in Agricultural Water Management Plans. Suppliers must report the certain specified information in their Agricultural Water Management Plans (AWMP).

RICE WATER MANAGEMENT AND RELATED WATER MEASUREMENT CHALLENGES

Even though the Sacramento Valley is characterized by dry and hot summers, winter storms can include intense and prolonged precipitation events. Runoff and snowmelt from surrounding mountain watersheds of the Sierra Nevada, southern Cascades and Coastal range can fill and overtop the Valley's riverbanks. Spring and early summer flooding has played a significant role in the region's hydrology.

Before the current and extensive network of levees, dikes and floodways was created on the Valley's major waterways, slow-moving floodwaters carried mostly fine sediments into the broad, flat basins adjacent to the rivers. In time, the deposition of these sediments formed the heavy clay soils that typify the basins. Because water moves slowly through these soils, floodwaters on the land surface are held for a long time. The combination of floodwater from the rivers and clayey soils made parts of the basins natural wetlands.

Both hydrology and soils render many land uses difficult or impossible within these basins. In particular, cultivation of upland (non-rice or unflooded) crops is possible on some of the better drained soils, but impractical on many of the heavier clay soils. Many upland crops are not capable of withstanding soils with sustained periods of soil saturation which leads to the drowning of roots as well as disease and fertility problems. It is estimated that over half of the land on which rice is grown in California today could likely not economically support other major crops (Calrice 2012).

Flooded Fields vs. Irrigation Events

Contrasted with discrete irrigation events with frequencies dependent on crop water requirements, rice fields are continuously flooded from before or shortly after planting in April/May until about 2 weeks before harvest, typically in September/October. Additionally, irrigation water is used for thermal management during critical periods of rice plant maturation, including panicle initiation occurring roughly 60 days after planting. During this period, sustained temperatures of less than 55 degrees Fahrenheit can have negative impacts on rice yields. Thermal management is accomplished by varying water depths within the rice fields. Due to the high specific heat of water, increasing water pool depths within the rice checks tends to minimize temperature fluctuations within the field, and vice versa.

All of the unique facets of rice cultivation lead to very different water management requirements as opposed to upland or row crops. By inspection of the water balance, it can be seen that water delivered to rice fields (inflows) can contribute to outflows consisting of (1) evapotranspiration, (2) deep percolation and (3) tailwater (i.e. surface outflows). Because the rice fields are flooded for the majority of the growing season, evapotranspiration is a generally not limited by water availability, but is controlled by other factors and crop stressors. Also, keeping rice fields flooded causes deep percolation to be most strongly a function of soil properties (i.e. the saturated hydraulic conductivity), rather than irrigation practices. Tailwater, however, is strongly tied to water management practices. If water deliveries to a rice field exceed evapotranspiration and deep percolation demands, tailwater outflows will be present (NCWA 2011).

Low Head Deliveries

As previously stated, rice cultivation primarily occurs in the low gradient regions of historical river basin flood plains. This topography generally leads to small head (or energy) differentials between supply canals and the fields receiving water deliveries. Low head differentials make certain measurement approaches less accurate if not all together infeasible. Measurement approaches that become challenging or infeasible under low head differentials include weirs, flumes, and orifices. Some measurement approaches, including velocity-area methods (acoustic doppler, magnetic, mechanical current meters), are less sensitive to low head differentials.

Large Range of Delivery Rates

There are essentially two different water delivery flow rates associated with irrigating a rice field: flood-up and maintenance. During flood-up, the goal is to quickly establish ponded water on the field surface. Depending on field size, flood-up delivery rates typically range from 10 to 25 cubic feet per second (cfs), and can last from a few hours to several days. Once the field is flooded to the desired depth, the flow is decreased to a maintenance flow rate. Maintenance flow rates are essentially the sum of the three outflows discussed above (evapotranspiration, deep percolation and tailwater). Depending on field size, maintenance deliveries typically range from 1 to 6 cfs, and typically last from several weeks to a few months. It is important to note that the same delivery infrastructure is used to deliver both flood-up and maintenance flows. Large ranges of flow deliveries (e.g. 1 to 25 cfs) pose problems to certain measurement approaches. Mechanical current meters, or propeller meters, can have difficulties measuring low flow rates because of slow velocities. Meter fouling due to aquatic vegetation also poses a significant challenge to volume measurements with propeller meters.

Summary of 2011 Investigations

Reconnaissance level investigations performed before and during the 2011 irrigation season on a sample of 38 farm turnouts in two rice-dominated irrigation districts in Northern California (Thiede and Davids 2012) revealed the following regarding the potential to use existing gates or weir boxes for turnout measurement (shown from left to right in Figure 1 below):

Figure 1. Standard Delivery Site Inlet (orifice gate) and Outlet (weir box)

1. Weir boxes installed at the discharge of existing farm delivery gates can achieve the new ±12 percent measurement regulation and deliver sufficient flow provided that sufficient head (pressure) is available at the turnout.
2. Approximately one quarter of the turnouts studied have sufficient head for weir boxes to work satisfactorily over the full range of flows.
3. On turnouts where weir boxes cannot be used, the existing gate can be used as an orifice device for measurement provided that certain physical modifications are made and gate-specific coefficients are developed for computing flow rate (based on gate opening and head loss across the gate).

During the 2011 field investigations a third farm delivery measurement device was identified that may have advantages over both weirs and orifice gates. This additional measurement device is referred to as the 'RemoteTracker'[5].

[5] Patent Pending.

REMOTETRACKER MEASUREMENT DEVICE

System Overview

The RemoteTracker is an integrated turnout flow measurement, data management and volumetric accounting system developed by H2oTech specifically for agricultural water suppliers. The RemoteTracker system is comprised of (1) a wirelessly controlled water velocity sensor, (2) a ruggedized tablet PC in the operator's vehicle and (3) a database running on a file server connected to the internet. The user interface on the tablet PC enables operators to view real time flow data from the wirelessly controlled water velocity sensor via a Bluetooth radio connection while adjusting flows at the turnout gate. Data is automatically transferred over a wireless wide area network (WWAN) to a centralized file server at the District headquarters where it is automatically loaded into a custom database application. The database performs quality control and quality assurance procedures on the data and then develops daily volumes for each delivery point with the District.

The wireless water velocity sensor is held in place at a precise location at the pipe outlet by an aluminum or stainless steel mounting bracket. The user interface, shown in Figure 2, was designed with simplicity and ease of use in mind. If ‘Auto Locate’ is selected, the program automatically populates the three site identification pull-downs at the top of the screen. If the operator needs to select a different site, the pull-downs can be manually changed. The site selection hierarchy is a three digit abbreviation of ‘Operator Route’ (i.e. ride, beat or division) on the left, a three digit abbreviation of ‘Canal’ in the middle and site name on the right. The last measured flow, and any pending orders are shown on the ‘Home’ tab. Many useful reports, including (1) Delivery History, (2) Pending Orders, (3) Fulfilled Orders and (4) Canal Management are available on the ‘Reports’ tab. These reports can be sorted at any spatial or temporal scale. The cloud based data management framework allows water order and delivery data collected by any operator to be automatically available for viewing by other operators or management staff in a matter of minutes.

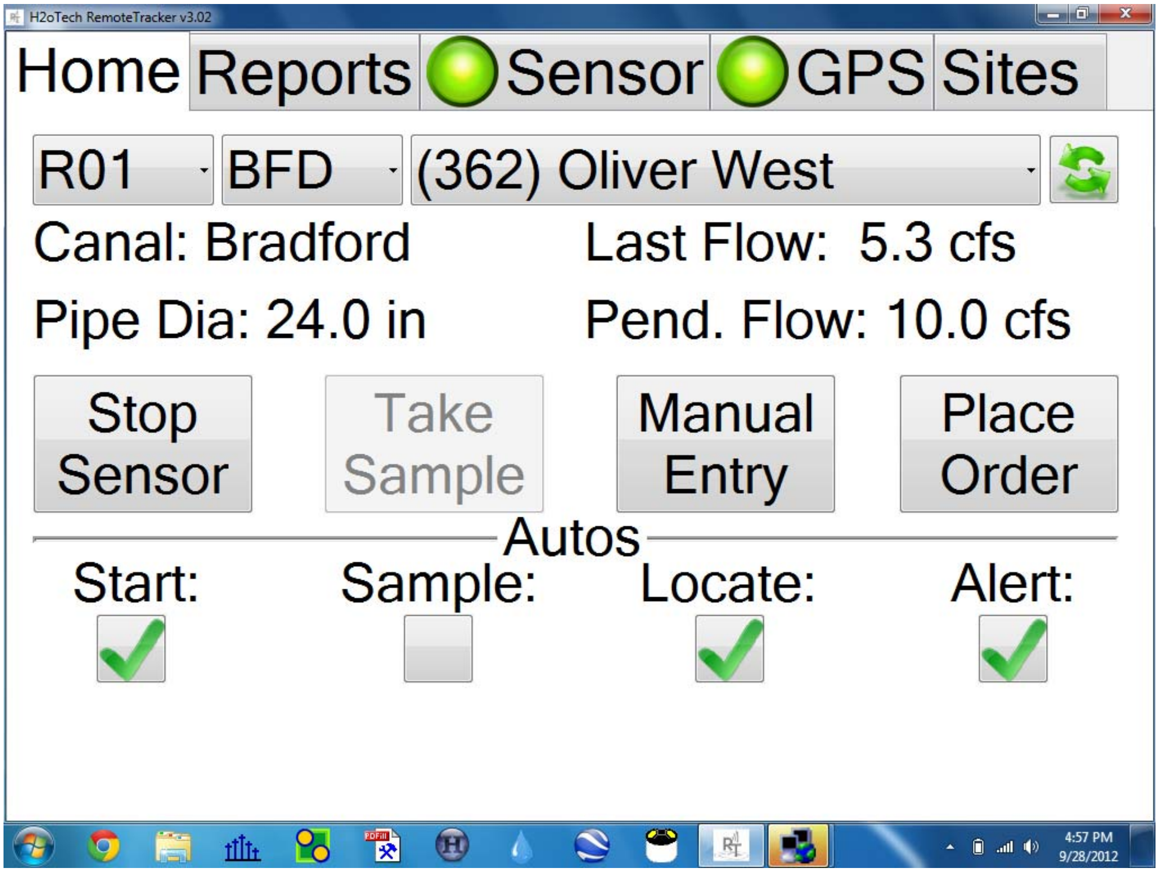

Figure 2. RemoteTracker User Interface - Home Tab Shown

The basic components of the RemoteTracker system are illustrated in Figure 3. Water velocity is collected by an acoustic Doppler velocimeter installed such that the sample volume is in the center of the pipe. Data is transmitted via a class 1 Bluetooth radio to a ruggedized tablet PC where it is processed, displayed and stored. Data is then transferred via a WWAN to a file server at the District headquarters. Data from each operator is aggregated with an automated database procedure and then returned to each operator via WWAN, thereby ensuring that delivery and order data is shared and accessible throughout the entire District.

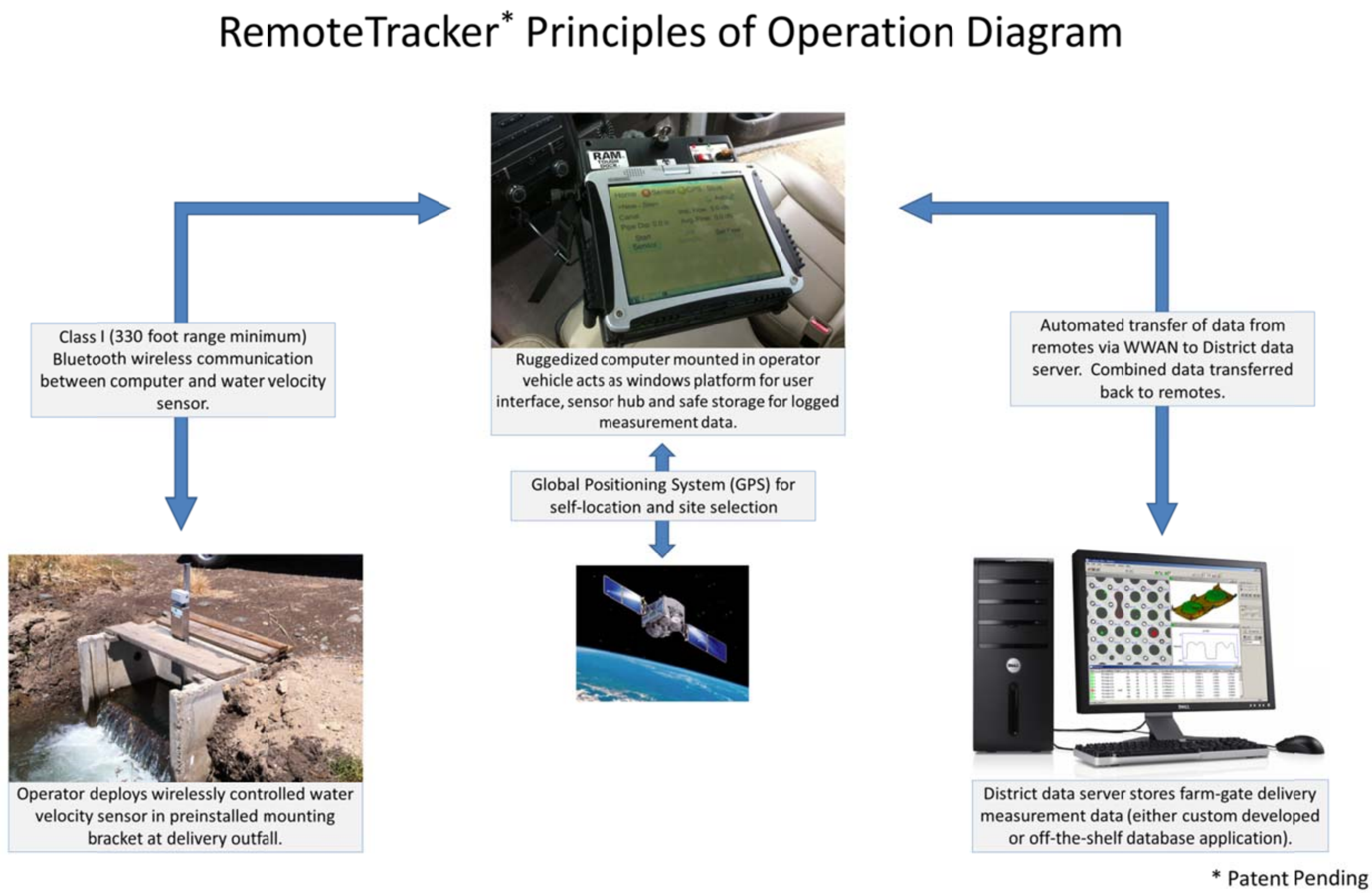

Figure 3. RemoteTracker Principles of Operation Overview

The key to pipe flow measurement using the RemoteTracker is the consistent relationship between a single velocity measurement at the center of the pipe and the average pipe flow velocity shown in Figure 4 derived from 146 measurements of center and mean pipe velocity. Based on this relationship, with the pipe diameter and cross sectional area known, the single point velocity can be accurately and reliably correlated with flow rate.

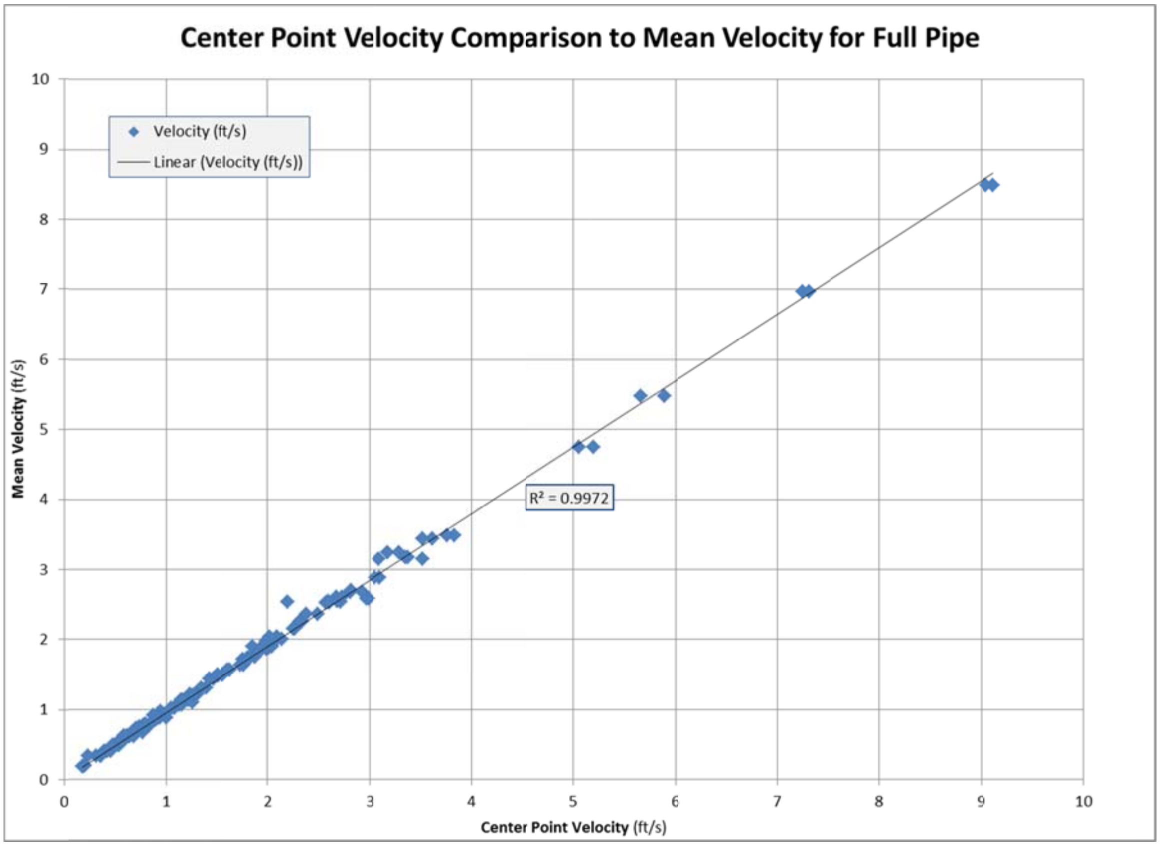

Figure 4. Relationship between Average and Center Point Pipe Flow Velocity

As for weirs and orifice gates, full pipe flow is required for the RemoteTracker to measure correctly. Therefore, a weir box is needed at each turnout to ensure full pipe flow as well as to accommodate the mounting bracket to hold the wireless water velocity sensor so that the sample volume is near the center of the pipe. An alternative sensor that provides water depth in addition to water velocity is currently being researched for integration into the RemoteTracker system to enable flow measurements in open channels and partially full pipes.

The RemoteTracker system can also be integrated with existing or new data management systems at the District office for report generation, accounting and billing. This capability can be added later to provide additional efficiencies in water billing and accounting procedures.

Field Verification Results

At two turnouts where the delivery spilled into a field ditch (or head ditch) rather than a field, both a RemoteTracker and a USGS mid-section method measurement (Rantz 1982) were taken and compared. Figure 5 shows the cross section report for one of the measurements in a typical earthen head ditch, in this case with a maximum depth of 2.5 feet, top width of 14 feet and bottom width of 5 feet. Typically, velocity measurements were performed at 0.5 foot intervals with velocities averaged over a 40 second period.

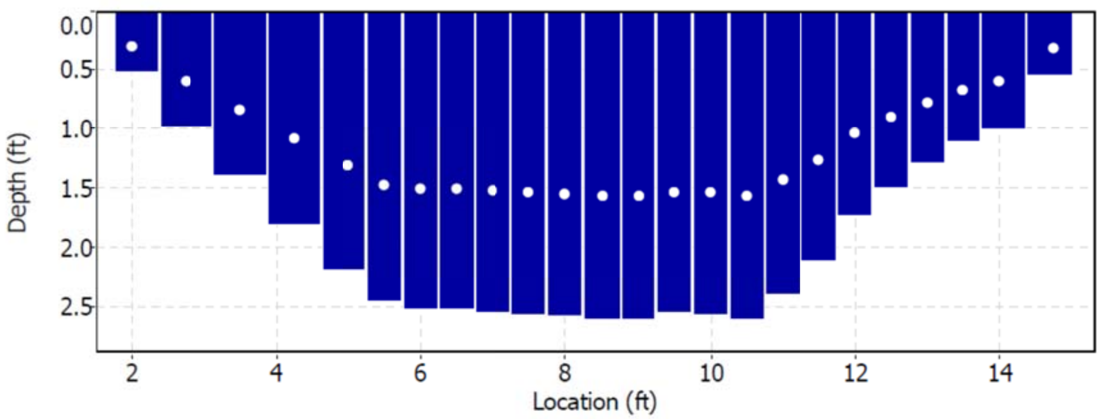

Figure 5. SonTek ADV Cross Section for Canal Verification Measurement

Five comparison measurements between the RemoteTracker and USGS mid-section method measurements with a SonTek ADV were performed in two irrigation districts in Northern California during the 2011 irrigation season. The percent difference between the two measurements averaged roughly 0.9 percent with a range of -0.8 to 3.4 percent, indicating that the RemoteTracker measurement methodology compares very well with the standard mid-section open channel methodology. The results of the comparison measurements are presented below in Figure 6 where the blue bars represent flow rates obtained with a SonTek ADV in an open channel downstream of the turnout, the red bars represent flow rates obtained with the RemoteTracker and the green triangles represent the percent difference between the two (secondary vertical axis).

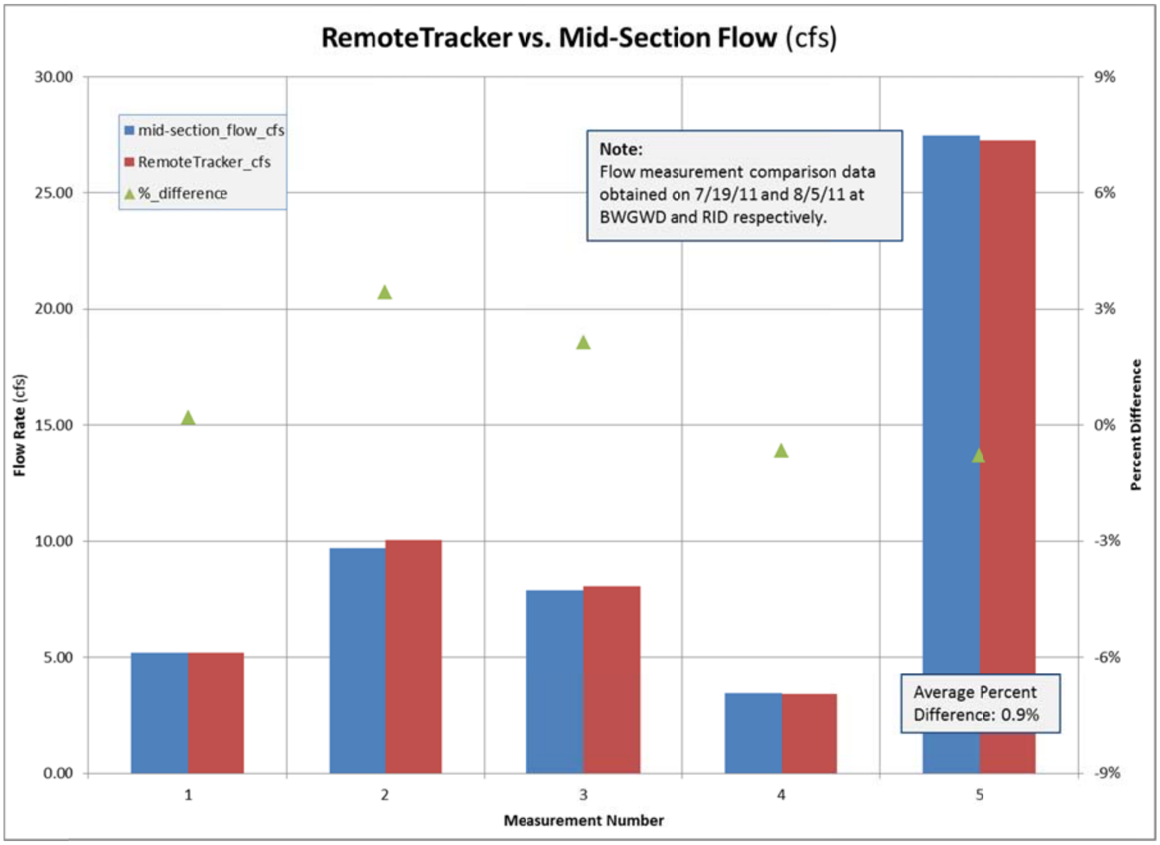

Figure 6. RemoteTracker and Mid-Section method Comparisons

Lab Verification Results

Additional testing was performed at the California State University Chico Agricultural Teaching and Research Center (CSUC ATRC) in July of 2012. Flow data obtained from the RemoteTracker was compared to measurements taken with a 10" magnetic flow meter manufactured by Water Specialties. Figure 7 shows the Water Specialties Magnetic meter with an Endress & Hauser Transit-Time Meter installed just upstream as an additional check. The 3 foot wide by 3 foot deep concrete flume was modified to simulate a typical delivery configuration by forcing all the flow through a 20 foot length of 18 inch HDPE smooth interior wall pipe submerged in the concrete flume. The RemoteTracker wireless water velocity sensor was installed at the pipe outfall using a temporarily constructed headwall with a mounting bracket as shown in Figure 8.

Figure 7. Water Specialties Magnetic Flow Meter at CSUC ATRC

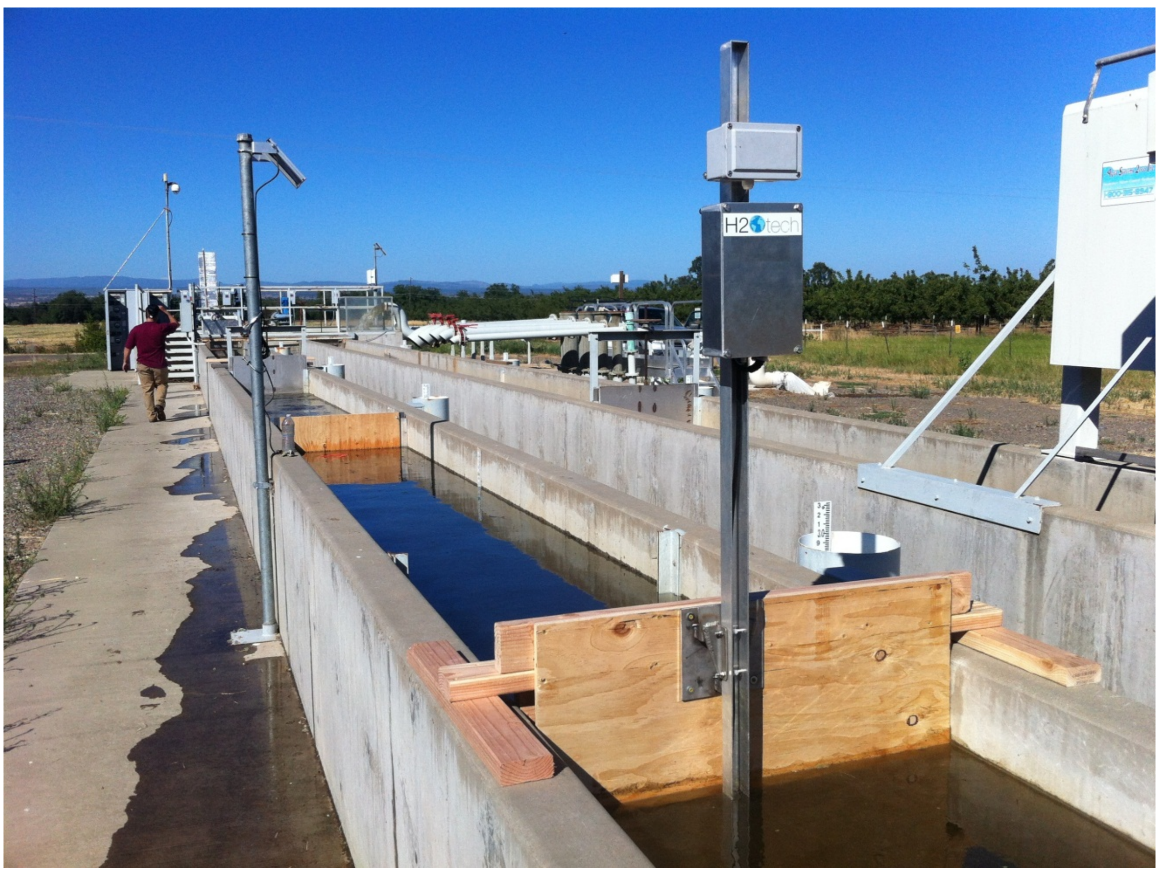

Figure 8. RemoteTracker Wireless Water Velocity Sensor Installed at CSUC ATRC

Seven comparison measurements between the RemoteTracker and magnetic meter were made ranging from 0.5 cfs to just over 3.0 cfs (the maximum pump capacity). The percent difference between the two measurements averaged roughly -2.6 percent with a range of -10.2 to 2.8 percent indicating that the RemoteTracker measurement methodology compares very well with the magnetic meter. Note that the -10.2 percent difference occurred at the lowest flow rate of approximately 0.5 cfs and represents an absolute difference of 0.05 cfs between the two measurement methods. The results of the comparison measurement are presented below in Figure 9 where the blue bars represent flow rates obtained with a magnetic meter, the red bars represent flow rates obtained with the RemoteTracker and the green triangles represent the percent difference between the two (secondary vertical axis).

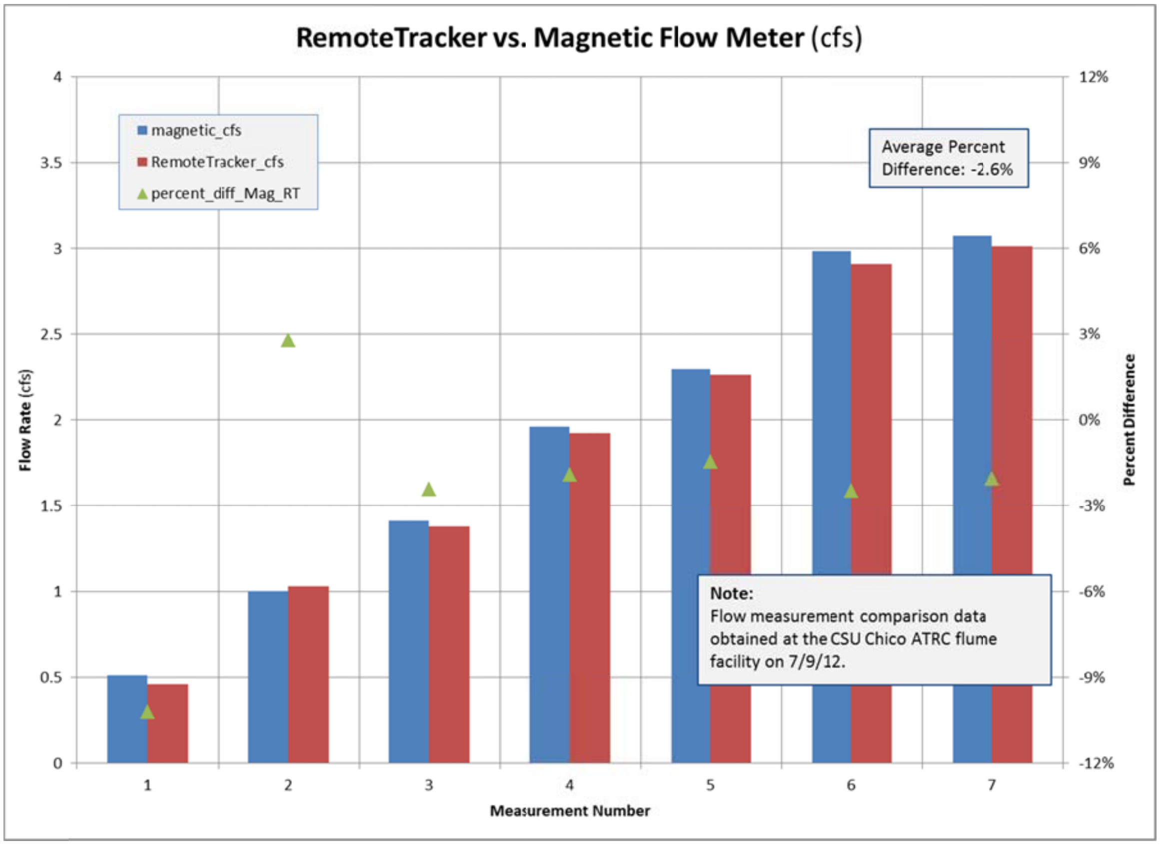

Figure 9. RemoteTracker and CSUC ATRC Magmeter Comparisons

Initial Piloting

The RemoteTracker is currently being piloted with three agricultural water providers in the Northern Sacramento Valley: Biggs-West Gridley Water District (BWGWD), Richvale Irrigation District (RID) and Reclamation District No. 108 (RD 108). At the time this paper was written, RD 108 has been successfully using the RemoteTracker for nearly five months, and RID and BWGWD for roughly two months.

RD 108 Pilot Project. Starting in 2011 and continuing into 2012, RD 108 began laying a technical foundation for developing its plan to comply with CWC §597. A critical portion of the foundation was pilot testing of alternative field turnout measurement methods, including: (1) existing orifice gates, (2) weirs set in precast boxes, and (3) the RemoteTracker (methods shown in Figure 10 below).

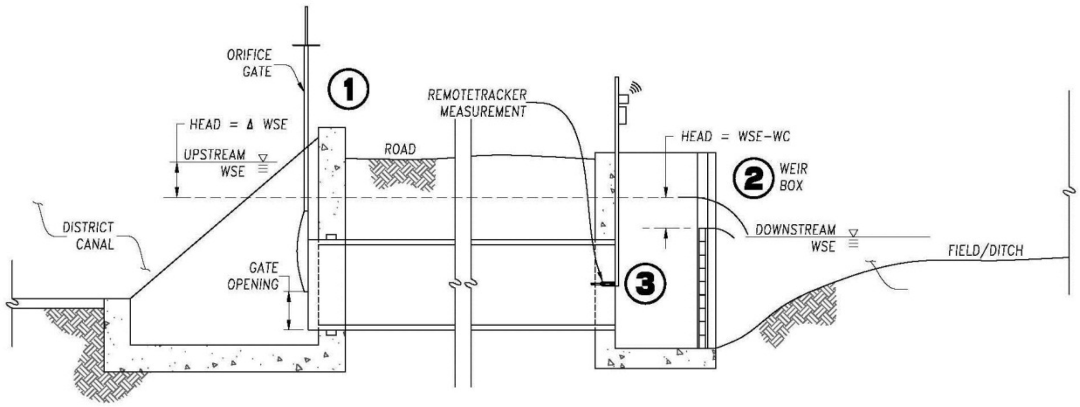

Figure 10. Schematic of the Three Measurement Methods Piloted at RD108 During the 2012 Irrigation Season

The concept of the pilot project (or project) was to isolate a reach of the canal system within RD108 to perform a water balance analysis. The 12C canal was selected for the project because it has (1) accurate inflow and outflow records from Rubicon FlumeGates and (2) a representative sample of crop types, delivery flow rates and delivery durations. The 12C canal serves a total of 22 turnouts comprised of three pump deliveries irrigating walnut orchards and 19 flood deliveries irrigating rice, alfalfa and corn.

Using flow data from the Rubicon FlumeGates[6] for the 'INFLOW' and 'OUTFLOW' terms, and independent estimates of canal seepage, Equation 1 was applied on a monthly time-step to determine the actual amount of water being delivered through the 22 turnouts in the pilot project (DEL_{WB}). Canal seepage was estimated by multiplying the average wetted perimeter by a representative seepage coefficient for a concrete lined canal in good condition of 0.07 cubic feet per square feet per day (USBR 1994). Evaporation from the canal water surface was considered to be an insignificant volume, and was therefore not included.

$$DEL_{WB} = INFLOW - OUTFLOW - Canal\ Seepage \qquad (Equation\ 1)$$

RD108 system operators, referred to as Waterman, collected flow data with each of the three measurement methods each time an irrigation event was started, modified or shutoff. A custom Microsoft Access database was developed to calculated daily water volumes at the turnout level for each measurement method. Daily volumes were then aggregated on a monthly time-step across all 21 sites to develop monthly delivery records for each measurement method. The calculated delivery volumes for orifice gates (GT), weirs (WR) and RemoteTracker (RT) are referred to as DEL_{GT}, DEL_{WR} and DEL_{RT} respectively.

[6] The accuracy of the flow measurement data from the Rubicon FlumeGates measuring inflow and outflow from the pilot reach was verified over the expected range of flows with a SonTek RiverSurveyor M9 ADCP. The results indicated that the flow data was sufficiently accurate for this investigation.

One RemoteTracker measurement site servicing a rice field consistently displayed erroneously high flow data, as compared to the gate measurements, for the duration of the pilot investigation. Since this was the only occurrence out of the 19 sites being measured, it was assumed that a problem existed with the site configuration or measurement parameters, including potential issues with the cross-section flow area calculation. Ideally, this site would be removed the analysis, but there is no way to accomplish this because the delivery volumes calculated by the water balance (DEL_{WB}) include all 22 of the deliveries for the entire analysis period. In other words, there is no way to remove a specific site from either the water balance results or the either of the three measurement methods. Therefore, for the site in question, gate data was used in lieu of RemoteTracker data.

Figure 11 illustrates the monthly delivery volumes calculated by the water balance (red bars) in relation to the monthly delivery volumes calculated by the RemoteTracker, Weir and Gate measurement methods (green, purple and blue bars respectively). It can be seen that weirs consistently overestimate volume due to submergence issues associated with a lack of head at several sites.

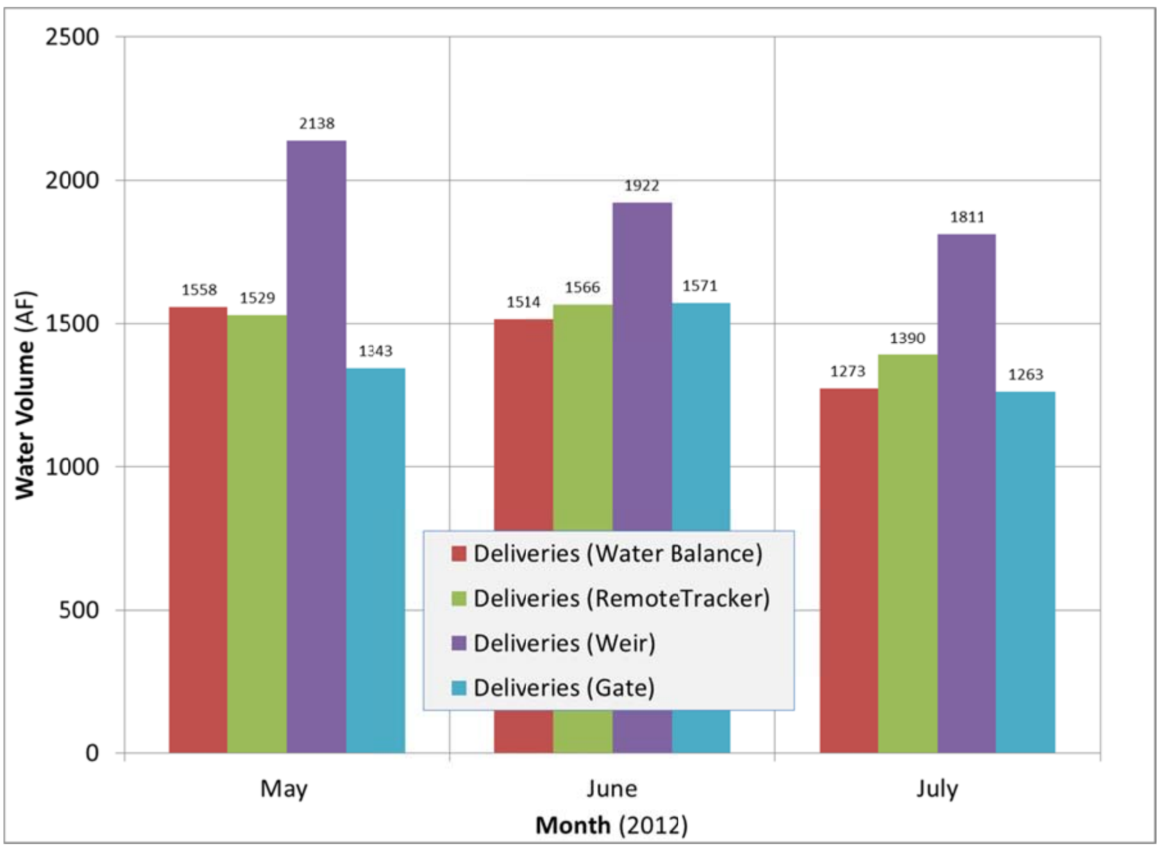

Figure 11. Monthly Delivery Volumes for the Three Measurement Methods in Reference to the Delivery Volume Solved for by the Water Balance (shown in red)

The percentage error for each measurement method was then calculated with Equations 2 through 4 for each month and for the bulk of the irrigation season (i.e. average of May through July). The definition of 'Accuracy' from CWC §597.2(a)(1) was used for the calculations, where the delivery volumes measured by the three different methods (i.e. DEL_{GT}, DEL_{WR} and DEL_{RT}) represent the 'measured value' and the water balance delivery closure term (DEL_{WB}) represents the 'actual value'.

$$ACCURACY_{GT} = \left(\frac{DEL_{GT}-DEL_{WB}}{DEL_{WB}}\right) * 100\ percent \qquad (Equation\ 2)$$

$$ACCURACY_{WR} = \left(\frac{DEL_{WR}-DEL_{WB}}{DEL_{WB}}\right) * 100\ percent \qquad (Equation\ 3)$$

$$ACCURACY_{RT} = \left(\frac{DEL_{RT}-DEL_{WB}}{DEL_{WB}}\right) * 100\ percent \qquad (Equation\ 4)$$

Figure 12 displays the monthly and average accuracies for the three measurement methods. On average, delivery volumes calculated with RemoteTracker (RT), Weir (WR) and Gate (GT) measurements were 3.6, 35.5 and -3.6 percent different that the water balance results respectively.

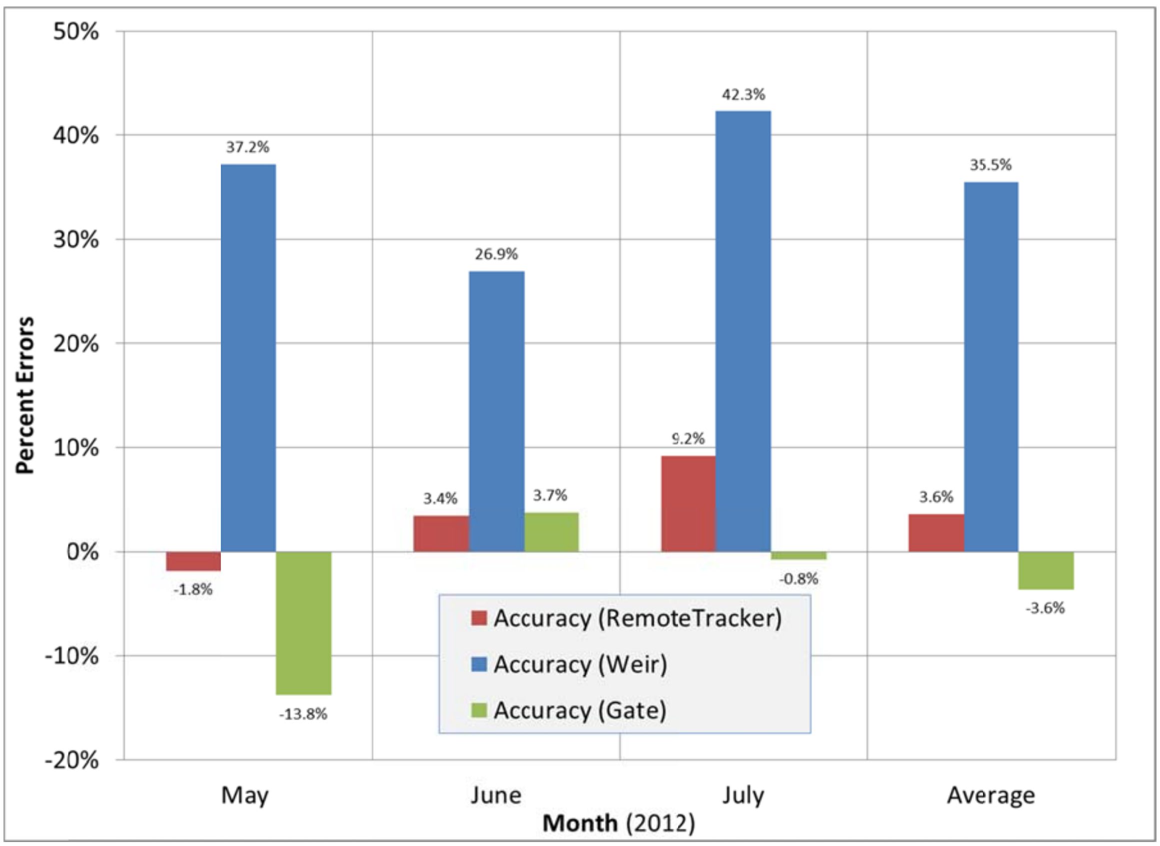

Figure 12. Monthly and Average Accuracies for the Three Measurement Methods

It should be noted that the accuracy results from the RD 108 pilot project presented in Figure 12 are aggregated for an entire reach of supply canal containing 19 gravity and three pump deliveries. In contrast, CWC §597 specifies accuracy requirements that apply to each delivery point (turnout or farm-gate).

CONCLUSIONS

Initial piloting indicates that the RemoteTracker is technically viable and offers certain advantages relative to other measurement options, particularly for rice dominated water suppliers. Preliminary field testing and laboratory testing indicates that the flow data is sufficiently accurate to comply with the accuracy requirements of CWC §597. Based on the laboratory and field testing, in addition to the pilot test results in each of the respective districts, RD 108, RID and BWGWD have selected the RemoteTracker device to achieve the measurement accuracy standards of CWC §597. The RemoteTracker's advantages include:

- Lower overall implementation costs than measurement methods requiring permanent devices at each delivery point
- More consistently accurate measurement of delivery flow rate (particularly compared to weirs and orifice gates)
- No need for individual site calibration (but individual site configuration brackets are required)
- Simple measurement procedure requiring minimal staff training
- Automated data logging
- Automated transfer of data to centralized data server
- Can be integrated with automated water accounting and billing processes

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