Using 21st Century Technology to Better Manage Irrigation Water Supplies

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USCID

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Preface

The papers included in these Proceedings were presented during the **USCID Seventh International Conference on Irrigation and Drainage**, held April 16-19, 2013, in Phoenix, Arizona. The Theme of the Conference was ***Using Technology to Better Manage Irrigation Water Supplies.*** An accompanying book presents abstracts of each paper.

Since the beginning of the 21st century, advances in agricultural science and technology have been unprecedented. Science and technology can drive increased agricultural productivity and economic growth to alleviate world hunger and poverty. New technologies are critical for developing sustainable agricultural systems that can remain productive in the long run. The focus of this Conference was to emphasize key issues of science and technology transfer for the agricultural industry. The Conference provided an ideal forum for farmers and irrigation districts to learn about new technologies available in the 21st century as well as to share their ideas and experiences with others.

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 Chairman express gratitude to the authors, session moderators and participants for their contributions.

Brian T. Wahlin
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"SPOT" MEASUREMENTS OF FLOW RATE CAN BE "GOOD ENOUGH" FOR CALIFORNIA'S HEIGHTENING AGRICULTURAL MEASUREMENT REQUIREMENTS

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ABSTRACT

Gathering accurate farm-gate delivery measurement data in response to the Agricultural Water Measurement regulation, or California Code of Regulations Title 23 Section 597 (CCR 23 §597) is a challenging task for many of California's agricultural water suppliers. Managing flow data for the purposes of (1) billing in part by volume and (2) providing aggregate reports to the State can be an equally onerous task. Additionally, many agricultural water purveyors are questioning if the cost of installing permanent measurement devices at each farm-gate is necessary to meet the volumetric accuracy requirements stated in CCR 23 §597.

In this paper, we briefly summarize the requirements of CCR 23 §597. An accuracy analysis performed in support of a laboratory volumetric accuracy certification for the RemoteTracker, as required by CCR 23 §597, is then presented. Embedded within the accuracy analysis is an examination of water level data from multiple irrigation districts located in California to assess the impacts of water level fluctuations on volumetric accuracy resulting from "spot" flow measurements (as opposed to continuously logging devices).

INTRODUCTION

From an agricultural water purveyor's perspective, the primary benefits of measurement at the farm turnout level are (1) the ability to precisely control and (2) accurately account for the amount of water being delivered to each customer. However, the cost[5] of fully implementing a measurement program on the farm turnout level by installing a permanent flow measurement device at every turnout in many cases outweighs the benefits. A method of decreasing costs in order to equalize the cost-benefit ratio is to find an alternative to installing a permanent flow measurement device at every farm

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[5] The use of cost here includes initial capital, operational and maintenance expenditures.

turnout. Aside from the case of flow automation of the farm turnout[6], the control (i.e. flow setting) of the farm turnout (or gate) is accomplished manually by district staff. It is during this period of manually setting the gate that accurate flow measurement is required for precise flow control. In other words, accurate flow measurement on a manually controlled gate provides no benefit towards the control of deliveries, with the exception of when district personnel are on site (i.e. at the gate).

Therefore, if the first of the two primary benefits of measurement (i.e. flow setting) can be accomplished by "spot" measurements while the operator is on site, the discussion then becomes centered on whether "spot" flow measurements can provide accurate volumetric delivery data. This paper focuses on developing a volumetric accuracy analysis that shows that "spot" measurements with the RemoteTracker are sufficiently accurate for volumetric accounting, and more specifically, a laboratory certification in accordance with the requirements of California Code of Regulations Section 597 (CCR 23 §597). In order to lay the foundation for the accuracy analysis, we first present a summary of CCR 23 §597. We then provide an overview of the measurement principles of the RemoteTracker, and some initial results from field, laboratory and pilot testing.

CALIFORNIA CODE OF REGULATIONS SECTION 597 (CCR 23 §597)

General

Senate Bill X7-7 (the "Water Conservation Act") was enacted in November 2009, requiring all water suppliers to increase water use efficiency. Agricultural water suppliers with irrigated areas above 25,000 acres were mandated to prepare and adopt agricultural water management plans by December 31, 2012, and update those plans by December 31, 2015, and every 5 years thereafter. The Water Conservation Act included Water Code Section 10608.48(i)(1) directing the California Department of Water Resources to adopt regulations providing for a range of options that agricultural water suppliers may use to implement volumetric measurement of farm turnout (i.e. farm-gate or turnout) water deliveries. The resulting regulation, California Code of Regulations Title 23 Division 2 Chapter 5.1 Article 2 Section 597 et seq. (CCR 23 §597), requires that, on or before July 31, 2012, agricultural water suppliers subject to the law shall measure the volume of water delivered to customers with sufficient accuracy to:

- Enable reporting of aggregated farm turnout delivery data to the State; and
- Adopt a pricing structure based at least in part on the quantity of water delivered.

CCR 23 §597 requires that existing farm turnouts like those in the District have a measurement accuracy of ±12 percent by volume, meaning that the measured volume of water delivered at each farm turnout must be no greater than 12 percent more, or 12 percent less, than the actual volume delivered. Additionally, any new or replacement measurement devices installed must be accurate to within:

[6] In most cases in the Western United States, cost prohibits flow automation of farm turnouts from being a viable option.

- ±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

The regulation requires that an accuracy certification be performed by either: (1) field testing of a random and statistically representative sample of existing farm turnouts, (2) field inspections and analysis of every existing farm turnout, with the testing or inspections documented by a registered engineer, or (3) a laboratory certification.

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 water velocity sensor (WWVS) 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 within the district.

The WWVS 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 1, 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.

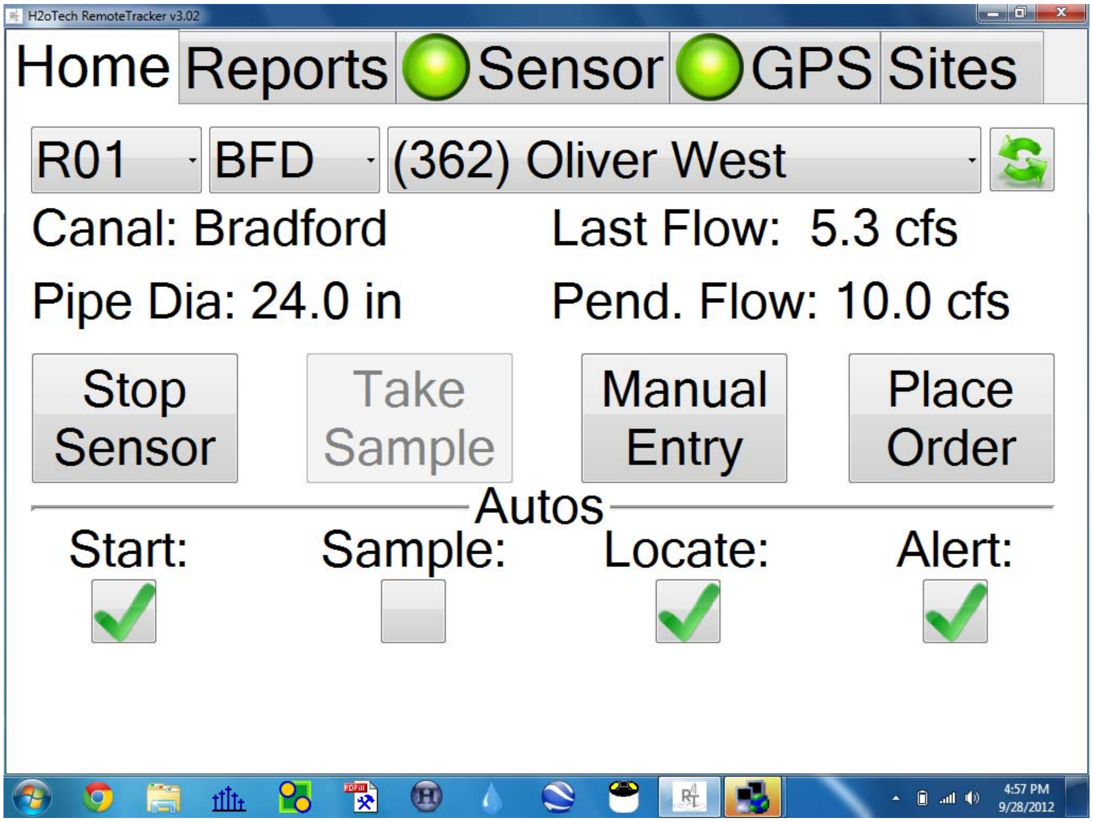

Figure 1. RemoteTracker User Interface - Home Tab Shown

Davids et al. (2012) provide a more detailed description of the RemoteTracker principles of operation, initial field verification, laboratory verification and district piloting results.

REMOTETRACKER ACCURACY ANALYSIS FOR VOLUMETRIC CONVERSION

Accuracy mandates established by CCR 23 §597 apply to delivery volume and not instantaneous flow rate or velocity. CCR 23 §597.4(e)(3)(B) states, "For devices that measure velocity only, the documentation shall describe protocols associated with the measurement of the cross-sectional area of flow and duration of water delivery…". This document provides descriptions of the protocols associated with the measurement of (1) average velocity, (2) cross-sectional area of flow and (3) duration of delivery, in addition to the corresponding accuracies associated with each measurement.

Because the RemoteTracker WWVS measures water velocity only, Equation 1 suggested in CCR 23 597.4(e)(3)(B) is used to calculate volume.

$$\forall = V * A * \Delta t \tag{1}$$

Where the variables are defined as:

- $\forall$: Volume
- V : Average Velocity
- A: Cross-Section Flow Area
- Δt: Duration of Delivery

This relative accuracy analysis assumes:

- 3 cubic foot per second (cfs) maintenance delivery
- A 24 inch inner diameter delivery pipe
- Normal distribution of measurement errors

A 3 cfs delivery was selected because it represents the lower range of agricultural water delivery rates and accuracy is harder to achieve at low flows. A 24 inch pipe is the average turnout pipe size within most agricultural districts. These assumptions lead to the listed variables having the values presented below.

- V_{RT} = RemoteTracker Velocity Measurement = 1.00 ft/s
- $V_{Avg}*$ = Average Velocity of the pipe at the time of the RemoteTracker spot measurement = 0.95 ft/s (determined by correlation with measured velocity; see Davids et al. 2012)
- D = Pipe Diameter = 2.00 ft
- A = Cross-Section Flow Area = 3.14 ft^2

Based on the following analysis, the expected accuracy in volumetric measurements performed with the RemoteTracker system is ±4.6 percent.

<u>Volumetric Accuracy.</u> Analysis Overview. Volumetric accuracy of water deliveries consists of the accuracies in each of the following three components:

- Average Velocity (V_{Avg})
- Cross-Section Flow Area (A)
- Duration of Delivery (Δt)

Assuming the input estimates to the three measured quantities above are uncorrelated, the total absolute accuracy is found using Equation 2 (NASA 2010 and NIST 2013).

$$\sigma_{\forall} = \pm\sqrt{\left(\frac{\partial\forall}{\partial V_{Avg}}\sigma_{V_{Avg}}\right)^2 + \left(\frac{\partial\forall}{\partial A}\sigma_A\right)^2 + \left(\frac{\partial\forall}{\partial\Delta t}\sigma_{\Delta t}\right)^2} \quad (2)$$

Where the variables are defined as:

- ∀: Volume
- V_{Avg}: Average Velocity
- Δt: Duration of Delivery
- σ: Absolute Accuracy (expressed in the units of the term in question)
- U: Relative Accuracy (expressed as a percentage)

The total relative accuracy is:

$$U_{\forall} = \frac{\sigma_{\forall}}{\forall} = \pm\frac{1}{\forall}\sqrt{\left(\frac{\partial\forall}{\partial V_{Avg}}\sigma_{V_{Avg}}\right)^2 + \left(\frac{\partial\forall}{\partial A}\sigma_A\right)^2 + \left(\frac{\partial\forall}{\partial\Delta t}\sigma_{\Delta t}\right)^2} \quad (3)$$

$$U_{\forall} = \pm\sqrt{\frac{1}{\forall^2}\left(\left(\frac{\partial\forall}{\partial V_{Avg}}\sigma_{V_{Avg}}\right)^2 + \left(\frac{\partial\forall}{\partial A}\sigma_A\right)^2 + \left(\frac{\partial\forall}{\partial\Delta t}\sigma_{\Delta t}\right)^2\right)}$$

Where the partial derivatives are:

$$\frac{\partial\forall}{\partial V_{Avg}} = A\Delta t \ , \ \frac{\partial\forall}{\partial A} = V_{Avg}\Delta t \ , \ \frac{\partial\forall}{\Delta t} = V_{Avg}A$$

Substituting in the solutions to the partial derivatives:

$$U_{\forall} = \pm\sqrt{\frac{1}{\forall^2}\left(\left(A\Delta t\sigma_{V_{Avg}}\right)^2 + \left(V_{Avg}\Delta t\sigma_A\right)^2 + \left(V_{Avg}A\sigma_{\Delta t}\right)^2\right)}$$

$$U_{\forall} = \pm\sqrt{\left(\frac{A\Delta t\sigma_{V_{Avg}}}{\forall}\right)^2 + \left(\frac{V_{Avg}\Delta t\sigma_A}{\forall}\right)^2 + \left(\frac{V_{Avg}A\sigma_{\Delta t}}{\forall}\right)^2}$$

$$U_{\forall} = \pm\sqrt{\left(\frac{\sigma_{V_{Avg}}}{V_{Avg}}\right)^2 + \left(\frac{\sigma_A}{A}\right)^2 + \left(\frac{\sigma_{\Delta t}}{\Delta t}\right)^2}$$

This becomes:

$$U_{\forall} = \pm\sqrt{\left(U_{V_{Avg}}\right)^2 + (U_A)^2 + (U_{\Delta t})^2} \quad (4)$$

Based on Equation 4, the relative accuracies of Average Velocity, Cross-Section Flow Area, and Duration of Delivery are required. The following sections detail their determination.

Relative Accuracy in Velocity. The following bullet points provide protocols for the collection of water velocity data.

- The RemoteTracker WWVS will be deployed in the delivery pipe outfall so that the sample volume is located in the center of the delivery pipe
- Water velocities will be collected with the RemoteTracker WWVS at:
  - The start of all delivery events
  - After any changes in delivery events
- Shutoffs will be recorded on the RemoteTracker user interface with the "Record Shutoff" button at the time the gate is closed

The accuracies in average velocity consist of three parts:

1. $\sigma_{V_{RT}}$: Accuracy of RemoteTracker velocity measurements
2. $\sigma_{V_{Avg^*}}$: Accuracy due to the process of correlating RemoteTracker velocity measured at the pipe center and the average velocity of the pipe at the time of the RemoteTracker spot measurement[7]
3. $\sigma_{\Delta V_T}$: Accuracy due to the difference between the average velocity at the time of the RemoteTracker spot measurement and the actual average velocity for the duration of the delivery (i.e. change in velocity over time)

The average velocity relative accuracy is:

$$U_{V_{Avg}} = \pm \frac{\sigma_{V_{Avg}}}{V_{Avg}} \tag{5}$$

Where the variables are defined as:

- V_{Avg}: Average Velocity
- $U_{V_{Avg}}$: Relative Velocity Accuracy
- $\sigma_{V_{Avg}}$: Absolute Velocity Accuracy

The average velocity of the entire irrigation event is the summation of the average velocity at the time of observation and the average change in velocity throughout the remainder of the event due to water level fluctuations.

[7] Average velocity at the time of the RemoteTracker spot measurement (V_{Avg} $*$) represents a snapshot of the average water velocity in a delivery pipe at the time of the RemoteTracker measurement.

$$V_{Avg} = V_{Avg} * + \Delta V_T \quad (6)$$

Where the variables are defined as:

- V_{Avg}: Average Velocity
- V_{Avg} $*$: Average Velocity at the time of the RemoteTracker spot measurement
- ΔV_T: Average Change in Velocity over time

Therefore:

$$\sigma_{V_{Avg}} = \pm\sqrt{\left(\frac{\partial V_{Avg}}{\partial V_{Avg\,*}}\sigma_{V_{Avg*}}\right)^2 + \left(\frac{\partial V_{Avg}}{\partial \Delta V_T}\sigma_{\Delta V_T}\right)^2} \quad (7)$$

Where the partial derivatives are:

$$\frac{\partial V_{Avg}}{\partial V_{Avg*}} = 1,\ \frac{\partial V_{Avg}}{\partial \Delta V_T} = 1$$

Substituting in the solutions to the partial derivatives:

$$\sigma_{V_{Avg}} = \pm\sqrt{\left(\sigma_{V_{Avg*}}\right)^2 + \left(\sigma_{\Delta V_T}\right)^2} \quad (8)$$

The following subsections present (1) the accuracy of the RemoteTracker velocity measurements, (2) the accuracy of the average velocity at the time of the RemoteTracker spot measurements ($\sigma_{V_{Avg}\,*}$) and (3) the accuracy in the change in average velocity over time ($\sigma_{\Delta V_T}$).

Accuracy of Remote Tracker Velocity Measurement

The RemoteTracker system uses a SonTek ADV for water velocity measurements. The SonTek ADV technical specifications sheet lists a velocity measurement error of 0.01 or 1.0% (SonTek 2006). Therefore, $\sigma_{V_{RT}}$ is equal to 0.010 ft/s, or 1.0% of 1.00 ft/s (V_D).

Accuracy of the Average Velocity at the Time of the RemoteTracker Spot Measurement

The average velocity is computed as the product of the velocity measured by the RemoteTracker and the coefficient correlating the RemoteTracker velocity measurement to the average velocity at the time of the RemoteTracker spot measurement.

$$V_{Avg}* = CV_{RT} \tag{9}$$

Where the variables are defined as:

- $V_{Avg}*$: Average velocity at the time of the RemoteTracker spot measurement
- C: Coefficient correlating the RemoteTracker velocity measurement to the average velocity at the time of the RemoteTracker spot measurement, which is equal to 0.95 (Davids et al. 2012)
- V_{RT}: RemoteTracker velocity measurement

Therefore:

$$\sigma_{V_{Avg^*}} = \pm\sqrt{\left(\frac{\partial V_{Avg^*}}{\partial C}\sigma_C\right)^2 + \left(\frac{\partial V_{Avg^*}}{\partial V_{RT}}\sigma_{V_{RT}}\right)^2} \tag{10}$$

Where the partial derivatives are:

$$\frac{\partial V_{Avg^*}}{\partial C} = V_{RT}, \frac{\partial V_{Avg^*}}{\partial V_{RT}} = C$$

Substituting in the solutions to the partial derivatives:

$$\sigma_{V_{Avg^*}} = \pm\sqrt{(V_{RT}\sigma_C)^2 + \left(C\sigma_{V_{RT}}\right)^2} \tag{11}$$

Based on water velocity data collected, the average error introduced by converting the RemoteTracker velocity measurement to the average velocity at the time of the RemoteTracker spot measurement (σ_C) is 0.014 or 1.4%.

Inserting the determined values into Equation11:

$$\sigma_{V_{Avg^*}} = \pm\sqrt{(1.0 * 0.014)^2 + (0.95 * 0.010)^2} = \pm\, 0.017\ ft/s$$

Accuracy of the Change in Velocity over Time (Impact of Canal Water Level Fluctuation on Volumetric Measurement Accuracy)

A Microsoft Access database was developed to assess the accuracy in the change in velocity over time based on nearly one million real water level records from 27 different sites from multiple irrigation districts spanning five irrigation seasons. Based on the orifice equation, the change in velocity through an orifice is solely a function of changes in head (or difference between upstream and downstream water level). Only water level data from the typical irrigation season (i.e. May through August) was used. It was assumed that measurements of head were performed every three days.

The difference between the head observed every three days and the actual average of the 15 minute data during the three day period was computed for each 15 minute record and then averaged over the reporting period (i.e. one month). Equation 16 was used to calculate the change in velocity over time (ΔV_T) for each three day period. The initial observed head (h_*) was assumed to be 0.5 feet to simulate a low head delivery. A low head was chosen because water level fluctuations impact the velocity of low head deliveries more significantly than high head deliveries.

Rearranging Equation 6:

$$\Delta V_T = V_{Avg} - V_{Avg} * \tag{12}$$

From the orifice equation (King 1963):

$$\mathrm{V} = \mathrm{C}(2\mathrm{gh})^{0.5} \tag{13}$$

Where the variables are defined as:

- V: Velocity
- C: Discharge Coefficient
- g: Gravitational Constant
- h: Head

Orifice gates in most agricultural water districts operate under submerged conditions (i.e. not free flow conditions). As upstream canal water levels fluctuate, the flow through the orifice would theoretically vary as a function of the changes in canal water level to the one-half power. However, since the orifice gates are submerged, the hydraulically connected downstream water level also varies together with the upstream canal water level. This provides a damping effect on the overall change in velocity due to upstream water level fluctuations. The California Polytechnic State University at San Luis Obispo Irrigation Training and Research Center (ITRC) suggest using a power of 0.38 in the orifice equation to simulate the damping effect of submergence for a range of downstream channel conditions (Burt and Geer 2012).

$$V = C(2gh)^{0.38} \tag{14}$$

Substituting values:

$$\Delta V_T = C(2gh_{avg})^{0.38} - C(2gh_*)^{0.38} \tag{15}$$

Where the variables are defined as:

- h_{avg}: Average Head
- h_*: Initial Observed Head

Factoring:

$$\Delta V_T = C(2g)^{0.38}\left((h_{avg})^{0.38} - (h_*)^{0.38}\right)$$

Substituting values:

$$\Delta V_T = C(2g)^{0.38}\left((h_* + \Delta h_{avg})^{0.38} - (h_*)^{0.38}\right) \quad (16)$$

Where the variables are defined as:

- Δh_{avg}= average change in head

Since the volumetric reporting mandates apply to a monthly or bi-monthly basis (California Water Code §531.10(a)), the change in velocity over time was then averaged on a monthly time step. The average of the absolute values of each of the average monthly changes in velocity over time was taken across all 27 sites. Largely due to the fact that water level fluctuations are normally distributed, the results of the hydraulic database model suggest that the average change in velocity over time due to water level fluctuation is:

$$\sigma_{\Delta V_T} = \pm\, 0.031\ ft/s$$

Inserting the calculated values into Equation A-8, the average velocity accuracy is:

$$\sigma_{V_{Avg}} = \pm\sqrt{(0.017)^2 + (0.031)^2} = 0.035\ ft/s$$

The relative accuracy of the average velocity is:

$$\boxed{U_{V_{Avg}} = \pm\frac{\sigma_{V_{Avg}}}{V_{Avg}} = \pm\frac{0.035\ ft/s}{0.95\ ft/s} = \pm\, 0.037\ or\ 3.7\%}$$

Relative Accuracy in Cross-Section Flow Area

The following bullet points provide protocols for the collection of cross-section flow area data.

- The cross-section flow area will be calculated by measuring the inner diameter of the delivery pipe at the location of the water velocity measurement and using Equation 18 to calculated area from inner diameter
- Inner pipe diameters will be measured with best professional practices when the pipe is dry

The accuracy in the inner pipe diameter measurement is assumed to be 0.02 feet (or 1/4 inch). The relative accuracy due to area is:

$$U_A = \pm\frac{\sigma_A}{A} \tag{17}$$

The correlation between diameter and area is:

$$A = \frac{\pi \mathrm{D}^2}{4} \tag{18}$$

Where the variables are defined as:

- A: Cross-Section Flow Area
- π: Pi
- D: Inner Diameter

The accuracy is:

$$\sigma_A = \pm\sqrt{\left(\frac{\partial A}{\partial D}\sigma_D\right)^2} \tag{19}$$

Where the partial derivative is equal to:

$$\frac{\partial A}{\partial D} = \frac{2\pi D}{4} = \frac{\pi D}{2}$$

The assumed pipe is 2.00 feet (24 inch) in diameter, giving an area of 3.142 ft^2

$$\sigma_A = \pm\sqrt{\left(\frac{\partial A}{\partial D}\sigma_D\right)^2} = \sqrt{\left(\frac{\pi D}{2}0.02\right)^2} = \sqrt{\left(\frac{\pi 2}{2}0.02\right)^2} = \pm\, 0.063\ ft$$

The relative accuracy in the cross-section flow area is:

$$\boxed{U_A = \pm\frac{\sigma_A}{A} = \pm\frac{0.063\ ft}{3.142\ ft} = \pm\, 0.020\ or\ 2.0\%}$$

Relative Accuracy in Duration of Delivery

The following bullet points provide protocols for the collection of duration of delivery data.

- The start time for delivery will be the date and time recorded in the RemoteTracker system when a velocity measurement is taken at the start of a delivery
- The stop time for delivery will be the date and time recorded in the RemoteTracker system when either:
  - “Record Shutoff” is pressed after a gate is closed at the end of a delivery or

- A new velocity measurement is taken after a change in delivery flow rate is made

A conservative value for the duration of an irrigation event is assumed to be a period of 24 hours. The possible accuracy in duration measurement is considered to be 15 minutes for the startup and 15 minutes for the shutoff (or 0.25 hours for both). Realistically, the actual accuracy in duration is much smaller when using the RemoteTracker system since the operator is recording water velocity data on site when gate position changes are made. The relative accuracy due to duration of delivery is:

$$U_{\Delta t} = \pm \frac{\sigma_{\Delta t}}{\Delta t} \tag{20}$$

Where:

$$\Delta t = Et - St \tag{21}$$

Where the variables are defined as:

- Δt: Duration of Delivery
- St: Start Time
- Et: End Time

The accuracy of the Duration of Delivery is:

$$\sigma_{\Delta t} = \pm\sqrt{\left(\frac{\partial \Delta t}{\partial St}\sigma_{St}\right)^2 + \left(\frac{\partial \Delta t}{\partial Et}\sigma_{Et}\right)^2} \tag{22}$$

Where the partial derivatives are equal to:

$$\frac{\partial \Delta t}{\partial St} = 1, \ \frac{\partial \Delta t}{\partial Et} = 1$$

$$\sigma_{\Delta t} = \pm\sqrt{(\sigma_{St})^2 + (\sigma_{Et})^2} = \sqrt{(.25)^2 + (0.25)^2} = 0.35\ hrs$$

The relative accuracy in the duration of delivery is:

$$\boxed{U_{\Delta t} = \pm \frac{\sigma_{\Delta t}}{\Delta t} = \pm \frac{0.35}{24} = \pm\, 0.015\ or\ 1.5\%}$$

Relative Accuracy in Volume

As previously stated this relative accuracy assumes a 3 cfs maintenance delivery in a 24" pipe. Inserting the calculated relative accuracy value for each component into Equation 4, the relative accuracy is as follows:

$$U_{\forall} = \pm\sqrt{\left(U_{V_{Avg}}\right)^2 + (U_A)^2 + (U_{\Delta t})^2}$$

$$U_{\forall} = \pm\sqrt{(.037)^2 + (.020)^2 + (.015)^2}$$

$$\boxed{U_{\forall} = \pm\, 0.045\ or\ \pm\, 4.5\%}$$

Based on the foregoing analysis and the resulting ±4.5% accuracy in delivery volume determined for the RemoteTracker, the RemoteTracker complies with the ±5.0% accuracy mandate in CCR 23 §597 for laboratory certification.

CONCLUSION

The primary benefits of measurement at the farm turnout level are (1) the ability to precisely control and (2) accurately account for the amount of water being delivered to each customer. From the perspective of controlling delivery flow rates, accurate flow measurement on manually controlled gates is only utilized when district personnel are on site (i.e. at the gate). The volumetric accuracy analysis presented above suggests that the RemoteTracker complies with the ±5.0% accuracy requirements in CCR 23 §597 for laboratory based accuracy certification. Analysis of water level fluctuations within this paper supports the conclusion of Burt and Geer (2012) that "the seasonal impact of fluctuating canal water levels is likely 0.0%, for all practical purposes." Therefore, "spot" measurements of flow rate can be "good enough" for California's heightening agricultural measurement requirements.

Initial field testing, laboratory testing and District piloting indicates that the RemoteTracker is technically viable and offers certain advantages relative to other measurement options. Based on the evidence provided herein, and the overall operational benefits realized by District operators, Reclamation District No. 108, Richvale Irrigation District and Biggs-West Gridley Water District have selected the RemoteTracker device to achieve the measurement accuracy standards of CCR 23 §597. The RemoteTracker's advantages include:

- Accurate flow measurement during the period of setting or adjusting delivery flow rates
- Volumetric measurement accuracy sufficient for the laboratory certification requirements of CCR 23 §597
- Lower overall implementation costs than measurement methods requiring permanent devices at each delivery point
- 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
- Feedback of delivery history to operators

- Orders management capabilities
- Can be integrated with automated water accounting and billing processes

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